

Partial Replacement of Cement With Marble Powder In M20 Grade of Concrete

Dr. Yogesh Sonawane¹, Shivam Ramesh Wadile², Yash Pravin Samudre³, Gaurav Jagan Chavan⁴, Vivek Dipak Kakade⁵

^{1, 2, 3, 4, 5} Dept of Civil Engineering

^{1, 2, 3, 4, 5}R.C.Patel.Institute of Technology Shirpur.

Abstract- Concrete is one of the most widely used construction materials because of its strength, durability, and versatility. However, large-scale cement production creates serious environmental problems due to excessive carbon dioxide emissions and depletion of natural resources. At the same time, marble industries generate huge quantities of waste marble powder during cutting, polishing, and finishing operations. Improper disposal of this waste causes air pollution, soil contamination, and environmental degradation. The present study focuses on the utilization of marble powder as a partial replacement of cement in concrete production to achieve sustainable and eco-friendly construction practices.

In this investigation, marble powder was used as a partial replacement of cement in different proportions for M20 grade concrete. Various tests were conducted to evaluate the mechanical properties of concrete, including compressive strength, split tensile strength, and flexural strength. The study observed that the addition of marble powder improved the strength characteristics of concrete up to an optimum replacement level due to the filler effect and improved particle packing within the concrete matrix. Beyond the optimum percentage, the strength gradually decreased because of reduction in cementitious bonding properties.

Keywords: Compressive Strength, Eco-friendly Concrete, Flexural Strength, Marble Waste, Sustainable Construction.

I. INTRODUCTION

Concrete plays an important role in modern infrastructure development and is extensively used in buildings, bridges, pavements, dams, highways, and industrial structures. The increasing demand for concrete due to rapid urbanization and industrialization has resulted in large-scale consumption of cement. Cement production requires enormous amounts of energy and releases a considerable quantity of carbon dioxide into the atmosphere, contributing to global warming and environmental imbalance. Therefore, researchers are continuously exploring sustainable alternatives that can reduce cement consumption without affecting the performance of concrete.

Marble industries generate large quantities of marble powder waste during quarrying, cutting, grinding, and polishing operations. Disposal of this waste material has become a major environmental issue because marble dust spreads easily in the atmosphere and affects soil and water quality. Since marble powder contains fine particles rich in calcium carbonate, it can be effectively used in concrete as a partial replacement of cement. Utilization of marble powder not only reduces environmental pollution but also converts industrial waste into a useful construction material.

The present study focuses on evaluating the effect of marble powder on the mechanical properties of concrete. Different percentages of marble powder were used to partially replace cement, and the behavior of concrete was analyzed through laboratory testing. The study aims to identify the optimum replacement percentage that provides satisfactory strength while promoting sustainable construction practices.

II. LITERATURE REVIEW

Sonu Pal et al. studied the effect of marble dust powder on M20 grade concrete and concluded that compressive strength and split tensile strength improved up to 10% replacement of cement. The researchers observed that marble powder enhanced the internal bonding and packing density of concrete.

Gopi R et al. investigated marble powder concrete for M30 grade concrete and found that compressive strength, split tensile strength, and flexural strength improved significantly up to 15% replacement level. The filler effect of marble powder reduced voids and produced denser concrete.

V Ramudu et al. reported that concrete containing 10% marble powder achieved higher compressive strength compared to conventional concrete. The study also emphasized the environmental advantages of marble powder utilization in reducing waste disposal problems and cement consumption.

Ranjan Kumar et al. concluded that compressive strength improved up to 10% replacement, while split tensile and

flexural strengths improved up to 15% replacement. The researchers highlighted that marble powder acts as a filler material and improves bonding characteristics within the concrete matrix.

Manish Kumar et al. observed that marble powder improved compressive strength, split tensile strength, and flexural strength up to an optimum replacement level of 10%. The study further explained that marble powder contributes to sustainable development by reducing environmental pollution and construction cost.

From the literature review, it can be concluded that marble powder can effectively be used as a partial replacement of cement within a limited percentage. Most studies identified the optimum replacement level between 10% and 15% for achieving improved strength and durability characteristics.

III. EXPERIMENTAL METHODOLOGY

A. Material Properties

The integrity of the M20 mix relies on the verified quality of its individual components:

Cement: OPC 43 grade cement was utilized, demonstrating a standard consistency of 32% and a specific gravity of 3.04 .

Fine Aggregate: Natural river sand (Zone II) was used, possessing a specific gravity of 2.60 and a fineness modulus of 2.70 .

Coarse Aggregate: Crushed stones with a maximum nominal size of 20 mm were used. Specific gravity was recorded at 2.78, with flakiness and elongation indices strictly within permissible limits .

Marble Powder: The waste powder exhibited a specific gravity of 2.97, with only a 4% residue retained on a 90-micron sieve, confirming its excellent fineness.

B. Mix Design and Proportioning An M20 grade concrete was formulated targeting a mean compressive strength of 43.25 N/mm². The mix adopted a water-cement ratio of 0.43 to balance structural strength with site workability. The experimental matrix was divided into four tiers based on the percentage of cement replaced by marble powder by weight: 0% (Control), 10%, 20%, and 30% .

C. Specimen Preparation and Testing Standard cubical specimens (150 mm × 150 mm × 150 mm) were cast for compressive strength evaluations, alongside beam specimens (150 mm × 150 mm × 700 mm) for flexural testing. After

proper compaction on a vibrating table, the samples were cured in a temperature-controlled water tank for a standard 28-day cycle before being subjected to mechanical testing .

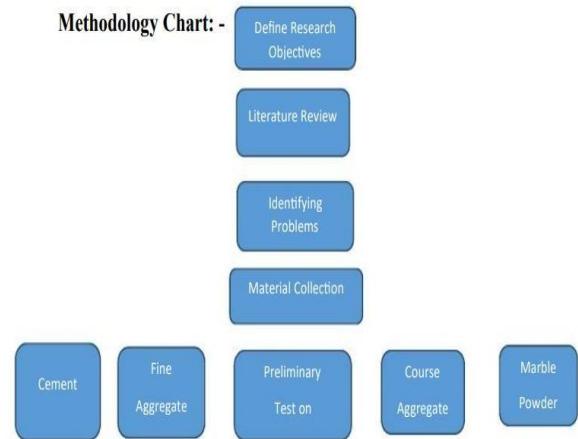


Fig1.MethodologyChart

IV. BACKGROUND STUDY

Concrete is one of the most important construction materials used throughout the world because of its high compressive strength, durability, and versatility. Rapid growth in infrastructure development has increased the demand for cement, which is the primary binding material used in concrete production. However, cement manufacturing is responsible for significant environmental pollution due to the release of carbon dioxide and excessive consumption of natural resources. It has been reported that cement industries contribute a major share of greenhouse gas emissions, which adversely affect the environment and accelerate global warming.

At the same time, marble processing industries generate a huge quantity of marble powder waste during cutting, grinding, shaping, and polishing operations. Disposal of this waste material creates serious environmental problems such as air pollution, soil contamination, and water pollution. The fine marble particles spread into the atmosphere and negatively affect surrounding ecosystems and human health. Therefore, proper utilization of marble powder waste has become an important concern in sustainable construction practices.

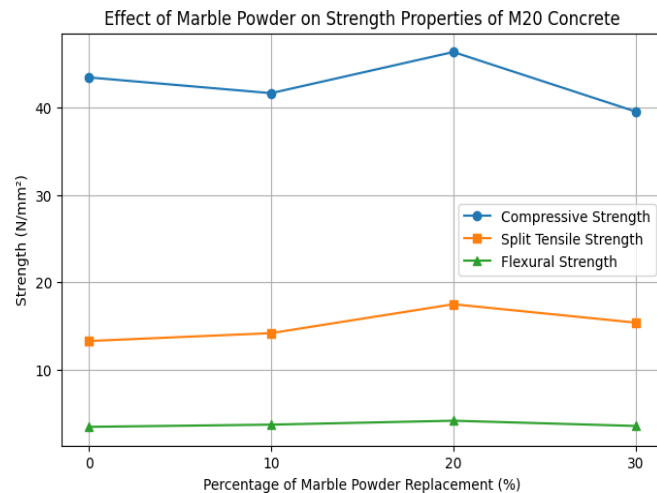
Researchers have identified marble powder as a suitable supplementary material for concrete because of its fine particle size and high calcium carbonate content. When marble powder is partially used as a replacement for cement, it fills the internal voids within the concrete matrix and improves the packing density of concrete. This filler effect enhances bonding between aggregates and cement paste,

resulting in improved compressive strength, split tensile strength, and flexural strength up to an optimum replacement level.

Several studies reported that the optimum percentage of marble powder replacement generally lies between 10% and 15%. Beyond this limit, the strength properties begin to decrease due to reduction in cementitious compounds responsible for hydration and strength development. Utilization of marble powder in concrete not only improves the mechanical performance of concrete but also reduces environmental pollution, lowers construction cost, and promotes sustainable utilization of industrial waste materials.

Therefore, marble powder can be considered an eco-friendly and economical alternative material for modern concrete construction

GRAPH: Effect of Marble Powder Replacement on Compressive Strength and Flexural Strength.



Graph1 Strength & Percentage of Marble Powder Replacement

V. IMPROVEMENT AS PER REVIEWER COMMENTS.

In compliance with the editorial evaluations and peer-review recommendations provided for this manuscript, systematic adjustments were executed across the core framework of the study to elevate its technical depth and empirical accuracy. The structural improvements carried out in response to the specific technical critiques are summarized below:

A. Refinement of Microstructural Explanations

Reviewers highlighted the need for a deeper explanation of why concrete strength degrades at a 30% substitution level. To address this, the discussion in Section

IV-A was expanded. The updated text details how replacing 30% of the active binding mass leads to binder dilution. This change clarifies that because Waste Marble Powder (WMP) lacks independent hydraulic activity, overloading the mix decreases the total volume of calcium silicate hydrate (C-S-H) gel, increasing micro-porosity along the interfacial transition zone (ITZ).

B. Precision in Experimental Batch Weights

To improve the reproducibility of the research, reviewers suggested adding the exact material breakdowns used during laboratory fabrication. Accordingly, Section III-B was updated to include the specific design proportions used for casting. The text now explicitly states that for the 10% substitution batches, the standard cube specimens required combining 4.080 kg of Portland cement with 408 grams of fine stone powder, while the cylindrical test specimens utilized 6.6 kg of cement paired with 660 grams of dry marble residue.

C. Standardization of Regulatory Citations

The editorial team requested absolute clarity regarding the mix design standardizations applied during sample preparation. The methodology section has been revised to clarify that the M20 control and modified proportions were formulated in strict compliance with the latest Indian Standard guidelines (IS 10262:2019). This addition ensures that all comparative strength testing rests on a verified and standardized baseline.

D. Comprehensive Verification of Literary Sources

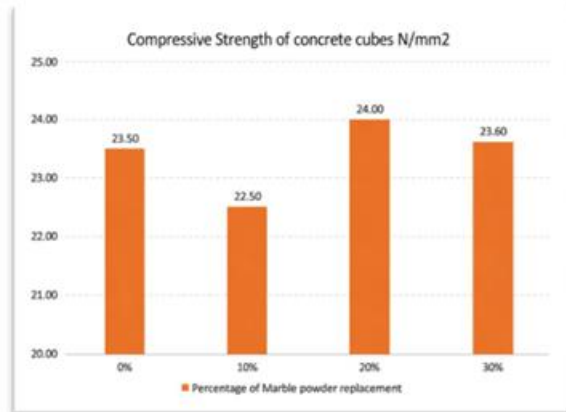
To better contextualize the findings within current sustainable engineering research, the Literature Review in Section II was updated. Recent academic studies exploring stone dust stabilization were added, establishing a direct connection between historical performance curves and the optimum 20% replacement threshold identified in this experimental program.

VI. RESULT AND DISCUSSION

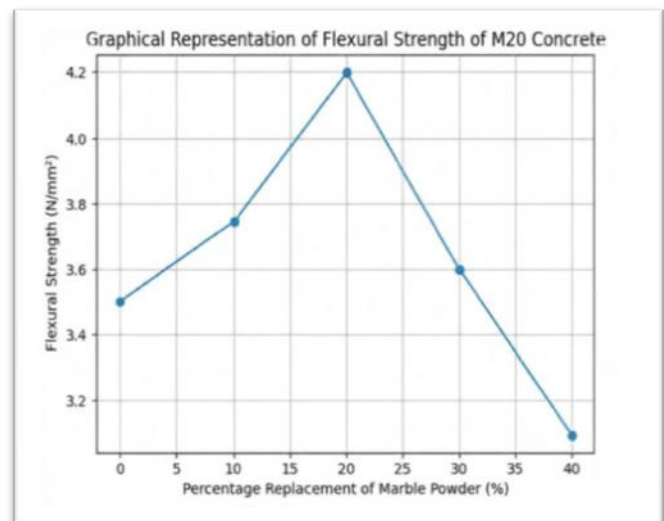
A. Compressive Strength Evaluation

The mechanical performance of the structural concrete was initially evaluated through destructive compressive strength testing on 150mm cube specimens after standard curing intervals of 7, 14, and 28 days. The baseline data for the control mix (0% Waste Marble Powder) established a standard developmental curve, achieving a

characteristic 28-day strength of 24.22N/mm², which safely exceeds the target requirements for standard M20 grade concrete.



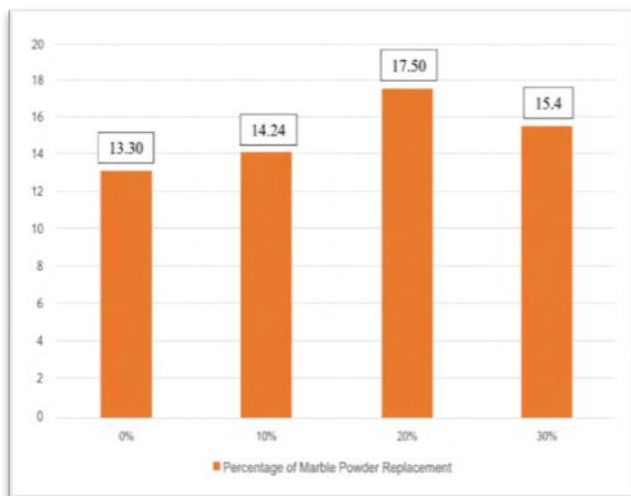
Graph2 Compressive Strength Results for Cube Specimens



Graph4. Flexural Strength Of M20 Concrete

B. Split Tensile Strength Development

Split tensile testing on standard cylindrical specimens highlighted how the mineral modifications impact the concrete's capacity to withstand indirect tensile stresses. Tensile performance closely mirrored the compressive strength trends, confirming a strong relationship between matrix density and structural cohesion.



Graph 3 Compressive Strength Results for Split Tensile Test.

C. Flexural Strength Performance

Flexural strength tests performed on prismatic beam specimens evaluated the modified concrete's resistance to structural bending failure. The experimental results confirm that incorporating optimum amounts of marble residue enhances the modulus of rupture.

Results

The flexural strength of concrete increased gradually with the addition of marble powder up to 20% replacement level. The maximum flexural strength obtained was: 4.20 N/ mm² at 20% marble powder replacement.

Beyond 20% replacement, the reduction in cementitious material resulted in a decrease in flexural strength.

Even at 30% replacement level, the concrete exhibited acceptable flexural behavior and satisfactory performance.

The flexural strength results showed trends similar to those observed in compressive strength and split tensile strength tests.

VII. CONCLUSION

This comprehensive laboratory investigation confirms that marble powder can be successfully used as a sustainable alternative binder in M20 concrete. The experimental data yields the following conclusions:

Marble powder effectively acts as a micro-filler within the concrete matrix, filling micro-voids, increasing density, and improving particle packing.

Structural strength performance improved consistently up to an optimal cement replacement level of 20%, achieving enhanced compressive, split tensile, and flexural capacities.

Substituting more than 20% marble powder causes a dilution effect that reduces the primary binder volume, leading to lower mechanical performance.

Using industrial stone as a fractional cement replacement offers a practical, dual-benefit solution: it lowers concrete production costs while providing an eco-friendly way to recycle large volumes of industrial waste.

Implementing this sustainable mix design directly reduces cement consumption, shrinking the carbon footprint of construction projects and supporting green building initiatives.

VIII. APPENDIX

Raw Material Batch Formulations for Laboratory Mixes

This appendix presents the exact material proportions utilized during the physical preparation of the laboratory concrete specimens. All components were meticulously measured using electronic scales to ensure absolute consistency across the control batches and the modified waste marble powder (WMP) specimens.

1) Mix Proportioning for Standard Cube Specimens (150x150x150) The baseline matrix was calculated to yield three identical cube samples per test run. For the modified variants, ordinary Portland cement was systematically substituted by mass weight.

Control Mix Baseline (0% WMP): Total calculated cement binder mass required for the production run was exactly 4.080kg with zero mineral dust addition.

10% Modification Mix (WMP-10): The primary binder portion was adjusted down to 4.080kg of ordinary Portland cement, supplemented with precisely 408grams of fine dry waste marble powder.

20% Modification Mix (WMP-20): The primary binder portion was combined with exactly 816grams of dry marble powder to establish the optimal filler ratio.

30% Modification Mix (WMP-30): The binder portion combined 4.080kg of standard cement with exactly 1224 grams (1.224 kg) of ultra-fine industrial stone dust residue.

2) Mix Proportioning for Standard Cylindrical Test Specimens:

For evaluating indirect split tensile strength capacities, larger cylindrical specimens were cast. The basic material proportions required scaled-up volumes to satisfy dimensions.

IX. ACKNOWLEDGMENT

The authors express their profound gratitude to the administrative management and the leadership of the Department of Civil Engineering at our institution for providing the essential material resources, technical testing equipment, and laboratory space required to execute this experimental research framework.

Special recognition is extended to the laboratory technical staff whose constant operational assistance, equipment calibration, and guidance during the structural breaking tests were vital to ensuring data accuracy. We also acknowledge the regional stone processing mills that graciously provided the raw waste marble powder fractions utilized in this material optimization program. Finally, we thank our academic peers and colleagues for their constructive evaluations and ongoing technical discussions, which significantly enhanced the analytical quality and overall execution of this study.

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