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Performance Evaluation of Interlocking Paving Blocks Incorporating Quarry Dust as a Partial Replacement for Sand

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Abstract
This study experimentally evaluates the influence of quarry dust as a partial replacement for natural river sand in the performance of interlocking paving blocks. Five replacement levels; 0%, 2.5%, 5%, 7.5% and 10% by mass of sand, were investigated using a nominal 1:2:4 mix proportion and a constant water–cement ratio of 0.70. Sixty interlocking specimens were produced, with three specimens from each mixture tested at 7, 14, 21 and 28 days. Preliminary characterization included particle-size distribution and specific gravity of the aggregates, while the fresh concrete was assessed using the slump test. The hardened specimens were evaluated through density and compressive-strength measurements. The specific gravities of the natural sand and quarry dust were 2.45 and 2.57, respectively. Slump reduced from 20 mm for the control mixture to 10.5 mm at 2.5% replacement and 0 mm at 5–10% replacement, indicating a marked increase in water demand as quarry dust content increased. Despite the reduction in workability, the compressive-strength results showed that the 2.5% mixture performed poorly, whereas strength increased progressively from 5% to 10% replacement. At 28 days, the control mixture recorded 7.47 N/mm², compared with 4.93, 5.90, 6.70 and 6.82 N/mm² for 2.5%, 5%, 7.5% and 10% replacement, respectively. The 10% mixture therefore gave the highest strength and density among the quarry-dust mixtures tested, although it did not exceed the control strength. The results indicate that quarry dust can be beneficial as a limited sand-replacement material in paving-block production when adequate compaction and mix-water control are provided. The study recommends 10% as the optimum replacement within the investigated range, while emphasizing that this conclusion is specific to the materials and mix conditions used.

Keywords: Quarry Dust; Interlocking Paving Blocks; Natural Sand; Compressive Strength; Density; Slump; Particle-Size Distribution; Sustainable Construction.

1. Introduction

Concrete is one of the most widely used construction materials because its constituent materials can be proportioned to obtain a range of engineering properties (Ezeagu, C. A., & Agusi, M. S. 2018; Raman et al., 2011). Fine aggregate is particularly important because it occupies the voids between coarse particles and influences packing, workability, water demand and the properties of the hardened matrix. (Balamurugan and Perumal 2013). Natural river sand remains a common fine aggregate, but increasing extraction and transportation requirements have encouraged research into alternative materials. Quarry dust, fine rock particles generated during crushing and processing operations, is one such material (Ekwueme et al., 2021). Its use can simultaneously reduce reliance on natural sand and divert a quarry by-product from disposal streams.

Previous investigations demonstrate that the response of concrete to quarry dust depends strongly on replacement level, aggregate grading, particle shape, water–cement ratio and compaction. Ilangovan et al. (2008) reported favourable strength and durability performance for concrete containing quarry rock dust, while Balamurugan and Perumal (2013) found that strength can vary substantially with

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replacement percentage. Nanda et al. (2010) investigated crusher dust in paving blocks and reported that replacement levels up to 50% produced only limited reductions in several measured properties. Other studies have likewise shown that quarry dust may improve packing and strength at suitable proportions, although high fines content can reduce workability because of increased specific surface area (Ezeagu, C. A., & Agusi, M. S. 2018; Raman et al., 2011).

Against this background, the present study focuses on a relatively narrow replacement range of 0–10% by mass of sand with quarry dust. The work is intended to determine whether small additions of quarry dust can improve the performance of interlocking paving blocks without requiring a complete replacement of natural sand.

2. Aim and Objectives

The aim of the study was to investigate the feasibility of using quarry dust as a partial replacement for natural sharp sand in the production of interlocking paving blocks.

- compare the basic physical characteristics of natural sand and quarry dust;
- produce interlocking paving blocks with controlled quarry-dust replacement levels;
- evaluate the workability of the fresh concrete mixtures;
- determine density and compressive strength at 7, 14, 21 and 28 days; and
- Identify the replacement level that provides the most favourable performance within the investigated range.

3. Materials and Methods

3.1 Materials

Ordinary Portland cement (Dangote Cement) was used as the binder. River sand obtained from a local supplier at Eke Awka, Anambra State, served as the conventional fine aggregate. Coarse aggregate with a reported size range of approximately 10–20 mm was sourced from Ishiagu, Ebonyi State. Quarry dust from the same general source area was used as the replacement material. Potable water obtained at Nnamdi Azikiwe University was used for mixing and curing. The laboratory work was conducted at the Civil Engineering Laboratory of Nnamdi Azikiwe University.

Table 1. Principal material characteristics reported in the study.

Material	Property	Measured value / description
Natural sand	Specific gravity	2.45
Quarry dust	Specific gravity	2.57
Coarse aggregate	Nominal size	Approximately 10–20 mm

3.2 Mix Proportion and Specimen Production

A nominal mix ratio of 1:2:4 (cement: fine aggregate: coarse aggregate) was adopted with a constant water–cement ratio of 0.70. Natural sand was partially replaced by quarry dust at 0%, 2.5%, 5%, 7.5% and 10%. A total of 60 specimens were produced, corresponding to five mixtures, four curing ages and three specimens per mixture at each age. Fresh concrete was placed in interlocking-block moulds and compacted before curing.

Table 2. Experimental matrix.

Mix	Quarry dust replacement (%)	Number of specimens
QD-0	0	12
QD-2.5	2.5	12
QD-5	5	12
QD-7.5	7.5	12
QD-10	10	12

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3.3 Aggregate Characterization

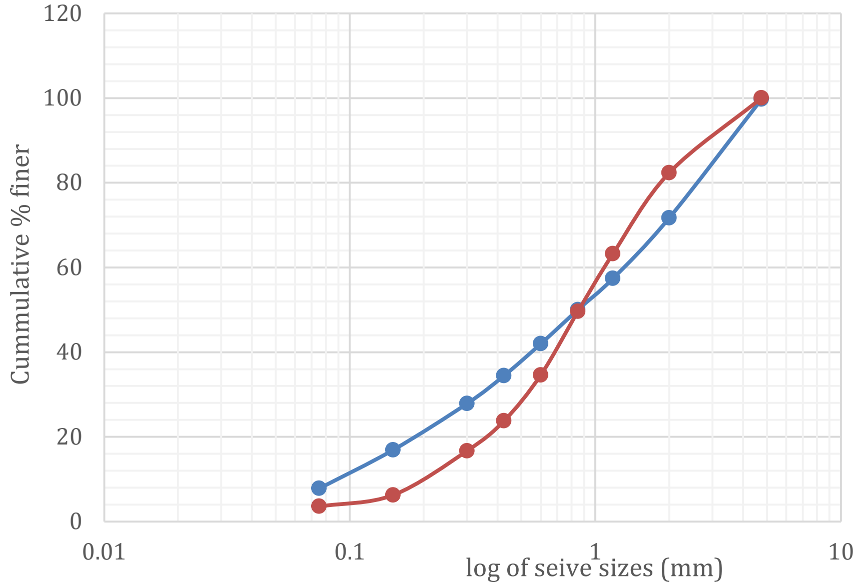

Figure 1 Particle size distribution curve for Quarry dust and sand

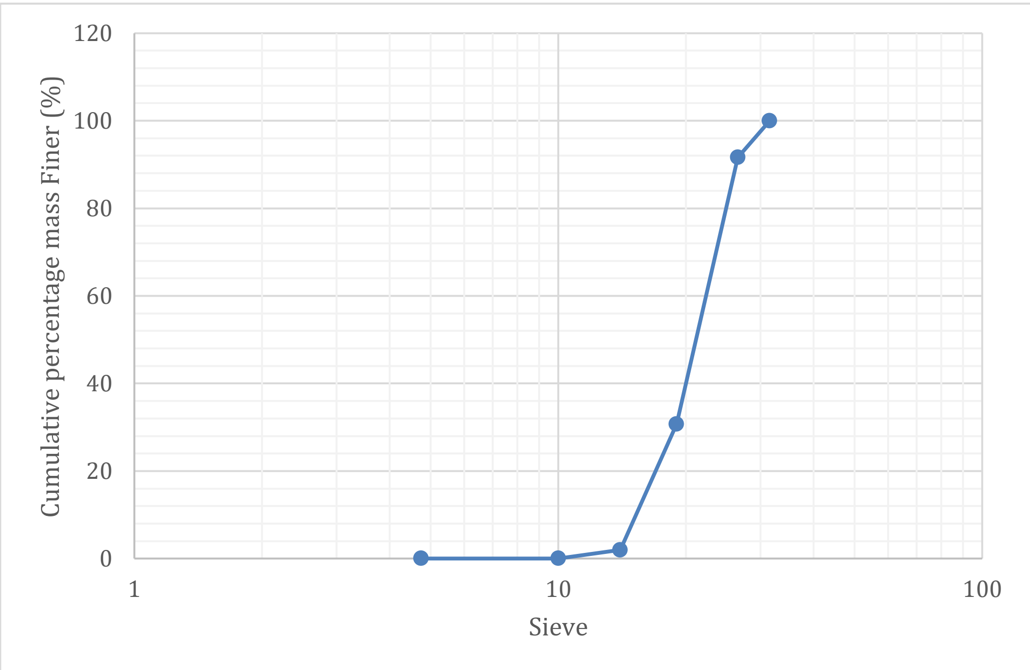

Figure 2 Particle size distribution curve for coarse aggregates

From the results of Particle-size distribution, the coefficient of uniformity, Cu = D6
0/D10, and coefficient of curvature, Cc = D30²/ (D60D10) are as follows: Cu = 5.50 and Cc = 1.23 for sand; Cu = 1.12 and Cc = 1.05 for quarry dust; and Cu = 1.24 and Cc = 1.01 for coarse aggregate. These results indicate that the sand was comparatively better graded than the quarry dust and that the quarry dust contained a relatively narrow distribution of fine particles.

3.4 Specific Gravity

Specific gravity was determined using the density-bottle method. The reported values were 2.45 for natural sand and 2.57 for quarry dust. The higher value for quarry dust indicates a slightly greater

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mass per unit volume of solid particles than the sand used in this investigation. The result is relevant to mixture packing and density, although specific gravity alone does not establish strength performance.

3.5 Workability

Slump testing was performed immediately after mixing. The measured slump values were 20 mm for the control mixture, 10.5 mm at 2.5% replacement and 0 mm at 5%, 7.5% and 10% replacement. The trend is consistent with the angular morphology and high fineness commonly associated with quarry dust. Such particles can increase the surface area requiring wetting and therefore reduce slump at a fixed water–cement ratio. Similar workability reductions have been reported by Ilangovan et al. (2008).

Table 3. Slump results at a water–cement ratio of 0.70.

Replacement (%)	Slump (mm)	Reported workability
0	20	Very low
2.5	10.5	Very low
5	0	Very low
7.5	0	Very low
10	0	Very low

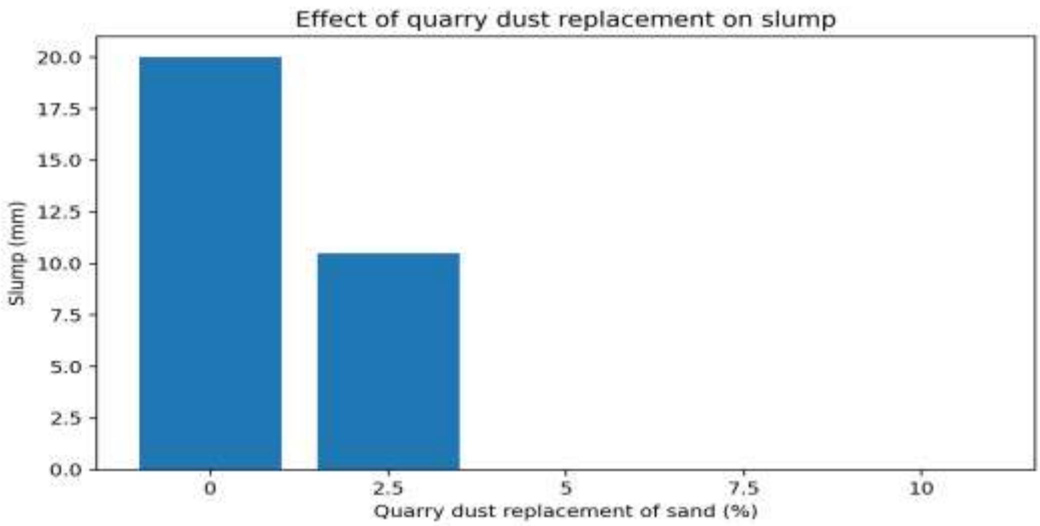

Figure 3. Effect of quarry dust replacement on measured slump.

3.6 Density and Compressive Strength

Three specimens from each mixture were tested at 7, 14, 21 and 28 days. Mean density and mean compressive strength were recorded for each age. Compressive strength was evaluated as the maximum load divided by the loaded cross-sectional area. The results below reproduce the numerical values reported in the source study.

Table 4. Mean density and compressive-strength results.

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Curing age (days)	Replacement (%)	Mean density (kg/m³)	Mean compressive strength (N/mm²)
7	0	2873.33	5.13
7	2.5	2550.00	3.00
7	5	2656.67	5.23
7	7.5	2530.00	5.30
7	10	2683.33	5.60
14	0	2710.00	5.43
14	2.5	2520.00	3.87
14	5	2593.33	5.30
14	7.5	2610.00	5.70
14	10	2790.00	6.10
21	0	2716.67	6.30
21	2.5	2503.33	4.00
21	5	2636.67	5.53
21	7.5	2643.33	6.40
21	10	2750.00	6.47
28	0	2683.33	7.47
28	2.5	2593.33	4.93
28	5	2640.00	5.90
28	7.5	2616.67	6.70
28	10	2776.67	6.82

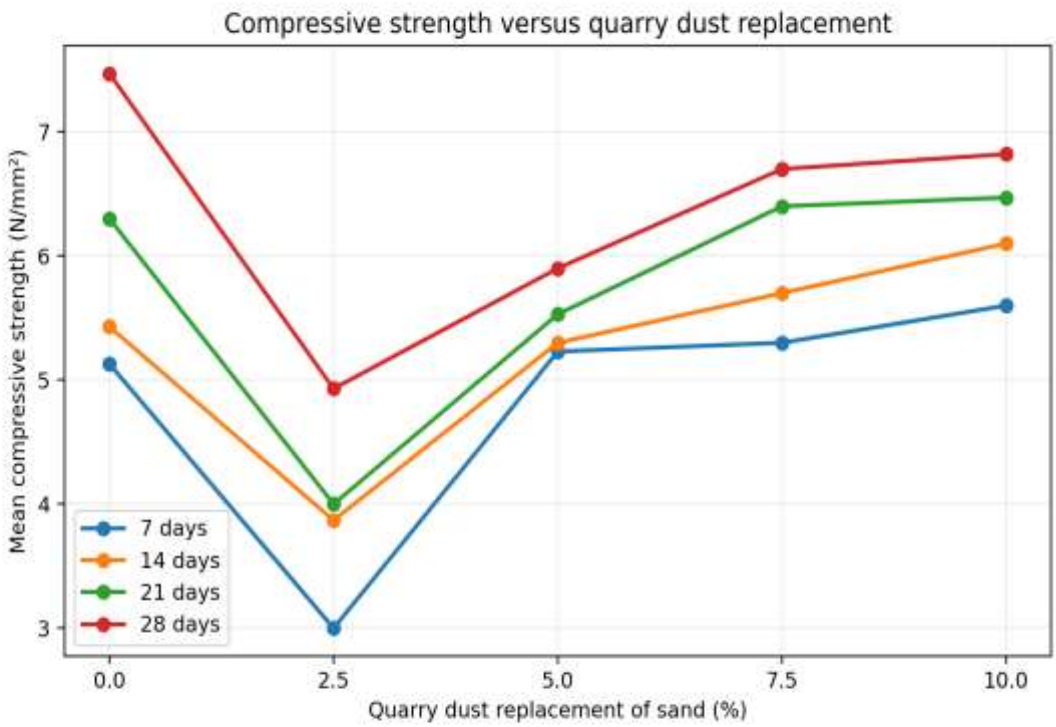

Figure 4. Compressive strength development with quarry dust replacement.

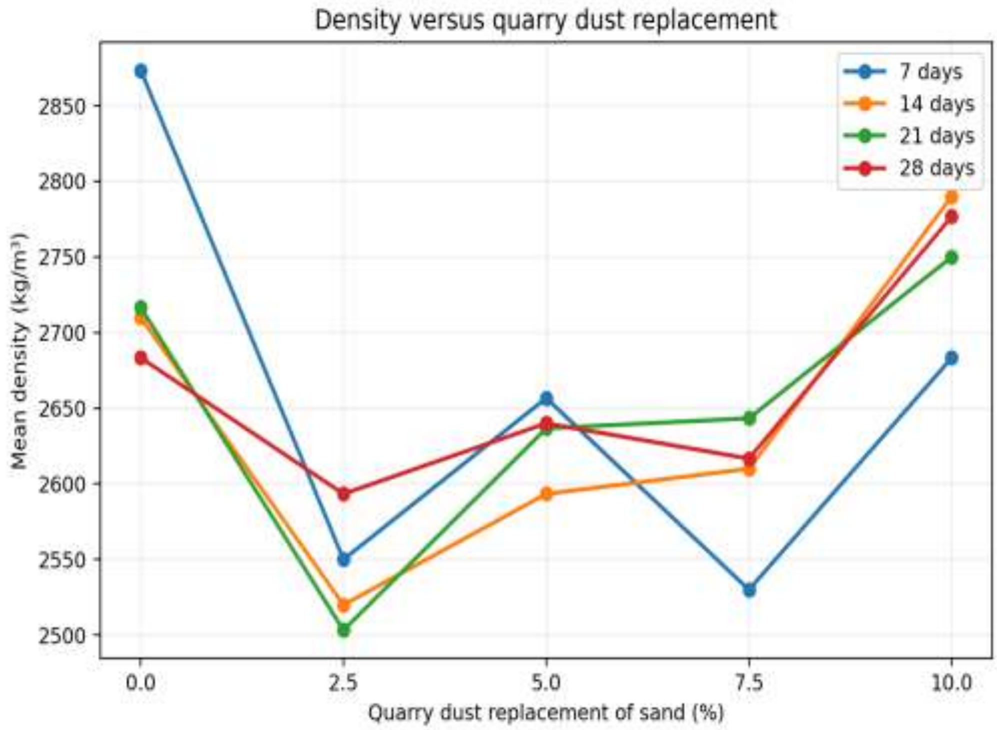

Figure 5. Variation of mean density with quarry dust replacement.

4. Results and Discussion

4.1 Aggregate Characteristics and Specific Gravity

The specific gravity of the quarry dust (2.57) was higher than that of the natural sand (2.45). The quarry dust was also characterized by a narrower particle-size distribution than the sand. The combination of finer particles and higher particle density can promote void filling when quarry dust is blended with sand. This provides a plausible explanation for the improved density observed at some replacement levels. However, the same fines that improve packing can increase water demand, which was clearly reflected by the slump results.

4.2 Workability

Workability decreased systematically as quarry dust content increased. The control mixture had a slump of 20 mm, which reduced to 10.5 mm at 2.5% replacement and became zero at 5–10%. This is an important practical finding because interlocking blocks require adequate consolidation to achieve uniform density and avoid internal voids. At the fixed water–cement ratio adopted in this study, increasing quarry dust produced a stiffer mixture. Accordingly, the improved hardened properties observed at some replacement levels should not be interpreted as evidence that higher quarry-dust content is automatically preferable. In production practice, the mix should instead be proportioned to provide sufficient compactability without simply adding uncontrolled water.

4.3 Compressive Strength

Compressive strength generally increased with curing age for all mixtures, reflecting continued cement hydration. The control mixture increased from 5.13 N/mm² at 7 days to 7.47 N/mm² at 28 days. The 2.5% replacement mixture was consistently the weakest, increasing from 3.00 to 4.93 N/mm² over the same period. In contrast, the 5%, 7.5% and 10% mixtures showed progressively better performance, with the 10% mixture recording 5.60, 6.10, 6.47 and 6.82 N/mm² at 7, 14, 21 and 28 days, respectively.

The data therefore indicate a non-linear response to quarry dust. A small 2.5% addition appears to have disturbed the original aggregate grading without supplying enough fines to create a meaningful filler benefit. At higher tested replacement levels, the increasing quantity of fine particles appears to have improved packing sufficiently to offset part of the workability penalty. This interpretation is consistent with published research showing that the optimum quarry-dust content is mix-dependent rather than universal. For example, Balamurugan and Perumal (2013) reported maximum strength at 50% replacement in their particular concrete mixtures, whereas Raman et al. (2011) identified 20% quarry dust as an optimum in high-strength rice-husk-ash concrete. These differences reinforce the importance of mix-specific optimization.

4.4 Density

Density varied with both curing age and replacement percentage. Within the quarry-dust mixtures, the 10% replacement level produced the highest 28-day density, 2776.67 kg/m³. The density data therefore support the interpretation that quarry dust can enhance particle packing under suitable conditions. Nevertheless, density did not increase monotonically at every age and replacement level, demonstrating that compaction and mixture uniformity also influence the measured values.

4.5 Identification of the Optimum Replacement Level

Within the investigated range, 10% quarry dust gave the highest compressive strength among the quarry-dust mixtures at every curing age and the highest 28-day density among those mixtures. However, it is important to distinguish the optimum modified mixture from the control: the control remained stronger at 28 days (7.47 N/mm²) than the 10% mixture (6.82 N/mm²). Therefore, the defensible conclusion is that 10% is the optimum replacement level within the tested quarry-dust mixtures because it gave the best combined density and compressive-strength performance, not because it exceeded the unmodified control.

Table 5. Comparison of 28-day performance.

Replacement (%)	28-day strength (N/mm²)	28-day density (kg/m³)
0	7.47	2683.33
2.5	4.93	2593.33
5	5.90	2640.00
7.5	6.70	2616.67
10	6.82	2776.67

5. Comparison with Previous Research

The present findings broadly agree with the wider literature in showing that quarry dust can be used as a fine-aggregate replacement, but that the optimum level depends on the mixture and processing conditions. Nanda et al. (2010) reported that crusher dust could be incorporated into paving blocks at much higher replacement levels with relatively small reductions in measured properties, while Ilangovan et al. (2008) reported favourable strength and durability characteristics for quarry-rock-dust concrete. Raman et al. (2011) found 20% quarry dust to be an optimum level in high-strength concrete containing rice-husk ash. These studies should not be interpreted as directly prescribing an optimum for the present paving-block mix; rather, they demonstrate that aggregate grading, water demand, binder content, compaction and the intended product all influence the response.

6. Practical and Environmental Implications

Replacing a portion of natural sand with quarry dust can provide a useful pathway for valorizing a quarry by-product while reducing demand for virgin natural sand. The environmental benefit is greatest when the quarry dust is locally available and can be transported economically. From a production perspective, the present study shows that workability must be carefully controlled. Mechanical vibration or other adequate compaction should be used for stiff mixtures, and future trials should investigate water-reducing admixtures or optimized water–cement ratios rather than increasing water indiscriminately.

7. Limitations of the Study

- The replacement range was limited to 0–10%; therefore, the study cannot establish the optimum at higher replacement levels.
- The water–cement ratio was fixed at 0.70, which strongly influenced the low-slump behaviour and may not represent an optimized paving-block mix.
- Only density, slump, aggregate characterization and compressive strength were reported. Abrasion resistance, water absorption, flexural strength and long-term durability were not measured in the supplied dataset.
- The study reports mean values but does not provide specimen-level results or standard deviations; consequently, statistical significance between mixtures cannot be established.

8. Conclusion

The study demonstrates that quarry dust can be incorporated as a partial replacement for natural sand in interlocking paving blocks. The material characterization showed a specific gravity of 2.45 for sand and 2.57 for quarry dust. Increasing quarry-dust content caused a pronounced reduction in slump at the fixed water–cement ratio of 0.70, with zero measured slump from 5% replacement upward.

Despite the reduction in fresh-concrete workability, the hardened properties showed a favourable response at moderate replacement levels. The 2.5% mixture consistently produced the lowest compressive strengths, while the 5–10% mixtures showed progressive improvement. At 28 days, the 10% mixture recorded 6.82 N/mm² and 2776.67 kg/m³, compared with 7.47 N/mm² for the control. Thus, 10% replacement is identified as the optimum among the modified mixtures tested, although the control still had the highest ultimate compressive strength.

Overall, quarry dust has potential as a partial sand-replacement material for interlocking paving blocks, particularly where the objective is to reduce natural-sand consumption while maintaining satisfactory density and strength. The result should, however, be applied within the tested material and mix conditions rather than generalized to all quarry dust sources.

9. Recommendations

1. Adopt 10% quarry dust as the preferred starting point for further trials based on the present experimental range, subject to verification against the required paving-block performance class.
2. Investigate lower water–cement ratios and suitable water-reducing admixtures to improve workability without compromising strength.
3. Conduct abrasion resistance, water absorption, flexural/splitting tensile strength and durability tests before field application.
4. Report specimen-level results, standard deviations and statistical significance in future work.
5. Extend the replacement range beyond 10% in a controlled experiment to determine whether a higher optimum exists for the particular quarry dust and aggregate grading.
6. Characterize quarry dust for mineralogy, deleterious materials, and fines content before large-scale use.

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