

Performance of Paving Blocks with Waste Marble Sand as Fine Aggregate

Running title: Waste Marble Sand Paving Blocks

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Abstract

Background: Marble processing produces mineral residue that can be reused in construction. Objective: To evaluate paving blocks containing 10%, 25%, and 50% waste marble sand. Methods: A posttest-only control-group experiment assessed 14-day compressive strength and water absorption according to SNI 03-0691-1996. One-way ANOVA and post hoc tests used $\alpha=0.05$. Results: Mean compressive strength/water absorption were 30.4 MPa/3.14% for control, 12.8 MPa/7.5% at 10%, 14.5 MPa/7.4% at 25%, and 22.8 MPa/4.5% at 50%. ANOVA was significant for compressive strength ($p=0.001$) and water absorption ($p<0.001$). At 50%, compressive strength did not differ from control ($p=0.393$), while water absorption did ($p=0.029$). Conclusion: The 50% mixture performed best among replacement groups and met the Class B criteria evaluated in this study.

Keywords: compressive strength; marble waste; paving block; sand replacement; water absorption

Research Highlights

- A 50% marble-sand substitution produced 22.8 MPa compressive strength and 4.5% water absorption at 14 days.
- The 50% mixture showed no significant compressive-strength difference from the control ($p=0.393$).
- Waste marble sand can replace half of natural sand in the tested paving-block mix while meeting the evaluated Class B criteria.

1 Introduction

Marble processing generates stone fragments, sand, sludge, and fine mineral residues during cutting, shaping, and polishing. In Tulungagung, East Java, marble-industry residues are still partly discharged or underutilized, creating a need for cleaner-production strategies that recover material value rather than transfer waste to the surrounding environment [2]. Reuse in construction is particularly relevant because the mineral fraction can potentially substitute virgin aggregate, simultaneously reducing disposal demand and extraction of natural sand.

Concrete paving blocks are suitable products for such material recovery because their performance can be evaluated using standardized mechanical and absorption criteria. Previous experimental work has demonstrated the technical feasibility of incorporating marble waste into concrete paving blocks, although performance depends on cement type, replacement proportion, particle characteristics, and mixture design [3]. For conventional concrete, Ghani et al. found that replacing sand with waste marble powder improved mechanical properties up to an optimum around 40% under their test conditions and reduced water penetration as replacement increased [4].

Other studies show that the optimum proportion is not universal. Bourzik et al. reported an optimum compressive-strength response at 15% sand replacement in concrete [5], whereas Ali et al. observed that increasing waste marble dust beyond 10% could reduce compressive strength in their mixtures, even though marble fines could reduce water absorption through a filler effect [6]. These differences indicate that locally sourced marble residues should be evaluated in the actual product and mix in which they will be used, rather than adopting a replacement percentage from another concrete system.

The present study therefore evaluated waste marble sand as a partial substitute for natural sand in paving blocks at replacement levels of 10%, 25%, and 50%, with a conventional paving block as the control. The study compared compressive strength and water absorption against SNI 03-0691-1996 and identified the most favorable replacement level among the tested mixtures [1].

2 Materials and Methods

2.1 Study design and setting

This study used a true experimental posttest-only control-group design. The experiment was conducted from January to August 2024, and mechanical testing was carried out at the Materials and Concrete Structures Laboratory, Institut Teknologi Sepuluh Nopember (ITS), Manyar Campus, Surabaya, Indonesia. The experimental groups consisted of one conventional paving-block control and three mixtures in which natural sand was partially replaced by waste marble sand at 10%, 25%, and 50% by sand mass.

2.2 Materials and mixture proportions

Waste marble sand generated by marble processing was used as the substitute fine aggregate. Cement and water quantities were kept constant at 479 g and 90 mL per specimen mixture, while natural sand and waste marble sand were varied according to the replacement level (Table 1).

Table 1. Mixture proportions for control and waste-marble-sand paving blocks

Marble sand (%)	Natural sand (%)	Marble sand (g)	Natural sand (g)	Cement (g)	Water (mL)
0	100	0	1933	479	90
10	90	193	1733	479	90
25	75	483	1449	479	90
50	50	966	966	479	90

Note: Cement and water quantities were held constant while the fine-aggregate proportions were varied.

2.3 Specimen preparation and testing

Paving blocks were molded to dimensions of 20 × 10 × 6 cm and compacted using hydraulic pressure. Three repeated specimens were prepared for each marble-sand treatment variation. The paving blocks were evaluated at 14 days; the water-absorption procedure included an immersion stage. Compressive strength and

water absorption were the primary performance outcomes. Testing and quality classification followed SNI 03-0691-1996 [1].

2.4 Outcome classification

Compressive strength was expressed in MPa and water absorption as a percentage. Based on the SNI categories applied in this study, the 10% and 25% mixtures were classified as Class C, while the 50% mixture and the control were classified as Class B. Because only compressive strength and water absorption were evaluated, SNI conformity statements refer specifically to these measured criteria rather than to every performance requirement in the standard.

2.5 Statistical analysis

Descriptive analysis summarized mean compressive strength and mean water absorption for each group. Group differences were evaluated using one-way analysis of variance (ANOVA). Post hoc pairwise comparisons were then used to compare each marble-sand mixture with the control. Statistical significance was defined as $p < 0.05$. A software output value of 0.000 is presented as $p < 0.001$ in the narrative.

2.6 Ethical considerations

The study involved laboratory testing of construction materials and did not involve human participants, personal data, animals, or clinical specimens. Human- or animal-research ethics approval and informed consent were therefore not applicable.

3 Results

3.1 Compressive strength and water absorption

The control paving block had the highest mean compressive strength (30.4 MPa) and the lowest mean water absorption (3.14%). Among the marble-sand mixtures, performance improved as replacement increased from 10% to 50%. Mean compressive strength increased from 12.8 MPa at 10% to 14.5 MPa at 25% and 22.8 MPa at 50%. Mean water absorption was 7.5%, 7.4%, and 4.5%, respectively (Table 2). The 50% replacement mixture therefore produced the strongest and least absorptive paving block among the three waste-marble treatments.

Table 2. Mean compressive strength, water absorption, and SNI classification at 14 days

Group	Compressive strength (MPa)	Water absorption (%)	SNI class*	Functional use in source
Control	30.4	3.14	B	Parking area
10% marble sand	12.8	7.5	C	Pedestrian area
25% marble sand	14.5	7.4	C	Pedestrian area
50% marble sand	22.8	4.5	B	Parking area

*Note: *Classification is based on the compressive-strength and water-absorption criteria evaluated according to SNI 03-0691-1996.*

The reported compressive-strength ranges for the marble-sand groups were 12.2–13.7 MPa at 10%, 13.7–15.2 MPa at 25%, and 21.0–22.8 MPa at 50%. The corresponding water-absorption ranges were 6.63–7.80%, 7.11–8.00%, and 4.42–4.71%. These ranges show that the 50% mixture consistently performed better than the 10% and 25% mixtures for both outcomes.

3.2 ANOVA and post hoc comparisons

One-way ANOVA indicated statistically significant differences among the control and replacement groups for both compressive strength ($p = 0.001$) and water absorption ($p < 0.001$) (Table 3).

Table 3. One-way ANOVA results for paving-block performance

Outcome	p-value	Interpretation
Compressive strength	0.001	Significant difference among groups
Water absorption	<0.001	Significant difference among groups

Post hoc comparisons showed that the 10% and 25% mixtures differed significantly from the control in compressive strength ($p=0.001$ and $p=0.002$, respectively), whereas the 50% mixture did not ($p=0.393$). For water absorption, all three replacement mixtures differed significantly from the control, including the 50% group ($p=0.029$) (Table 4).

Table 4. Post hoc comparisons between control and marble-sand replacement groups

Comparison	Compressive strength p-value	Water absorption p-value	Interpretation
Control vs 10%	0.001	<0.001	Both outcomes significantly different
Control vs 25%	0.002	<0.001	Both outcomes significantly different
Control vs 50%	0.393	0.029	Strength not significant; absorption significant

Note: The source manuscript reported water-absorption p-values of 0.000; these are conventionally presented as $p<0.001$.

4 Discussion

The main finding was that the 50% waste-marble-sand mixture provided the best balance of strength and water absorption among the three replacement formulations. At 14 days it achieved a mean compressive strength of 22.8 MPa and mean water absorption of 4.5%, compared with 12.8 MPa/7.5% at 10% replacement and 14.5 MPa/7.4% at 25%. The 50% mixture was categorized as Class B under the SNI criteria evaluated in the original study, supporting its potential use for parking-area paving. However, the control remained numerically stronger (30.4 MPa) and less absorptive (3.14%), so the 50% mixture should be described as the optimal waste-marble formulation rather than as superior to conventional paving blocks.

The statistical results reinforce this distinction. Although the overall ANOVA was significant, post hoc analysis showed no statistically significant difference in compressive strength between the 50% mixture and the control ($p=0.393$). By contrast, water absorption at 50% remained significantly different from the control ($p=0.029$). Thus, the 50% replacement achieved control-comparable compressive strength in the reported post hoc test, but not equivalent absorption performance. The 10% and 25% mixtures were significantly different from control for both outcomes and were classified as Class C.

These findings are plausible in light of prior work, but they also illustrate why the optimum marble-waste proportion is mixture-specific. Gencel et al. demonstrated that waste marble can be incorporated into concrete paving blocks, although increasing marble content affected mechanical properties and other durability indicators [3]. Ghani et al. reported an optimum around 40% sand replacement in conventional concrete and observed reduced water penetration with greater marble-powder content [4]. Bourzik et al. found their highest compressive strength at 15% sand replacement [5], while Ali et al. reported decreasing compressive strength beyond 10% in their concrete system [6]. The range of reported optima indicates that particle grading, cement content, water-to-cement ratio, compaction, curing, and the physical form of the marble residue materially influence performance.

A filler or packing effect is one possible explanation for the lower absorption observed in the 50% mixture relative to the 10% and 25% mixtures. Fine marble particles can occupy voids within a cementitious matrix and reduce capillary pathways; such behavior has been observed experimentally in marble-dust concrete [6]. In the present study, however, particle-size distribution, porosity, density, mineralogy, and microstructure were not

measured. The proposed packing mechanism should therefore be treated as an interpretation rather than a directly demonstrated mechanism. Because the residue used here was marble sand, findings from studies using very fine marble powder are informative but not directly interchangeable.

From an environmental-health perspective, incorporating marble-processing residue into paving blocks provides a route for material recovery and can reduce uncontrolled disposal of mineral waste. Recent cleaner-production work in the Tulungagung marble sector has likewise identified reuse of marble sludge and solid residues in construction-related products as a practical waste-minimization pathway [2]. The present experiment adds product-level performance data by showing that a 50% sand substitution can retain useful mechanical performance under the tested mix. Nevertheless, the study did not quantify avoided waste disposal, natural-sand savings at production scale, emissions, leaching, or life-cycle impacts; environmental benefits should therefore not be overstated.

The study has several limitations. Testing was performed at 14 days rather than including a conventional 28-day strength endpoint, only three replacement proportions were investigated, and detailed test-instrument specifications were not reported. Abrasion resistance, dimensional tolerance, long-term durability, leaching, particle-size distribution, and chemical characterization of the marble sand were also not evaluated. Future studies should confirm the 50% formulation at 28 days, use a larger explicitly documented replicate number, test additional replacement levels around 40–60%, and evaluate abrasion and durability parameters required for field paving applications.

5 Conclusion

Waste marble sand can be used as a partial fine-aggregate substitute in the tested paving-block mixture, with 50% replacement producing the best performance among the three waste-marble formulations. At 14 days, the 50% mixture achieved a mean compressive strength of 22.8 MPa and water absorption of 4.5%, compared with 12.8 MPa/7.5% at 10% and 14.5 MPa/7.4% at 25%. The overall group differences were significant for compressive strength ($p=0.001$) and water absorption ($p<0.001$). In post hoc analysis, compressive strength at 50% was not significantly different from the control ($p=0.393$), although water absorption remained significantly different ($p=0.029$). Based on the evaluated criteria, the 50% mixture was classified as SNI Class B and is the most promising formulation for further validation for parking-area paving applications.

6 Declarations

Ethics approval and consent to participate

Not applicable. The study involved laboratory testing of construction materials only and did not involve humans or animals.

Consent for publication

Not applicable; no identifiable personal information is included.

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Competing interests

The authors declare no competing interests.

Author contributions (CRediT)

Assign CRediT roles for Muhammad Nauval Jamaluddin, Demes Nurmiyanti, Fitri Rokhmalia, and Iva Rustanti.

Data availability

The numerical results used in this article are reported in the tables. Additional study records, if available, may be requested from the corresponding author.

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Generative AI statement

Generative AI (OpenAI ChatGPT) was used for English translation and language editing, and formatting assistance. The authors remain responsible for the scientific content, data integrity, citation accuracy, originality, and final approval of the manuscript.

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