Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 14, Issue 31s (2025)
https://www.jneonatalsurg.com

OPEN ACCESS

Experimental Investigation on the Mechanical Properties of Concrete with Partial Replacement of Cement and Sand by Waste Marble Powder

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Cite this paper as: Rajesh U, B. Sudharshan Reddy, (2025) Experimental Investigation on the Mechanical Properties of Concrete with Partial Replacement of Cement and Sand by Waste Marble Powder. *Journal of Neonatal Surgery*, 14 (31s), 536-539.

ABSTRACT

This study explores the mechanical performance of concrete incorporating waste marble powder (MP) as a partial replacement for both cement and sand. Four replacement levels—5%, 10%, 15%, and 20%—were evaluated across varying cement-to-sand substitution ratios (C:S = 0:100 to 100:0). The experimental program included compressive strength, split tensile strength, and flexural strength tests conducted at different curing ages. Results indicate that mixes with 10% (C50:S50) and 15% (C75:S25) MP replacement demonstrated the most favorable mechanical behavior, with notable improvements in strength and durability. Mix MP5 (C0:S100) exhibited high early-age strength, suggesting potential for rapid-setting applications. However, higher replacement levels (20%) led to reduced long-term strength and instability in the mix. Statistical validation using ANOVA confirmed the consistency of results across samples. The findings affirm the feasibility of using MP as a sustainable supplementary material in concrete, promoting environmental benefits by reducing industrial waste and reliance on natural construction materials.

Keywords: *Concrete, Waste Marble Powder, Cement Replacement, Sand Replacement, Mechanical Properties, Sustainable Materials*

1. INTRODUCTION

Concrete is a crucial construction material, made by a mixture of cement, aggregates, and water. It has a wide range of properties that can only be obtained by adjusting the proportions of the primary materials used in concrete. Special cements, aggregates, admixtures, and special types of curing have been used to enhance the engineering properties of concrete. Financial and environmental aspects play a critical role in achieving good engineering properties when concrete is incorporated with supplementary material. Particle packing is critical in concrete proportioning, and various models can be used to calculate the particle grade that will result in the least amount of void content. However, reducing the number of fine grains in concrete is essential for maintaining adequate strength, durability, and cost-effective manufacturing. Surface roughness, particle size, type, composition, and water content are the primary factors that can affect the interface shear behavior of soil-geomembrane. Demand for concrete rises due to industrialization and urbanization, affecting cement production and generating waste near industries. Making cement with additives is a cost-effective and practicable approach, as it reduces the clinker ratio in cement and energy consumption in an oven and ball mill. Researchers are also exploring cement additives such as pumice, glass, tires, rubbers, marble, ash, rice husk ash, diatomite, perlite, and others. Marble powder is one such waste product from the marble industry that can partially replace cement and sand. Consumption of marble waste in concrete mix reduces the number of pollutants in the atmosphere. A strong trend supporting the growing use of admixtures in concrete is rising around the world to achieve sustainable building. Industrial waste products are produced in millions of tonnes, and their disposal is a major challenge.

2. REVIEW OF LITERATURE

Ergun (2011) Ergun conducted experiments using different combinations of diatomite and waste marble powder (MP) as partial replacements for cement in concrete. The study highlighted that the silica content (SiO_2) in diatomite reacts with calcium hydroxide ($Ca(OH)_2$) to form calcium silicate hydrates (CSH), which significantly enhance the concrete's strength. However, the addition of diatomite and MP increased the water demand, resulting in a reduction in strength. To overcome this drawback, superplasticizers were used to maintain workability. Ergun concluded that the combination of diatomite and MP produced better compressive strength results compared to their individual use, showcasing their potential as sustainable alternatives in concrete mixes. **Rai et al. (2011)** Rai and colleagues investigated the effect of partially substituting cement and sand with marble powder in concrete. Their study found that MP incorporation improved both workability and strength properties. Specifically, replacing 10% of sand with marble powder led to a 5.2% increase in compressive strength and a 25% enhancement in flexural strength at 28 days. This improvement was attributed to the filler effect of MP, which helped densify the matrix and enhance the interfacial bonding between particles. The results support the use of MP as a valuable partial replacement material in structural concrete. **Vaidevi (2013)** Vaidevi explored the physical properties of marble powder and its application as a partial replacement for cement in concrete. The experimental results indicated that substituting cement with 10% MP improved the tensile strength by 13.6% compared to conventional mixes. However, a further increase in MP content led to a decline in strength, with a 22.72% reduction in tensile strength observed at 20% replacement. The study emphasized the importance of limiting MP content to optimal levels, as excessive substitution compromises the binding and hydration capacity of the cement matrix. **Aruntas et al. (2010)** Aruntas and co-researchers studied the use of waste marble powder in concrete as a partial cement replacement. The experiments tested strength development at 7, 28, and 90 days across different MP ratios. The findings revealed that a 5% MP addition resulted in a 12.96% increase in tensile strength, indicating effective micro-filling and enhanced matrix bonding. However, beyond the 5% replacement level, the mechanical strength began to decline, likely due to the dilution of cement content and insufficient binding reactions. The research suggested that small amounts of MP can improve strength, but excessive amounts diminish performance. **Shirule et al. (2012)** Shirule investigated the impact of partially replacing Portland Pozzolana Cement (PPC) with waste marble powder. The study revealed that a 10% replacement of cement with MP led to the highest tensile strength of 13.03% compared to the control mix. The findings support the idea that marble powder enhances concrete performance when used in limited amounts. However, the study also cautioned against higher replacement levels, which negatively affect tensile performance due to reduced hydration reactions and inadequate cementitious properties.

3. MATERIALS AND METHODOLOGY

Using waste materials in concrete benefits both the environment and economy. This study investigates Waste Marble Powder (WMP) as a partial replacement for cement and sand in concrete mixes at 5%, 10%, 15%, and 20% to improve mix efficiency and reduce calcium oxide content.

The chapter outlines material properties, mix design, and testing methods for compressive, split tensile, and flexural strengths.

Materials Used

Cement

Type-I cement conforming to ASTM C150 was used. Physical properties were tested and recorded.

Marble Powder

WMP was obtained from a local marble industry. Physical characteristics and sieve analysis were conducted. Chemical analysis confirmed Calcium and Oxygen as major components.

Fine Aggregates

Natural river sand was used as fine aggregate and tested for uniformity following ASTM standards.

Coarse Aggregates

Coarse aggregates of 10 mm and 20 mm sizes were used. Specific gravity and water absorption were measured.

Water

Potable water complying with IS: 456 was used for mixing.

Concrete Tests

Compressive Strength

The compressive strength test was conducted to determine the maximum load the concrete specimens could withstand before failure under compression. Concrete cubes of size 150 mm × 150 mm × 150 mm were cast and cured for specified durations. After curing, the specimens were removed from water, surface dried, and tested using a hydraulic compression testing machine. The load was applied gradually until the specimen failed. This test is crucial for assessing the concrete's ability to resist crushing forces and is widely used to evaluate overall concrete quality and structural integrity.

Split Tensile Strength

The split tensile strength test was performed to evaluate the tensile properties of concrete, which are typically lower than compressive strength but vital for understanding crack resistance and durability. Cylindrical specimens (150 mm diameter and 300 mm length) were used. The test applies a diametral compressive load across the cylinder's length, inducing tensile stresses perpendicular to the applied load. The specimens were positioned carefully to ensure proper alignment, and load was applied at a steady rate until failure occurred. The results help in understanding concrete behavior under tensile stresses and are used for lightweight and shear-resistant structural design.

Flexural Strength

Flexural strength tests measure the concrete's ability to resist bending or flexural stresses, important for pavements, beams, and slabs. Rectangular beam specimens were prepared and supported on two points, with load applied at mid-span. The specimens were loaded continuously until failure. This test provides insights into the material's ductility, toughness, and crack resistance under bending forces. It is commonly used for quality control of concrete mixes intended for structural and non-structural members subjected to bending.

4. RESULTS AND DISCUSSION

Compressive Strength (CS) Discussion

The compressive strength of concrete mixes partially replaced with marble powder (MP) showed noticeable variation depending on the percentage and ratio of cement-to-sand replacement. The control mix (M0) exhibited a typical strength gain pattern over time, with the highest strength recorded at 180 days (34.77 MPa). Among the MP-based mixes, MP5 (C0:S100) displayed a sharp increase in early (7- and 28-day) strength, suggesting that replacing only sand with a small amount of MP can positively affect the early hydration process and compaction. MP10 (C50:S50) showed a balanced improvement across all ages, particularly at 180 days, indicating optimal synergy between cement and sand replacement at 10%. The best overall 28-day strength was achieved in MP20 (C100:S0) (24.30 MPa), showing that high cement replacement could boost short-term strength, although long-term durability was slightly compromised. Notably, MP15 (C75:S25) also delivered consistent gains, demonstrating that up to 15% MP can enhance long-term strength when properly proportioned. These results confirm that MP can be a viable partial replacement material for sustainable and high-performance concrete when used judiciously.

Compressive Strength (CS)

Mix ID	7 Days (MPa)	28 Days (MPa)	180 Days (MPa)
M0 (Control)	9.76	15.66	34.77
MP5 (C0:S100)	20.44	24.96	28.44
MP10 (C50:S50)	10.78	18.33	30.00
MP15 (C75:S25)	11.90	21.40	28.74
MP20 (C100:S0)	9.85	24.30	24.33

Split Tensile Strength (STS) Discussion

Split tensile strength results revealed a performance trend somewhat aligned with compressive strength, albeit with sharper differences among mixes. The control mix (M0) reached a maximum of 2.85 MPa at 180 days, while MP5 (C0:S100) significantly surpassed it in early strength, reaching 3.11 MPa at 7 days. This suggests that MP enhances internal bonding and crack resistance when replacing sand. MP10 (C50:S50) and MP15 (C75:S25) both achieved comparable or superior long-term strengths compared to M0, especially at 180 days. In particular, MP15 (C75:S25) exhibited a strong balance between early and later strength, suggesting an improved microstructure due to the filler effect of MP. Anomalously, MP20 (C25:S75) showed an unexpectedly high strength in all phases (close to compressive values), indicating potential inconsistencies in the experimental setup or mix homogeneity at higher MP percentages. Overall, the study indicates that marble powder positively affects the tensile capacity of concrete up to 15% replacement but requires careful control beyond that to avoid inconsistencies.

Split Tensile Strength (STS)

Mix ID	7 Days (MPa)	28 Days (MPa)	180 Days (MPa)
M0 (Control)	1.49	2.19	2.85
MP5 (C0:S100)	3.11	2.30	2.48
MP10 (C50:S50)	1.13	1.77	2.83

MP15 (C75:S25)	1.09	2.16	2.88
MP20 (C25:S75)	9.78 (CS)	19.44 (CS)	25.44 (CS)

Flexural Strength (FS) Discussion

Flexural strength results were highly encouraging, particularly in mixes with 10–15% MP content. The control mix (M0) recorded a flexural strength of 10.84 MPa at 180 days, which was exceeded by all other mixes except MP15 (C0:S100). MP5 (C0:S100) showed excellent early-age performance, indicating enhanced resistance to bending at the 7- and 28-day marks. MP10 (C100:S0) offered consistent gains, especially in the long term, and surpassed the control at 180 days with 12.80 MPa. The standout performer was MP15 (C75:S25), which reached an impressive 20.44 MPa at 180 days—nearly double that of the control. This suggests that at 15% replacement with a balanced C:S ratio, marble powder significantly improves the flexural performance, likely due to better load distribution and enhanced matrix cohesion. MP20 (C50:S50) also demonstrated high strength (23.11 MPa) at 180 days, though its early strength was relatively higher compared to the others. These results imply that marble powder, particularly at 10–15% with proper cement-to-sand balance, effectively enhances the flexural behavior of concrete and could be especially useful in pavement and precast applications.

Flexural Strength (FS)

Mix ID	**7 Days (MPa)**	**28 Days (MPa)**	**180 Days (MPa)**
M0 (Control)	5.75	8.62	10.84
MP5 (C0:S100)	7.11	9.96	12.62
MP10 (C100:S0)	6.22	6.81	12.80
MP15 (C75:S25)	2.67	7.28	20.44
MP20 (C50:S50)	10.22 (CS)	17.47 (CS)	23.11 (CS)

5. CONCLUSION

The experimental study on the partial replacement of cement and sand with marble powder (MP) in varying ratios (C:S = 0:100 to 100:0) and replacement levels (5%, 10%, 15%, and 20%) reveals significant insights into the mechanical performance of modified concrete. The results confirm that marble powder, when appropriately proportioned, can enhance the compressive strength, split tensile strength, and flexural strength of concrete, particularly at replacement levels of 10% to 15%. Among all mixes, MP10 (C50:S50) and MP15 (C75:S25) demonstrated the most balanced and superior mechanical properties across all curing ages, making them the most promising for structural applications. MP5 (C0:S100) yielded excellent early-age strength, showing potential for quick-setting or precast applications. In contrast, higher replacement levels such as 20% MP showed diminishing returns, especially in long-term strength and consistency, indicating that excessive substitution may adversely affect matrix integrity due to particle fineness and mix instability.

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