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Utilizing Crushed Periwinkle Shell in Concrete Paving Stone Production: A Sustainable Approach for Low-Cost Construction

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Abstract

Introduction

This study investigates the feasibility of incorporating crushed periwinkle shell (CPS) as a partial replacement for aggregate in paving stone production, with the aim of comparing the compressive strength of conventional paving stone with CPS paving stone and reduction in production cost.

Methods

A full factorial experimental design method was adopted. The physical properties, mechanical properties, and cost difference were assessed through water absorption, workability, and compressive strength tests. A 1:4 mix design was adopted and batched by weight. Stone dust was replaced with CPS at 0%, 25%, 50%, and 75%, with a water-cement (w/c) ratio of 0.5. Strengths were determined at 7, 14, 21, and 28 days of curing. Samples were cured by both total submersion and curing by sprinkling.

Results

The result showed an average water absorption rate of 7.55%, as specified in ASTM C936, with 75% replacement having the optimum water absorption condition of 4.74%. The workability test revealed that the slump values increased as the percentage replacement of CPS was increased. It was also discovered that the compressive strength increases as the curing age increases and possesses a fluctuating value as the percentage replacement of stone dust with CPS increases. Cost analysis demonstrated a reduction in material cost as the percentage replacement of constituents increased.

Conclusion

From the result of the study, it can be safely stated that CPS can be used as a partial replacement of fine aggregate in the production of paving stone, especially in coastal areas where the periwinkle shell is in abundance.

Categories: Advanced Materials, Environmental and Sustainable Engineering
Keywords: aggregate, agro waste, crushed periwinkle shell (cps), compressive strength, paving stone

Introduction

Paving stones, otherwise known as paving blocks or interlocking blocks, are ideal for footpaths due to their ease of laying and finishing. These precast solid products are made of cement concrete and come in various sizes and shapes, including rectangular, square, and round blocks, designed for interlocking. The raw materials needed for their manufacture include cement and aggregates mixed together with water. Paving blocks are widely used in pavements, footpaths, gardens, passenger waiting sheds, bus stops, industrial areas, and other public spaces, particularly in urban settings. Therefore, it is advantageous to establish production units in urban and semi-urban areas near these markets. Increasing demand for the use of paving stones for aesthetics and road construction in Nigeria has brought about a continuous rise in its price. This necessitated the exploration of diverse materials in their production. Ongoing efforts aim to find alternative materials to partially replace stone dust in paving block mixtures, seeking new substitutes for natural aggregates that offer the same strength and durability at a reduced production cost [1].

Efficiently managing waste is crucial for enhancing environmental sustainability. A key waste management strategy involves using these materials in construction to reduce waste in landfills. Utilizing agricultural waste materials can also foster more sustainable, environmentally friendly construction practices [2]. The interest in using agricultural waste as a substitute for traditional natural aggregates in

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concrete is driven by environmental and economic concerns. This approach is particularly important in countries like Nigeria, where there is limited availability of natural coarse aggregates in certain regions (like coastal areas), and construction costs are high due to factors such as increased demand for cement and high transportation costs for construction materials. Agricultural wastes, identified as potential replacements for traditional aggregates in concrete, are lightweight materials, such as periwinkle shells and palm kernel shells (PKS). Despite their potential, these agricultural wastes have not yet been fully integrated as aggregates in sustainable concrete structures in Nigeria [3].

Researchers have explored the use of periwinkle shells, sourced from a protein-rich food staple in Nigeria's riverine and coastal communities, along with other agricultural waste, as potential aggregates for lightweight concrete production [4]. Yeole [5] studied the mix designs of paver blocks using waste rounded steel aggregates and rubber pads. Oladiran [6] investigated the performance of periwinkle shells and PKS as coarse aggregates in concrete. Kore [7] assessed the impact of marble waste as coarse aggregate on lean cement concrete properties. Khankhaje et al. compared the effects of oil PKS and cockle shell on pervious concrete pavement properties. Habib [8] reviewed the manufacture of concrete paver blocks using waste materials and by-products. Khandve [9] investigated concrete paving blocks using marble stone industry waste. Ezekiel [10] researched PKS as a partial replacement for normal-weight aggregate in concrete. Adeboje [11] examined the engineering properties of paving stones made with bamboo ash as a partial replacement for cement. Owolabi [12] assessed PKS as aggregate in concrete and laterite blocks. Sunday [13] investigated the compressive strength of concrete with PKS as a partial replacement for coarse aggregate.

Numerous studies have explored the feasibility of using periwinkle shells and other agricultural waste materials, previously considered pollutants due to their presence in open dump sites, as partial substitutes for conventional, costly normal-weight coarse aggregates in lightweight concrete production. These studies, which incorporated periwinkle shells at varying replacement levels with conventional coarse aggregates, demonstrated their suitability for lightweight concrete manufacturing. To address high concrete costs, depletion of natural resources, and environmental pollution, this study aimed to assess the feasibility of incorporating crushed periwinkle shell (CPS) into concrete paving stone production as a partial substitute for stone dust in low-cost construction. Using CPS in paving stone production promises substantial cost savings, reduces the need for extensive aggregate mining, and significantly mitigates environmental pollution.

Materials And Methods

The materials employed were periwinkle shell, cement, and granite. Full factorial experimental methods were employed in accordance with the provisions of BS EN 197-1:2011.

The periwinkle shell (Figure *1*) was obtained from a local market at Oyingbo, Yaba, Lagos State. The species of periwinkle shell used was the African periwinkle, botanically known as *Tympanotonus fuscatus*, as shown in Figure *1*. The size of the periwinkle shell used ranged between 30 mm and 45 mm in length. The periwinkle shell was washed in soapy water and then sun-dried to remove water completely, after which it was crushed manually into about 1 mm-5 mm size. The fine aggregate that was used is granite chippings, which comply with BS 812:2 and EN 12390-7 and are sourced from a local quarry depot in Bariga, Lagos State. Ordinary Portland Cement complying with NIS 444-1:2014 was used as the binding agent. The cement was obtained from a commercial cement store in Bariga, Lagos State. Dangote Portland Cement of grade type 42.5N (denoting the minimum compressive strength of cement in megapascals at 28 days of curing) was used.

A concrete mix ratio of 1:4 and a water/cement ratio of 0.5 were selected for the experimental program. The constituent materials were batched by weight using absolute volume methods, and fresh concrete was mixed manually on a concrete pavement using a spade. No admixtures were added to the concrete mixes. The CPS has a bulk density of kg/m^3 with 98.7% of sieve passing (4.75 mm). The mixes were poured into standard molds of 200 mm × 100 mm × 100 mm to produce rectangular paving stone cubes. Aggregate was replaced with CPS at 0%, 25%, 50%, and 75%. A total of one hundred and eight (108) paving stone samples were cast, 6 samples each containing 0%, 25%, 50%, and 75% of CPS as a partial replacement for aggregate. A total of 54 samples were immersed completely in a normal (freshwater) concrete mix, while the other 54 samples were cured by sprinkling, out of which 12 samples were separated for water absorption testing at day 28 of curing. All cubes were demolded 24 hours after casting and water-cured both by complete immersion and by sprinkling to compare strengths.

FIGURE 1: Tympanotonus fuscatus species

Results

Workability of crushed periwinkle mix (CPS)

The slump test results presented in Table *1* indicate a progressive increase in workability with higher percentages of CPS replacement. Specifically, slump values rose from 60 mm at 0% CPS to 80 mm at 75% CPS. This increase suggests that incorporating CPS into the concrete mix enhances its fluidity, thereby making the mix more workable. Such an improvement in slump value implies that the concrete becomes easier to place and compact, which is particularly beneficial for applications such as paving stones where manual compaction is often employed.

Sample	Percentage PKS-gravel replacement	Slump (mm)
Control mix (S1)	0% Replacement (control sample)	60
S2	25% Replacement	60
S3	50% Replacement	75
S4	75% Replacement	80

TABLE 1: Showing the workability of CPS paving stone mix

CPS, crushed periwinkle shell; PKS, palm kernel shells

Water absorption analysis

The results of the water absorption test conducted after 28 days, as presented in Table 2, reveal a decreasing trend with increasing CPS content. Specifically, water absorption dropped from 9.5% in the control mix (0% CPS) to 4.74% at 75% CPS replacement. This trend indicates that the inclusion of CPS in the mix may contribute to a denser and less permeable concrete matrix, thereby reducing the ability of the material to absorb water. Such a reduction in water absorption suggests enhanced durability and makes the concrete more suitable for applications where resistance to moisture ingress is important.

Mix	Weight of sample after immersed in water w2 (kg)	Dry weight w1 (kg)	% water absorption	Concrete quality as CEB
Control mix (S1)	2.65	2.42	9.50	Within range
S2	2.58	2.38	8.40	
S3	2.56	2.38	7.56	
S4	2.43	2.32	4.74	

TABLE 2: Shows the average rate of water absorption for CPS concrete paving stone at a curing duration of 28 days

The standards referenced follow those set by the Comité Euro-International du Béton (CEB), which is French for "European Committee for Concrete".
CPS, crushed periwinkle shell

Weight of paving stone sample

As shown in Table 3, there is a general increase in the weight of paving stone specimens as curing time progresses, irrespective of the curing method employed. This increase is observed consistently across all samples, indicating that hydration continues effectively throughout the curing period. The gain in weight is expected and reflects the ongoing absorption and retention of moisture within the concrete matrix, which is crucial for the proper development of mechanical properties. Figure 2 is a graphical representation further corroborating the comparative analysis of the weight of the paving stone sample subjected to two different curing methods: complete submersion in water and surface sprinkling. The graph highlights the differences in weight gain or retention as a result of the curing process used, providing insight into the effectiveness of each method in terms of moisture absorption and material stability.

% CPS replacement	Weight of samples (kg)							
	7 days		14 days		21 days		28 days	
	T.SMG	SPR	T.SMG	SPR	T.SMG	SPR	T.SMG	SPR
0%	2.48	2.25	2.62	2.35	2.63	2.42	2.65	2.5
25%	2.53	2.30	2.53	2.33	2.58	2.38	2.58	2.48
50%	2.49	2.25	2.5	2.38	2.56	2.40	2.56	2.52
75%	2.43	2.28	2.49	2.37	2.53	2.40	2.57	2.42

TABLE 3: Weight comparison between samples cured by total submersion and sprinkling

T. SMG, total submersion; SPR, sprinkling; CPS, crushed periwinkle shell

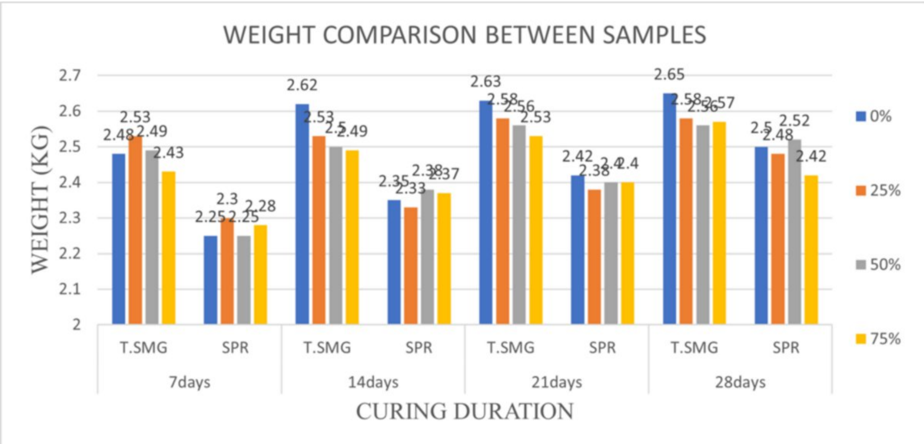

FIGURE 2: Graphical illustration comparing the weight of paving stone samples cured by total submersion in water and by sprinkling

Compressive strength of paving stone sample using different curing methods

Compressive Strength of Paving Stone Sample: Curing by Total Immersion

The compressive strength results presented in Table 4 reveal a clear increase in strength with longer curing durations. Notably, the concrete mix with 75% CPS replacement achieved a strength of 8.8 N/mm^2 at 28 days when cured by total immersion. This demonstrates that a high percentage of CPS does not hinder the strength development of concrete under proper curing conditions and may even be compatible with achieving adequate structural performance for applications such as pedestrian paving. Figure 3 is a graphical representation depicting the compressive strength of paving stone samples after being cured through full water submersion. This illustration demonstrates the structural performance as influenced by the immersion-curing method.

% CPS replacement	Compressive strength (N/mm²)			
	7 days	14 days	21 days	28 days
0%	5.5	6.8	7.5	7.67
25%	4.65	6.2	6.87	7.33
50%	6.12	6.17	6.67	6.92
75%	6.5	7.12	8.67	8.80

TABLE 4: Compressive strength of paving stone sample: curing by total submersion of samples in water

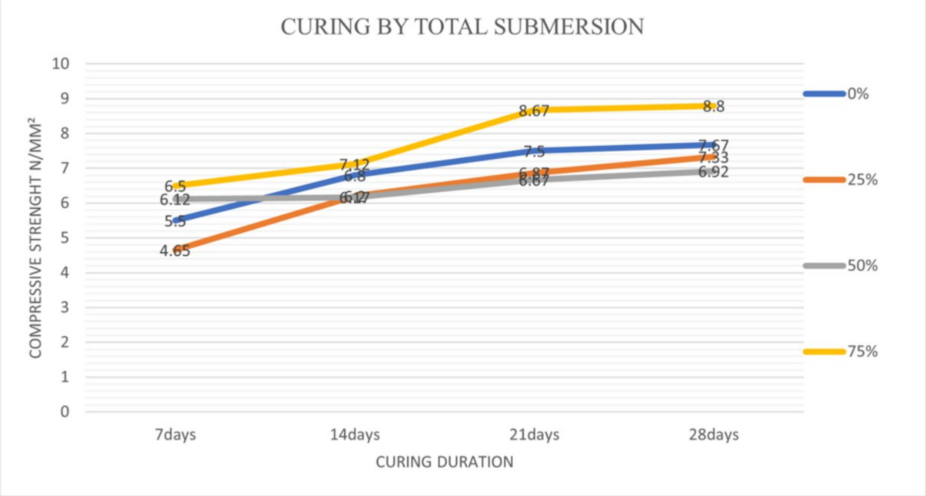

FIGURE 3: Graphical illustration of the compressive strength of a paving stone sample when cured by total submersion in water

Compressive Strength of Paving Stone Sample: Curing by Sprinkling

The compressive strength results obtained from the sprinkling curing method, as presented in Table 5, show a similar trend to those observed under immersion curing. Specifically, the mix containing 75% CPS reached a compressive strength of 8.82 N/mm² at 28 days. This confirms that high levels of CPS replacement do not compromise strength development when proper curing is applied and demonstrates that sprinkling is an effective curing method for CPS concrete. Figure 4 is a graphical representation showing the compressive strength of the paving stone samples cured using the sprinkling method. The illustration reflects how this particular curing technique affects the sample's structural integrity.

% CPS replacement	Compressive strength (N/mm²)			
	7 days	14 days	21 days	28 days
0%	5.67	8.08	8.17	8.67
25%	5.9	6.67	7.67	8.00
50%	6.25	6.2	6.67	7.17
75%	7.75	8.08	8.82	8.82

TABLE 5: Compressive strength of paving stone sample: curing by sprinkling water

CPS, crushed periwinkle shell

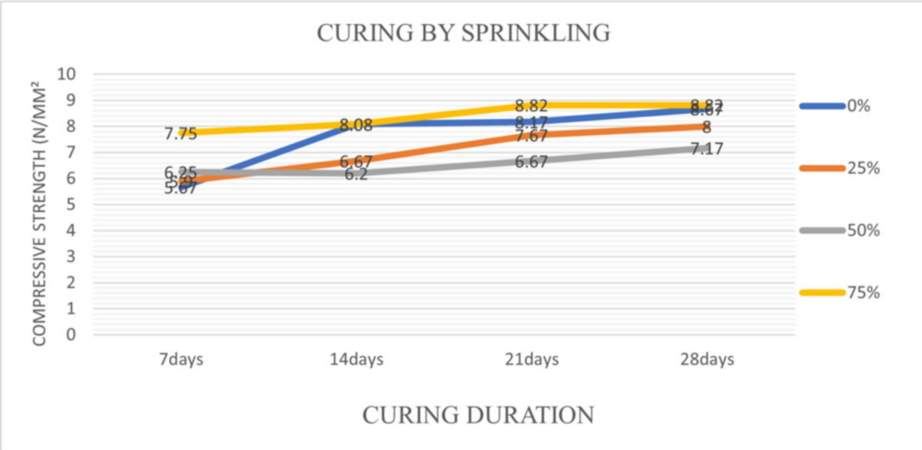

FIGURE 4: Graphical illustration of compressive strength of paving stone sample when cured by sprinkling

Strength Comparison Between Samples Cured by Total Submersion and Curing by Sprinkling

The results from the comparative analysis presented in Table *6* show that both curing methods, total immersion and sprinkling, produce similar compressive strengths, with the sprinkling method slightly outperforming immersion by a narrow margin. Specifically, the 75% CPS mix cured by sprinkling achieved a compressive strength of 8.82 N/mm² at 28 days, compared to 8.8 N/mm² under immersion curing. This suggests that sprinkling is not only an effective alternative to traditional curing but may offer practical and cost-saving advantages for field applications where immersion is less feasible. Figure *5* is a graphical comparison of the compressive strength of the paving stone samples under two different curing methods: complete water submersion and surface sprinkling. This illustration further corroborates the impact of each curing technique on the structural performance.

% CPS replacement	Compressive strength (N/mm²)							
	7 days		14 days		21 days		28 days	
	T.SMG	SPR	T.SMG	SPR	T.SMG	SPR	T.SMG	SPR
0%	5.5	5.67	6.8	8.08	7.5	8.17	7.67	8.67
25%	4.65	5.9	6.2	6.67	6.87	7.67	7.33	8.00
50%	6.12	6.25	6.17	6.2	6.67	6.67	6.92	7.17
75%	6.5	7.75	7.12	8.08	8.67	8.82	8.80	8.82

TABLE 6: Table showing compressive strength values for CPS paving stone when cured by total submersion and sprinkling

T. SMG, total submersion; SPR, sprinkling; CPS, crushed periwinkle shell

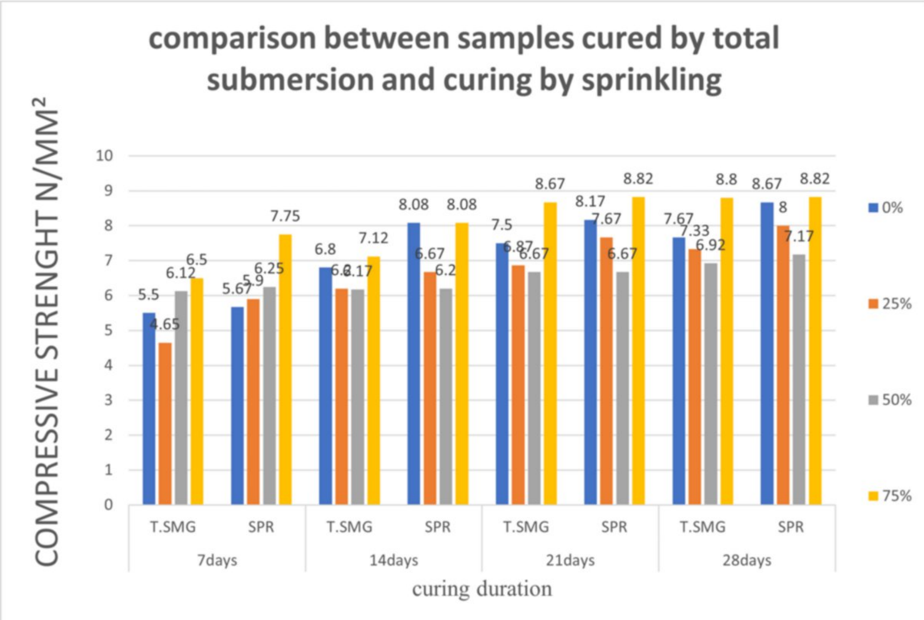

FIGURE 5: Graphical illustration comparing the compressive strength of paving stone samples when cured by total submersion in water and by sprinkling

Discussion

Workability of crushed periwinkle shell (CPS) mix

The slump test results (Table *1*) indicate an increase in workability with higher percentages of CPS replacement, with slump values rising from 60 mm at 0% CPS to 80 mm at 75% CPS. This trend suggests that the incorporation of CPS enhances the fluidity of the concrete mix, potentially due to the smoother texture and lower angularity of CPS compared to conventional aggregates. Contrastingly, previous studies have reported a decrease in workability with increased CPS content. For instance, [14] observed that as the periwinkle shells increased from 1% to 100%, there was a corresponding decrease in slump values, indicating reduced workability. Similarly, an exploratory study by [15] found that the slump values decreased in the concrete mixture as the quantity of CPS increased. The observed increase in workability in this study suggests that CPS can be beneficial in enhancing the ease of concrete placement, especially for paving stones that require manual compaction. The discrepancy between this study and previous research indicates that factors such as particle size distribution, shape, and surface texture of CPS, as well as mix proportions, can significantly influence workability. Further studies should investigate the specific characteristics of CPS that affect workability, including detailed analyses of particle morphology and surface properties.

Water absorption analysis

The water absorption results after 28 days (Table *2*) show a decreasing trend with higher CPS content, ranging from 9.5% at 0% CPS to 4.74% at 75% CPS. This suggests that CPS incorporation may lead to a denser concrete matrix with reduced permeability. This finding contrasts with earlier studies where increased CPS content led to higher water absorption. For example, studies [16] reported that the water absorption of periwinkle shell aggregate was up to 12.99%, indicating higher porosity. Additionally, a study by Umoh et al. found that water absorption increased with higher CPS content. The reduced water absorption observed in this study implies improved durability and suitability for applications where lower permeability is desired. The contrasting results with previous studies highlight the need to understand the underlying mechanisms, such as the potential pozzolanic activity of CPS or its effect on the pore structure of concrete. Microstructural analyses using techniques like scanning electron microscopy could provide insights into the interaction between CPS and the cement matrix, elucidating the reasons behind the reduced water absorption.

Weight variation of paving stone samples

While this study highlights the pattern of weight gain over time, it does not specifically isolate the influence of CPS content on this trend. Nonetheless, the observed behavior is consistent with general principles of concrete curing, where extended hydration leads to mass gain due to the incorporation of water into the cementitious matrix. Prior research has not placed significant emphasis on weight variation as a function of CPS content, leaving a gap in understanding how CPS characteristics-such as porosity and water absorption capacity-might influence this aspect of performance. The steady increase in weight can be interpreted as a sign of effective curing, which is essential for ensuring the durability and strength of the final product. However, to gain a deeper understanding of the role of CPS in this process, future studies should explore the relationship between CPS content and weight variation more closely. This would involve evaluating moisture transport mechanisms, absorption behavior, and water retention within the concrete, especially in the context of CPS's inherent physical properties. Such insights could help optimize mix designs for improved performance and durability.

Compressive strength of paving stones

Curing by Total Immersion

Data show that compressive strength increases over time for all mixes, with a surprising trend: although the control mix (0% CPS) performed steadily, the highest 28-day strength was observed at 75% CPS replacement (8.80 N/mm^2), outperforming the control (7.67 N/mm^2). At 25% and 50%, early strengths varied, with 50% showing better early results but lower final strength than 25%. This suggests that while moderate replacement levels are effective, higher levels, contrary to typical expectations, may significantly improve long-term strength, possibly due to improved particle interlock or compaction. However, further study is needed to confirm the reliability and broader applicability of these results.

Previous studies have reported different outcomes. For example, research by Adewuyi et al. observed a reduction in compressive strength as the proportion of CPS increased. This discrepancy highlights the potential influence of factors such as mix design, particle characteristics, and curing methods on strength development. The findings of the current study suggest that when adequately cured, particularly through immersion, concrete mixes with high CPS content can still achieve satisfactory strength levels. These results imply that CPS, when used in optimal conditions, could serve as a sustainable alternative aggregate without compromising mechanical integrity. However, the divergence from earlier research emphasizes the need for further investigation into variables such as particle size distribution, binder interaction, and long-term strength performance. Such studies could help refine the use of CPS in structural and semi-structural concrete applications.

Curing by Sprinkling

The compressive strength results reveal a non-linear response to varying levels of CPS replacement. While the control mix (0% CPS) follows a steady strength gain, partial replacements exhibit a pattern: 25% CPS shows slightly lower early strength but nearly matches the control by 28 days, while 50% CPS starts stronger at 7 days but underperforms at 28 days. Most notably, the 75% CPS mix outperforms all others, reaching the highest 28-day strength of 8.80N/mm^2. This suggests that higher CPS content-contrary to conventional expectations-may enhance long-term strength, possibly due to improved particle packing or matrix bonding. The results indicate potential for CPS as a viable partial fine aggregate replacement, though more data would be needed to validate durability and consistency.

This finding is particularly significant in light of the limited research on curing techniques specifically tailored to CPS concrete. Unlike immersion curing, which may not always be practical on construction sites due to water demand and logistical constraints, sprinkling offers a more accessible and resource-efficient alternative. The comparable strength outcomes observed between the two curing methods in this study suggest that sprinkling can serve as a viable option without sacrificing performance. This represents a meaningful contribution to existing literature, where such comparative analysis of curing methods for CPS-modified concrete is largely absent. The implications of this result point toward more flexible curing strategies for sustainable concrete production, especially in regions where conventional curing methods are impractical. Future studies could explore the long-term durability effects of different curing techniques on CPS concrete, as well as their performance under varying environmental conditions.

Comparative Performance

Data illustrate the effect of CPS replacement on compressive strength across two curing methods-T.SMG and SPR-over 7 to 28 days. In both sets, the 75% C.P.S. mix consistently records the highest strength at all curing stages, culminating at 28 days with 8.80N/mm² (T.SMG) and 8.82N/mm² (SPR), outperforming the control mix (0% CPS) in each case. Notably, the 25% and 50% mixes show fluctuating performance: 50% has strong early gains at 7 days but lower long-term strength, while 25% shows steady growth but never surpasses the control. This suggests that while moderate replacements are viable, 75% CPS. content yields optimal strength, potentially due to enhanced matrix packing or shell-cement interaction. These findings support the viability of high-level CPS substitution in non-conventional concrete applications, though additional testing on durability and workability would solidify its applicability.

The discussion of these findings points to the broader implication that concrete with high levels of CPS content can still attain adequate compressive strength when supported by appropriate curing practices. The viability of sprinkling as a curing method offers significant value in contexts with limited access to large volumes of water or where continuous submersion is logistically impractical. However, it is worth noting that the compressive strengths achieved in this study are lower than those reported in some previous works. For instance, Umoh et al. documented a strength of 18 N/mm² with a 50% CPS replacement, a figure notably higher than the results observed in the present study. This discrepancy suggests that factors such as mix design optimization, cement type, aggregate grading, and curing environment play a critical role in determining final strength outcomes. To address these variations and enhance the mechanical performance of CPS concrete, future research should focus on refining mix proportions, investigating the role of admixtures, and experimenting with hybrid curing techniques. Additionally, long-term performance and durability assessments under real-world conditions would help validate the practical suitability of CPS in structural and non-structural concrete applications.

Cost analysis

The cost analysis reveals a modest yet meaningful 4.85% reduction in overall construction cost when 75% of stone dust is replaced with CPS, primarily due to the material's availability as a low-cost waste by-product. This finding aligns with previous research by Umoh et al., who reported a 6.8% cost savings at just 30% CPS replacement, thereby supporting the economic viability of CPS in concrete mix design. However, the current analysis focuses primarily on initial material costs and does not account for indirect expenses such as collection, cleaning, grading, and transportation of CPS, which may vary significantly by location. A more comprehensive methodology would incorporate not only material prices but also labor and handling costs, logistical challenges, and processing overhead.

Conclusions

This study investigated the use of CPS as a partial replacement for granite aggregate in concrete paving stones. Various replacement levels (0%, 25%, 50%, and 75%) were tested to assess their effects on the workability, water absorption, weight, and compressive strength of the paving stones.

The results indicate that the incorporation of CPS increased the workability, with higher percentages of CPS resulting in higher slump values. This suggests that CPS can be effectively used to produce medium-to high-workability concrete suitable for manual compaction in paving stone applications.

Water absorption tests revealed that paving stones with CPS exhibited varied rates of water absorption, with some mixes (notably those with 25% and 50% CPS) displaying average water absorption levels. Despite this variability, all mixes were within the acceptable range for pedestrian and garden applications as per ASTM C936 standards.

Weight analysis showed a consistent increase in the weight of paving stone samples with curing time, regardless of the curing method (total submersion or sprinkling). This indicates that CPS does not negatively affect the density of the paving stones.

Compressive strength tests demonstrated that paving stones with CPS achieved satisfactory strength levels, particularly at the 75% replacement level, which reached a compressive strength of 8.82 N/mm² after 28 days of curing. This strength is suitable for pedestrian and walkway interlock pavement applications. Comparatively, samples cured by sprinkling showed slightly higher compressive strengths than those cured by total submersion.

Finally, a cost analysis revealed a reduction in the overall cost of paving stones with CPS, particularly at the 75% replacement level, indicating economic benefits in addition to the technical feasibility.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Samuel A. Sonibare, John O. Okesoto

Acquisition, analysis, or interpretation of data: Samuel A. Sonibare, John O. Okesoto

Drafting of the manuscript: Samuel A. Sonibare

Critical review of the manuscript for important intellectual content: Samuel A. Sonibare, John O. Okesoto

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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