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Enhancing Sustainability in Concrete Production through the Incorporation of Waste Materials

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Abstract – The disposal of waste from the marble and granite industry poses a significant global environmental challenge, with millions of tons of waste generated annually. This waste, when discarded indiscriminately, contributes to pollution, land degradation, and health hazards. Effective recycling and reuse of such waste materials are critical to addressing these issues while promoting sustainable industrial practices. This study investigates the potential for recycling marble and granite waste generated during cutting processes in the marble industry as a partial substitute for sand. The research emphasizes a sustainable approach to construction by repurposing waste materials, which otherwise pose significant environmental challenges when disposed of indiscriminately. The incorporation of marble and granite dust as a replacement for sand at varying levels was evaluated for its impact on the workability and mechanical properties of concrete, including compressive strength, split tensile strength, and flexural strength. The findings highlight the feasibility of utilizing marble and granite waste as supplementary materials in concrete, offering the dual benefit of reducing reliance on natural resources like sand and promoting sustainable waste management practices. This approach contributes to the advancement of eco-friendly construction methodologies while maintaining the structural integrity and performance of concrete.

Keywords: Foamed Concrete, Supplementary Cementitious Materials, Waste Materials, Mechanical Properties, Thermal Properties

I. Introduction

Sustainability is the practice of meeting present needs without compromising the ability of future generations to meet their own. It primarily focuses on addressing current and future economic, environmental, and social challenges through innovative, real-world solutions. One significant area of concern is the construction industry, which accounts for approximately 40% of global energy consumption, including the energy required for the construction, operation, and maintenance of buildings [1]–[5]. With urbanization on therise and construction activity projected to expand for decades, the demand for sustainable construction practices has become more urgent than ever [6], [7].

In Egypt, the extraction and processing of decorative sedimentary carbonate rocks, commercially known as marble and granite, is a thriving industry. However, this industry generates substantial waste, with marble and granite sludge powder containing heavy metals as a by-product. Approximately 50% of the material processed in the dimension stone industry is converted into waste in the form of stone powder [8]–[10].The slurry generated during processing, often containing fine particles of marble, makes water unsuitable for reuse and is subsequently discarded, leading to large volumes of waste. This disposal not only occupies valuable cultivable land but also creates significant environmental challenges [11].

Despite these issues, marble and granite waste hold significant potential for reuse in construction, particularly in the manufacture of reinforced concrete. Utilizing these industrial solid wastes in concrete production addresses two key challenges: mitigating environmental pollution associated with waste disposal and conserving natural resources, such as sand, which are rapidly depleting. Incorporating marble and granite powder into concrete as a partial replacement for sand offersa sustainable solution to these problems [12]–[14].

In this study, we explore the use of marble and granite powder as a partial substitute for sand in M50-grade concrete. Concrete samples were prepared with varying levels of sand replacement—0%, 10%, and 20% by volume. The workabilityof the concrete was evaluated in its plastic state, while its compressive strength, tensile strength, and flexural strength were assessed after curing for 7 and 28 days. This approach aimsto demonstrate the feasibility of incorporating waste materials into sustainable construction practices while maintaining the performance standards of concrete.

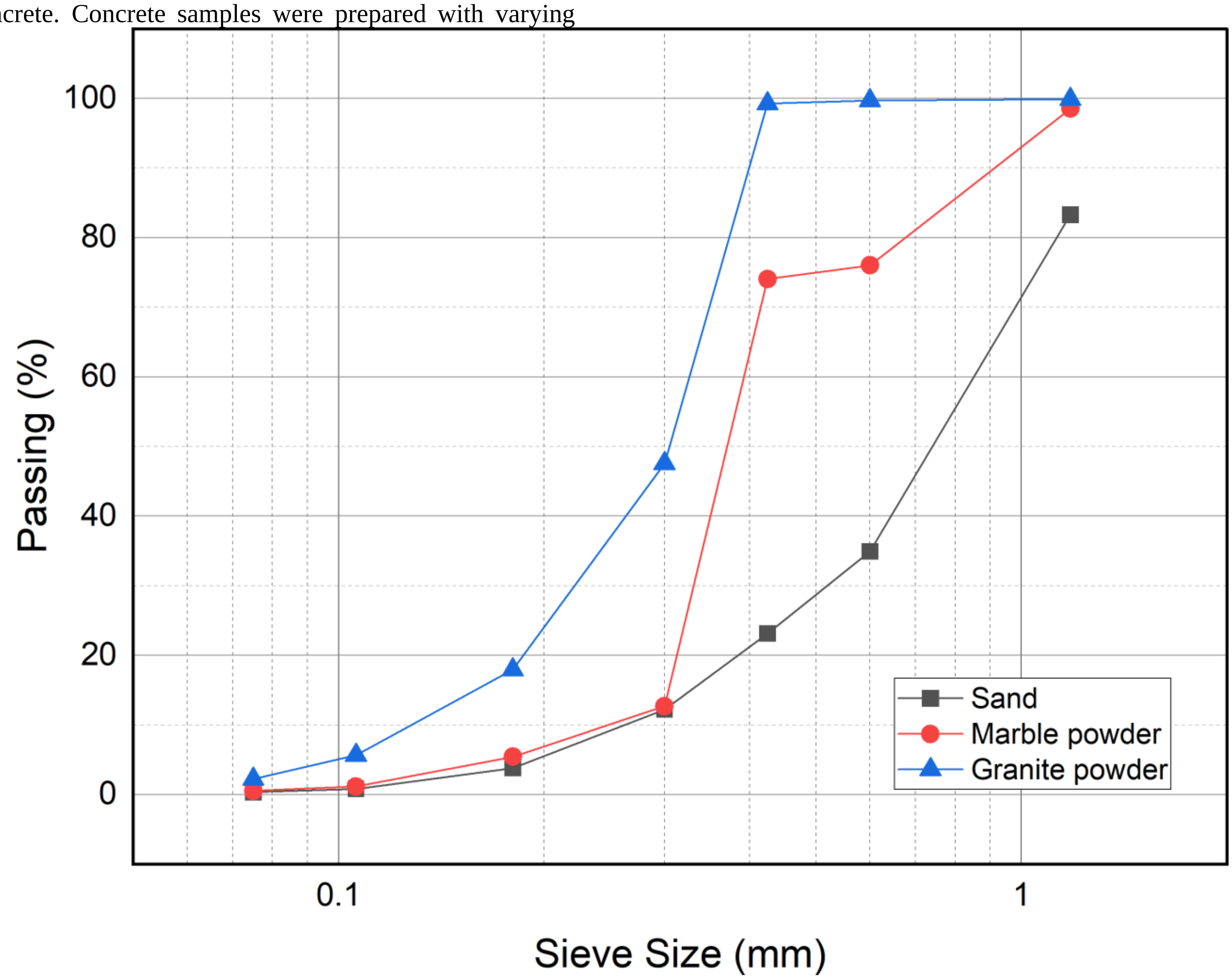

Fig. 1. The size distribution for the used different fines

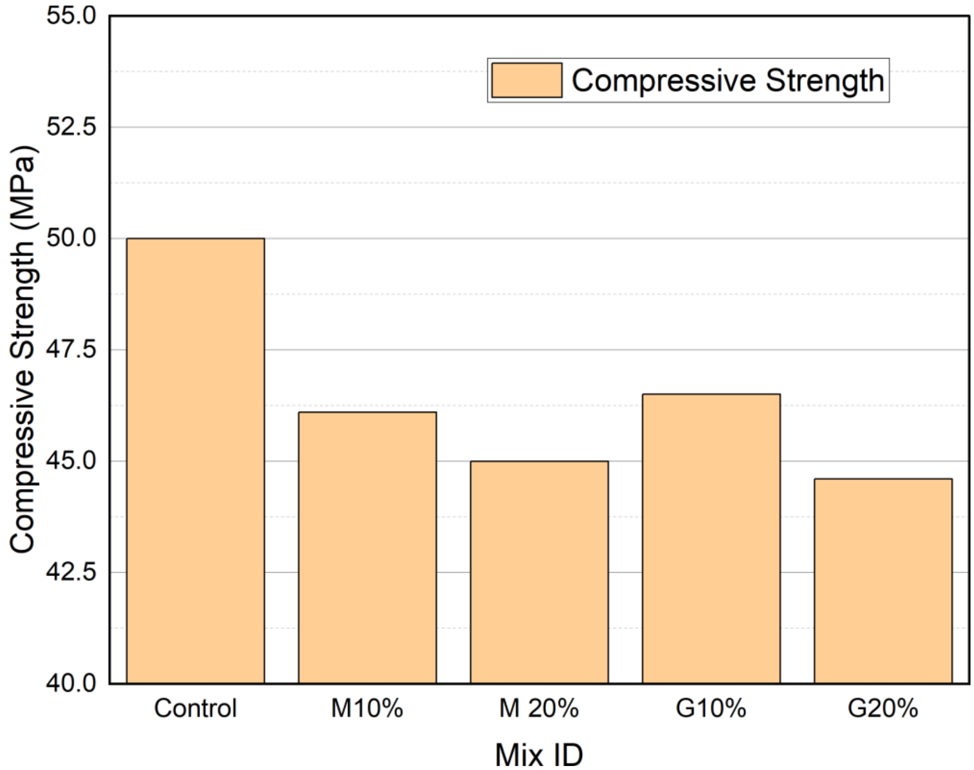

Fig. 2. Compressive Strength

Table 1: Composition Table

Mix ID	H.W.K (kg)	W.G.B	W.M.B	Water (L)	Gravel (kg)	Sand (kg)	Cement (kg)
Control	7 kg	-	-	186	1160	630	350
M 10%	7	-	63	186	1160	567	350
M 20%	7	-	126	186	1160	504	350
G 10%	7	63	-	186	1160	567	350
G 20%	7	126	-	186	1160	504	350

II. Methodology

A. Materials

Ordinary Portland Cement (OPC), particularly CEM I 52.5, was used as the primary binder in the concrete mix, witha minimum content of 350 kg/m³. This cement was chose for its low alkali content, moderate fineness, and low C3A content, which minimize water demand, ettringite formation, and heat of hydration. Additionally, CEM III/B was considereda promising alternative. Superplasticizers, specifically third-generation polycarboxylates and polycarboxylate ethers, were incorporated at approximately 2% of the cement content to enhance flowability and reduce the water-to-cement (w/c) ratio without compromising workability. Clean water with a pHof 7 and minimal harmful substances was used, adhering to code requirements, with a salt content between 3-5%. Coarse aggregate, sourced from broken limestone rock and conforming to IS: 383-1970, was angular, chemical-free, and retained on a 4.75μm sieve. Natural sand in a saturated dry condition (SSD) was employed as fine aggregate, meeting ASTM C33/C33M standards. Marble and granite residues from Shaq Al-Taban were utilized as fine powders. The marblepowder had a specific gravity of 2.7 and an absorption rate of 3.8%, while the granite powder exhibited a density of 920–970kg/m³ and moisture content ranging from 0.3–0.5%. These materials were calibrated to ensure suitability for sustainable concrete production.

B. Mix Design

Marble and granite waste were utilized as partial replacements for natural sand in concrete. The mechanical properties, including compressive, tensile, and flexural strengths, were evaluated after 7 and 28 days of curing. Concrete mixtures were prepared by replacing sand with marble and granite powders at substitution levels of 0%, 10%, and 20% by weight,as detailed in the following table.

C. test

The workability of fresh concrete was assessed using the slump test to evaluate its consistency and plasticity, ensuring compliance with the target slump range. For hardened concrete, compressive strength was measured on standard 15x15x15 cm cubes at 7 and 28 days using a calibrated compression machine, following casting, vibration, curing, and testing protocols. Split tensile strength was determined by loading cylindrical specimens longitudinally until failure and calculating the tensile strength based on the fracture load. Flexural strength was evaluated using flexure tests, where samples were subjected to bending forces until failure to determine their maximum load-bearing capacity.

III. Results And Discussion

A. Workability

This study presents the results of laboratory experiments evaluating the workability of concrete blocks prepared by partially replacing sand with marble and granite powders. Five different concrete samples were prepared by substituting 0%, 10%, and 20% of sand with marble and granite powders (individually) by total weight. The experiments were conducted using an M-grade concrete mix, with the proportions of each component, including the waste materials, determined based on the concrete nominal mix design. The weight of the constituents for each replacement level is detailed in Table 7, which also includes the workability results for each mix.

Fig. 3. Slump test

B. Compressive Strength

The compressive strength results for concrete incorporating marble and granite powder as partial sand replacements, evaluated at 0%, 10%, and 20% replacement levels after 28 days, reveal key insights into their effects. The control sample with no replacement achieved a compressive strength of 50 MPa, serving as the baseline. At 10% replacement, compressive strength decreased to 46.1 MPa for marble powder (8% reduction) and 46.5 MPa for granite powder (7% reduction). At 20% replacement, marble powder resulted in a strength of 45 MPa (10% reduction), while granite powder exhibited 44.6 MPa (11% reduction). These reductions indicate a general trend of declining strength as the replacement level increases, likely due to reduced binding capabilities and increased porosity from the powders. Granite powder demonstrated marginally better performance due to its denser composition. While 10% replacement may be acceptable for applications tolerating slight strength reductions, higher levels significantly compromise performance, requiring careful consideration.

C. Splitting Tensile Strength

The split tensile strength results for concrete incorporating marble and granite powders as partial sand replacements at 0%, 10%, and 20% replacement levels after 28 days highlight significant trends. The control sample achieved a tensile strength of 4.1 MPa, serving as the baseline. At 10% replacement, marble powder reduced the tensile strength to 3.7 MPa (10% reduction), while granite powder showed asmaller reduction to 3.9 MPa (5% reduction), indicating better performance. At 20%, marble powder exhibited a significant reduction to 3.1 MPa (24% decrease), whereas granite powderretained a strength of 4 MPa, matching the control. Marble powder’s reduced performance is attributed to its softer nature,while granite powder’s superior results may stem from its denser composition and better bond within the concrete matrix. These findings suggest granite powder as a viable replacementat higher levels, while marble powder is more suitable for limited replacements to preserve tensile strength.

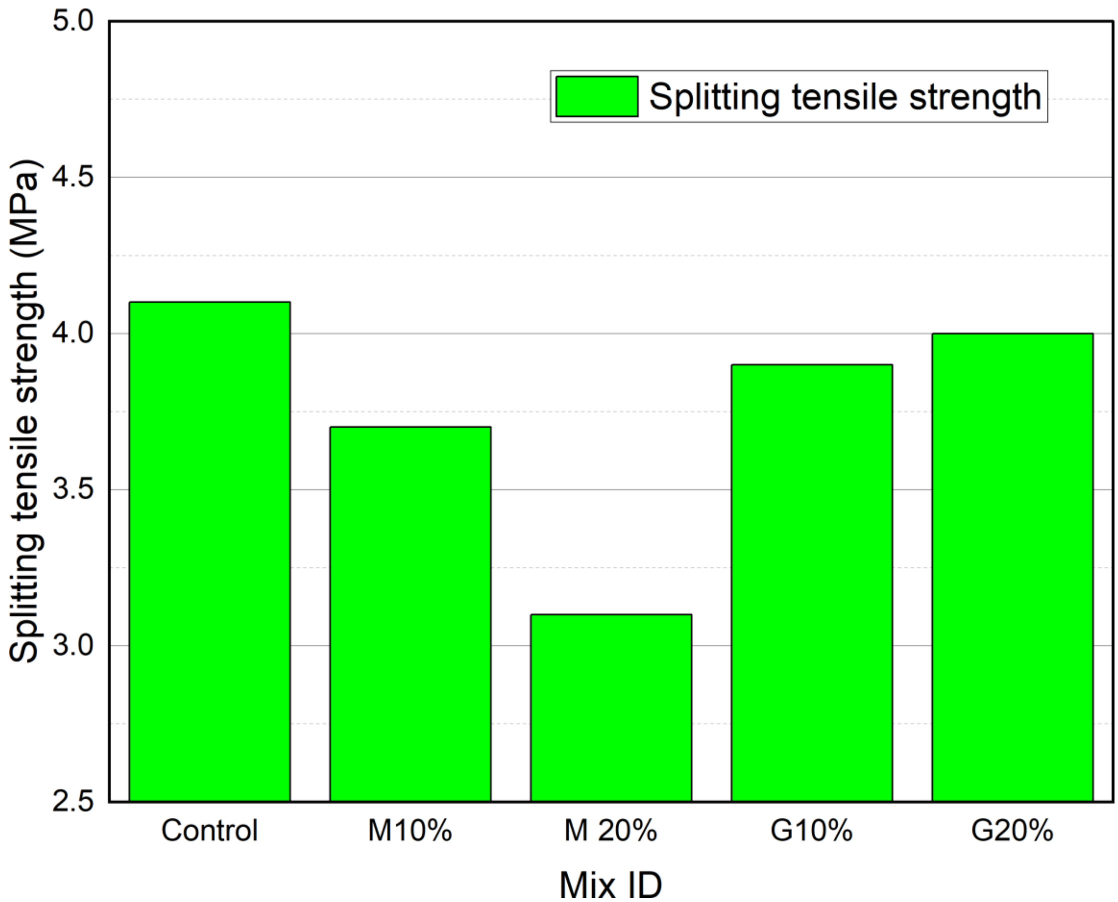

Fig. 4. Splitting tensile strength

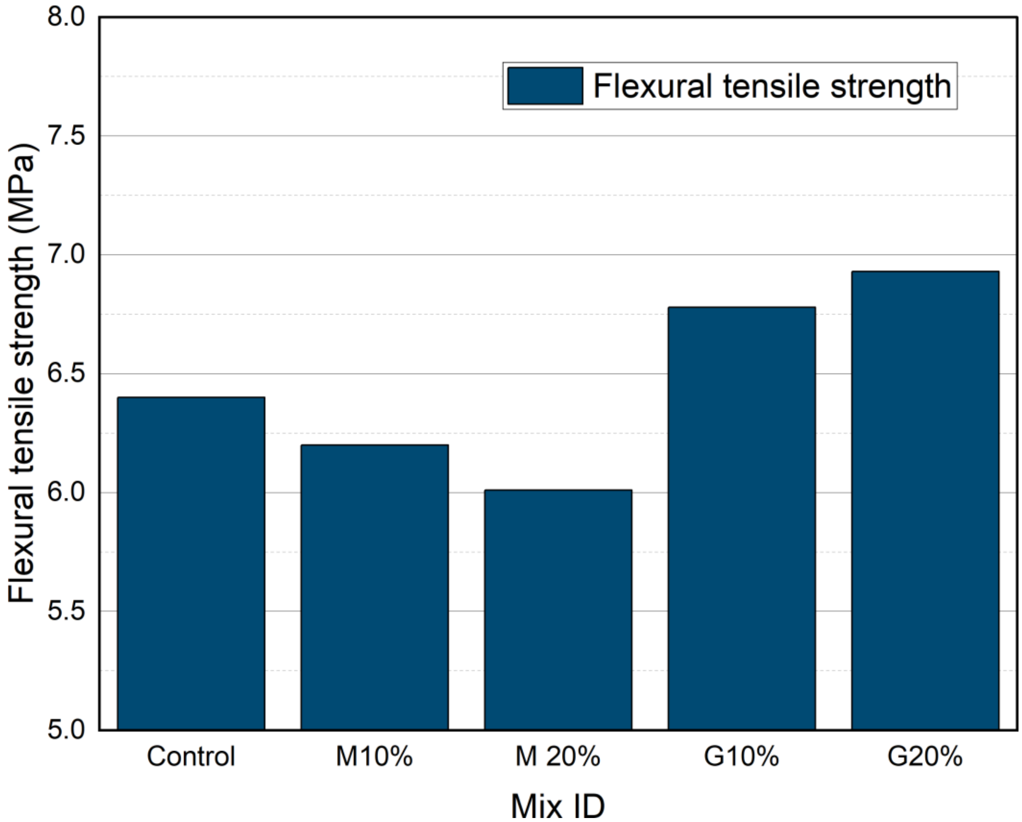

Fig. 5. Flexural tensile strength

D. Flexural Tensile Strength

The flexural strength results for concrete incorporating marble and granite powders as partial sand replacements at 0%, 10%, and 20% replacement levels after 28 days reveal notable trends. The control sample achieved a baseline strength of 6.4 MPa. At 10% replacement, marble powder caused a slight reduction to 6.2 MPa (3% decrease), while granite powder enhanced the strength to 6.78 MPa (6% increase). At 20%, marble powder further reduced the flexural strength to MPa (6% decrease), whereas granite powder significantlyincreased it to 6.93 MPa (8 improvement). These findings suggest that granite powder improves flexural strength due to its harder composition, which enhances particle interlock and matrix bonding. Conversely, marble powder consistently reduced strength, likely due to its softer nature. Granite powder is thus recommended for applications requiring improved bending resistance, even at higher replacement levels, while marble powder should be limited to lower ratios for non-critical uses.

IV. Summary And Conclusions

The main findings of this study:

- Adding marble powder at a 10% replacement rate for sand increased concrete workability by 50%. However, it resulted in a decrease of compressive strength by 8%, tensile strength by 10%, and flexural strength by 3%.

- Adding granite powder at a 10% replacement rate for sand reduced concrete workability by 25%, likely due to the 1.5% additive material used. This substitution causeda 7% decrease in compressive strength, a 5% decreasein tensile strength, but an increase of 6% in flexural strength.

- Using marble powder at a 20% replacement rate forsand significantly improved workability by 150%, but led to reductions in compressive strength by 10%, tensilestrength by 24%, and flexural strength by 6%.

- Incorporating granite powder at a 20% replacement rate for sand enhanced workability by 225%. However, it resulted in a 11% decrease in compressive strength, a 2.5% decrease in tensile strength, and an 8.5% increase in flexural strength.

- Marble powder had a positive impact on workability, but a negative impact on compressive strength, tensile strength, and flexural strength as the replacement percentage increased.

- Granite powder showed a positive impact on workability and flexural strength, but a negative impact on com- pressive strength and tensile strength with increasingreplacement percentages.

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