

Experimental Investigation of Periwinkle and Palm-Kernel Shells as Partial Replacement of Coarse Aggregate in Concrete

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Abstract

The increasing demand for sustainable construction materials has intensified the search for environmentally friendly alternatives to conventional concrete aggregates. This study investigates the mechanical performance of concrete produced with periwinkle shells (PWS) and palm kernel shells (PKS) as partial replacements for natural coarse aggregates. Concrete mixes were prepared using a nominal mix ratio of 1:1.5:3 and a water-cement ratio of 0.5, with PWS, PKS, and combined PWS-PKS replacing conventional coarse aggregate at levels of 10%, 15%, 20%, and 25% by volume. A total of 351 specimens comprising 117 cubes, 117 cylinders, and 117 beams were cast and tested for workability, compressive strength, splitting tensile strength, and flexural strength following standard procedures. Results indicated that workability decreased with increasing shell content due to the high water- absorption characteristics of the shell aggregates. Mechanical properties generally declined as the replacement level increased; however, the blended PWS-PKS concrete exhibited superior performance compared with single-shell replacements. At 28 days, the 10% combined PWS-PKS mix achieved a compressive strength of 19.3 N/mm² (which is above the minimum benchmark of 17 N/mm² as specified by ACI 318-19) closely approaching the control strength of 20.5 N/mm². Similar trends were observed for flexural and splitting tensile strengths. The study identifies 10–15% replacement as the optimum range for achieving acceptable engineering performance while promoting resource conservation and waste utilization. The findings demonstrate that periwinkle and palm kernel shells possess significant potential as sustainable lightweight aggregates for non-heavy structural and general construction applications.

Keywords: Compressive strength, Lightweight aggregate, Palm kernel shell, Periwinkle shell, Sustainable concrete

Introduction

Concrete is the second most globally consumed material due to its versatility, durability and relatively low cost (Jaganmohan, 2024). Traditional concrete production is primarily made of cement, fine and coarse aggregates, such as gravel, crushed stones and sand. Among these constituents, the coarse aggregates comprise a majority of up to 75% of the total volume and play a significant role in determining the strength and overall performance. The rapidly growing population, urbanization and development have driven increasing demand for concrete from over 10 billion tons to approximately 18 billion tons annually by 2050 (Shafigh et al., 2014). These volumes come with serious consequences; environmental degradation and resource depletion (Kirthika et al., 2020). The heavy reliance on concrete as a primary construction material utilizes excessive raw materials, while contributing a significant 8% of global CO₂ emissions (Skinner & Lalit, 2023). Additionally, the cost of these aggregates has made construction relatively expensive, given the capital-intensive nature of the process (Mukura et al., 2018).

The quest to meet the global climate target of 25% reduced emissions by 2050 has grown in response with

studies and advocacy for resource conservation and replacement of traditional aggregates in concrete mixtures. This effort requires significant changes across the concrete value chain, implementing a circular economy, using less material while incorporating recycled waste materials such as fly ash, concrete, plastics among others (Federico & Chidiac, 2009). Incorporating agricultural solid waste as aggregate in both structural and non-structural concrete can significantly enhance environmental friendliness and sustainability, (Shafigh et al., 2014). Periwinkle and palm-kernel shells have emerged as promising alternatives due to their abundant availability in tropical regions as by-products of agricultural and food processing industries. The lightweight nature of periwinkle shell (PS) and palm kernel shell (PKS) offers several advantages in concrete applications, including reduced density, improved thermal insulation properties, and potential cost savings. Incorporating these materials into concrete mixtures may lead to enhanced workability and reduced overall material consumption, contributing to sustainable construction practices.

Recent studies have explored the potential of periwinkle shells (PWS) and palm kernel shells (PKS) as sustainable alternatives to conventional coarse aggregates in concrete. Ogundipe et al. (2021) reported that partial replacement with PKS reduced density while maintaining adequate strength for lightweight applications. Similarly, Osasu (2021) highlighted the economic and environmental benefits of incorporating PWS, though noting a slight reduction in compressive strength at higher replacement levels. Eziefula et al. (2017) demonstrated that PKS concrete can achieve acceptable mechanical properties when used in moderate proportions, while Ikponmwo et al. (2019) emphasized the durability performance of PWS-blended mixes under varying exposure conditions. However, their utilization as substitutes for coarse aggregate in concrete is still in the nascent stage of research and development. Factors such as particle size distribution, moisture content, and compatibility with cementitious binders need to be carefully evaluated to ensure optimal performance and durability of the resulting concrete mixtures. More research on the sustainability of using PWS and PKS as a substitute for coarse aggregate in concrete production will give more confidence to its usage in the construction industry. This research aims to investigate the sustainable use of PS and PKS as substitutes for coarse aggregate in concrete through a systematic experimental approach. The specific objectives of this study are: to determine the compressive, flexural and split tensile strength of concrete specimen and to compare the performance of these mixes against a control concrete in order to establish the extent to which combined PWS-PKS substitution can meet structural strength benchmarks.

This study aligns with the three pillars of sustainable development in specific ways: environmentally, by conserving natural stone resources through partial replacement with PWS and PKS and thereby reducing the carbon footprint associated with quarrying and cement production; economically, by lowering material costs and promoting the use of locally available waste shells in affordable housing construction; and socially, by fostering inclusive employment opportunities within the collection, processing, and supply chain of PWS and PKS aggregates.

Materials and Methods

Materials

Portland Limestone cement of grade 42.5N conforming to the CEM II class of NIS 444-1 was used as binder in this study. River sand of maximum size 4.75 mm, conforming to grading zone III was used as fine aggregates. For coarse aggregates, mechanically crushed, washed and sun-dried periwinkle shells (PWS), palm kernel shells (PKS) and natural aggregate of crushed sizes between 6mm and 12.5mm were used. The edges and surface of the aggregates were rough and spiky to ensure good bonding within the matrix. All materials were locally sourced, properly cleaned with fresh water before use. Clean borehole water available in the campus was used for mixing. Pictures of coarse aggregates sample are as shown in Figure 1, while the basic physical properties of the aggregates used in this study are given in Table 1

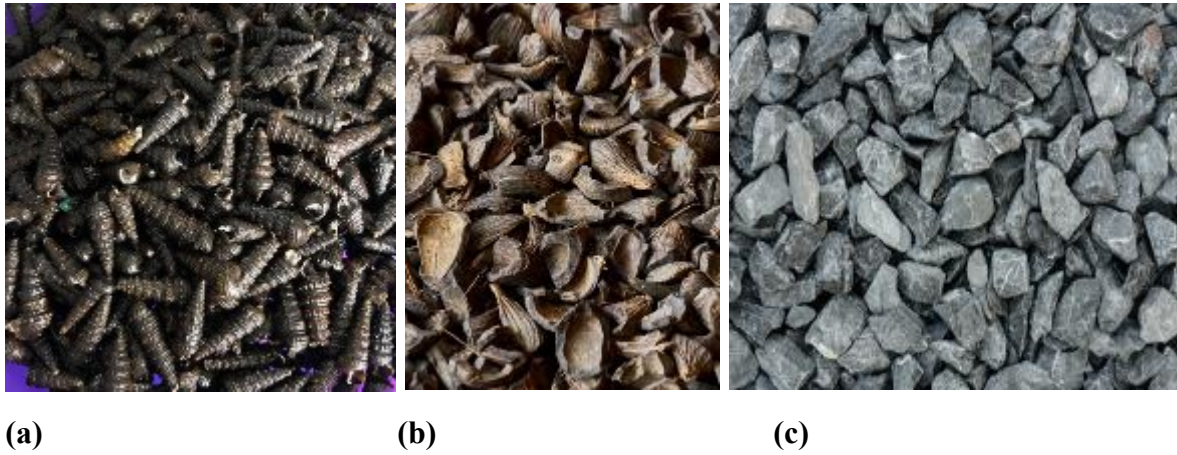


Figure 1: (a) Periwinkle shell; (b) Palm kernel shell; (c) Granite

Table 1: Physical properties of aggregates

Physical and Mechanical Properties	Granite	PWS	PKS	Sand
Maximum size (mm)	12.50	12.50	12.50	4.75
Water absorption (%)	0.27	15.3	22.50	-
Specific gravity	2.67	1.35	1.24	2.60
Bulk density (kg/m ³)	1625	545	592	1700
Crushing value (%)	20.44	0.16	0.14	-
Impact value (%)	7.50	1.57	3.50	-
Shape	Angular	Rough	Angular	-
Colour	Darkish	Greyish	Dark-brown	Brownish

Mix Proportions

Concrete for this study was produced using a nominal mix ratio of 1: 1½: 3 (cement: fine aggregate: coarse aggregate) and a water–cement ratio of 0.5 with a target strength of M20 grade. This mix ratio was selected because it represents a commonly used concrete mix suitable for medium-strength applications. The proportion ensures adequate cement content for strength development while maintaining workability. Periwinkle shells and palm kernel shells were introduced as partial replacement for conventional coarse aggregate at 0% (Control mix), 10%, 15%, 20% and 25%. For each replacement level, the total coarse aggregate volume remained constant, even when PWS and PKS were combined. Careful batching and measurements were done to ensure uniformity and accuracy across all mixes. A total of 117 cubes, 117 cylinders and 117 short beams were cast. Samples were later tested for compressive, splitting tensile and flexural strengths using standard test procedures. The details of the mix proportions used in this study are presented in Table 2.

Table 2. Mix proportions

Mix ID	% of Replacement	Cement (kg/m ³)	Sand (kg/m ³)	NCA (kg/m ³)	PWS (kg/m ³)	PKS (kg/m ³)	w/c	Water (kg/m ³)
PWSPKS00	0	432	648	1320	0	0	0.5	216
PWS10	10	432	648	1188	132	0	0.5	216
PWS15	15	432	648	1122	198	0	0.5	216
PWS20	20	432	648	1056	264	0	0.5	216
PWS25	25	432	648	990	330	0	0.5	216
PKS10	10	432	648	1188	0	132	0.5	216
PKS15	15	432	648	1122	0	198	0.5	216
PKS20	20	432	648	1056	0	264	0.5	216
PKS25	25	432	648	990	0	330	0.5	216

PWSPKS10	10	432	648	1188	66	66	0.5	216
PWSPKS15	15	432	648	1122	99	99	0.5	216
PWSPKS20	20	432	648	1056	132	132	0.5	216
PWSPKS25	25	432	648	990	165	165	0.5	216

NCA- Natural Coarse Aggregate; PWS- Periwinkle Shell Aggregate; PKS – Palm Kernel Shell Aggregate; w/c-Water/Cement

Experimental Procedure

Workability test

Workability of the various mixes were assessed using standard slump tests in accordance with specifications given in BS EN 12350-2: 2000. Figure 2 shows the slump test being conducted on one of the mixed.



Figure 2: Slump test

Curing of test specimens

After casting, the concrete specimens were kept in the laboratory for 24 hours, before they were de-molded and totally immersed in clean water in a curing tank to ensure complete hydration is achieved as recommended in BS EN 12390-2 (2009). On each day of testing, excess moisture was wiped from the surface of each specimen and subsequently left in the open air for about two hours before tests were carried out. This ensures that the test specimens will be air-dry before testing.

Tests for mechanical properties

The significant mechanical properties such as compressive strength, splitting tensile test, and flexural strength test were studied. For compressive strength tests 100 mm cubic concrete specimen in accordance to BS EN 12390 were prepared and tested at 7, 21 and 28 days. Splitting tensile tests were done on 100mm diameter and 200 mm height cylinder specimen following the procedure recommended by BS EN 12390 standard. For flexural strength, four-point loading tests were performed on 100 × 100 × 500 mm prisms according to BS EN 12390. In each case of all these tests, averages of tests result on three samples were reported.

Results and Discussion

Workability

Table 3 is the result of slump tests for all the mixes. It was observed that slump values decrease with increase in the percentage of both PWS and PKS. However, the rate of decrease is less in PKS concrete than in PWS concrete. The smoothness of one side of PKS may have been responsible for this. However, the values dropped drastically for 20% replacement and a zero 5mm slump was recorded at 25% replacement.

Table 3: Slump tests result

Mix ID	% of Replacement	Slump (mm)
PWSPKS00	0	76
PWS10	10	62
PWS15	15	55
PWS20	20	40
PWS25	25	5
PKS10	10	65
PKS15	15	60
PKS20	20	50
PKS25	25	10
PWSPKS10	10	62
PWSPKS15	15	50
PWSPKS20	20	45
PWSPKS25	25	10

Compressive Strength

Figures 3 to 6 show the results of compressive strength after 7, 21 and 28 days. This is the most significant property of hardened concrete because it gives an idea of the working load that the concrete could sustain. It is measured by testing the maximum compressive load a concrete can withstand per unit area of the concrete cross-section. It is calculated mathematically from (1) below:

$$\text{Compressive strength (N/mm}^2\text{)} = \frac{\text{Crushing load (N)}}{\text{Area of concrete(mm}^2\text{)}} \quad (1)$$

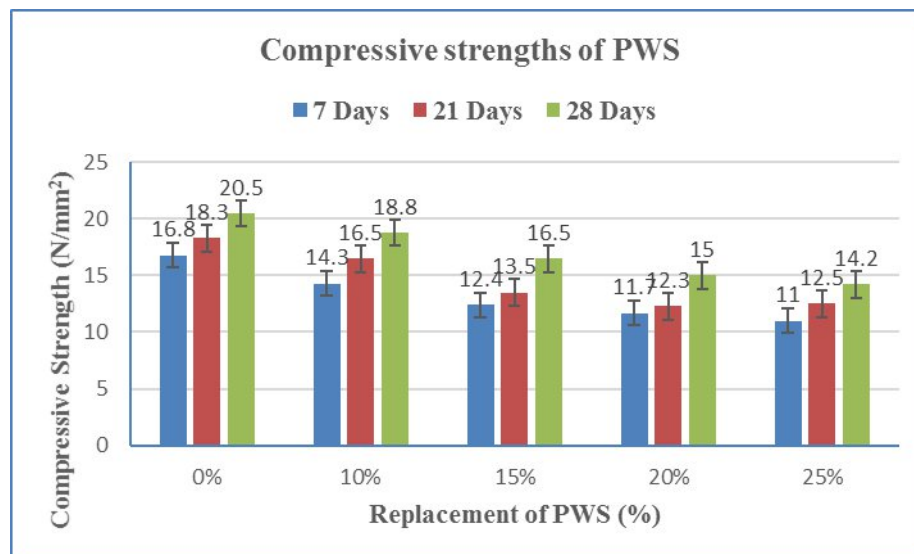


Figure 3: Compressive strengths of concrete with PWS

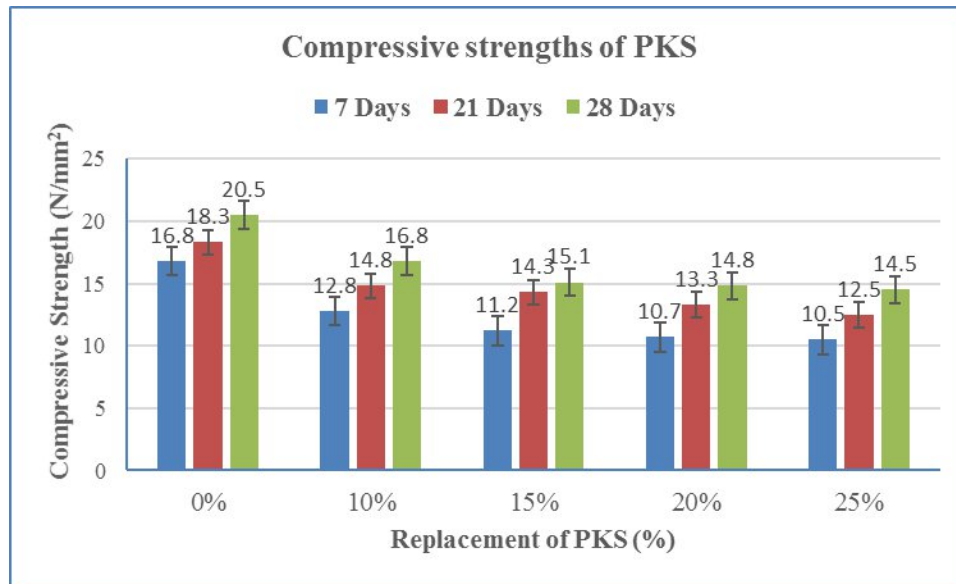


Figure 4: Compressive strengths of concrete with PKS

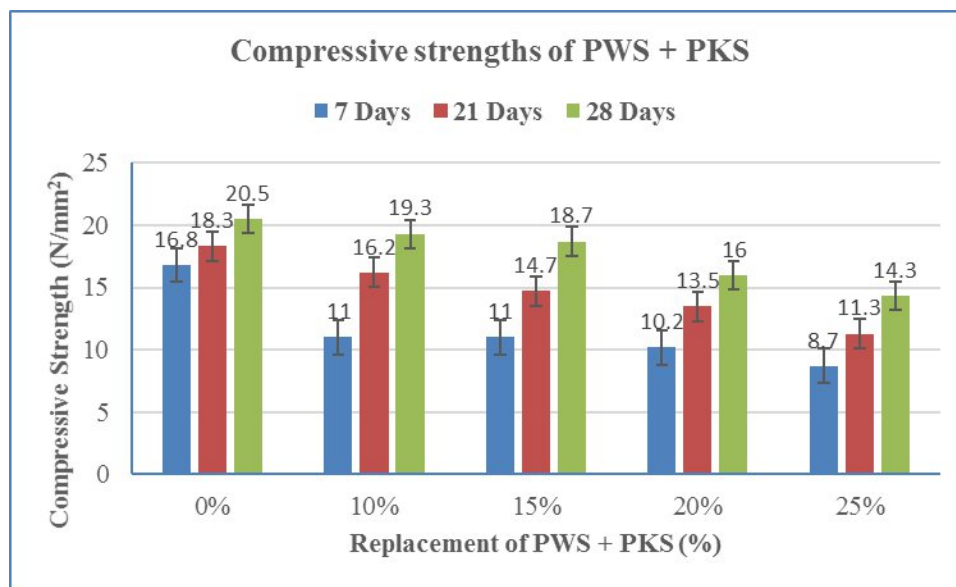


Figure 5: Compressive strengths of concrete with PWS + PKS

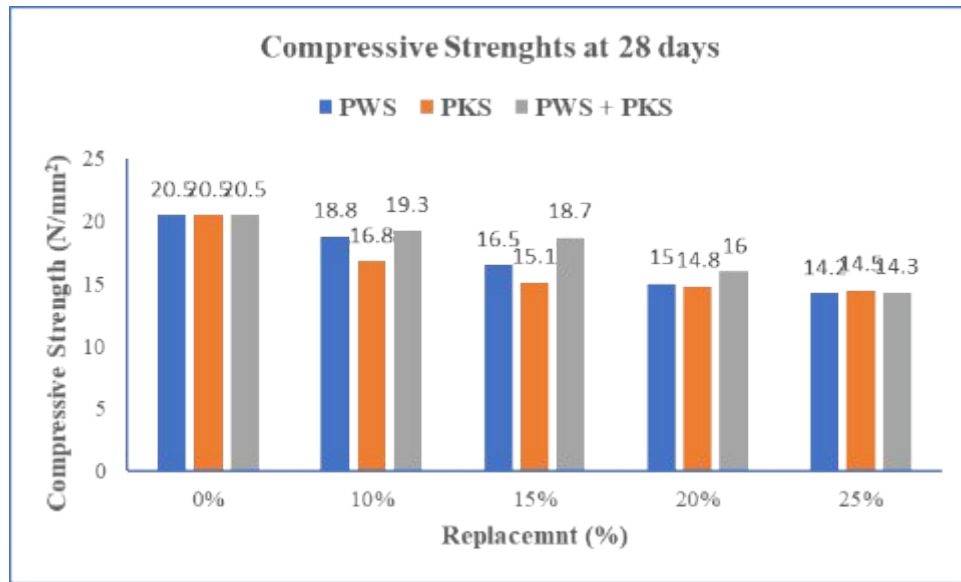


Figure 6: Comparison of compressive strengths of all concrete mixes at 28 days

From Figures 3 to 6 above, the control mix, zero replacement, recorded compressive strengths of 16.8 N/mm², 18.3 N/mm², and 20.5 N/mm² at 7, 21, and 28 days respectively. These values were consistently higher than those of the modified mixes, indicating the superior structural performance of conventional granite aggregates. The high strength observed in the control concrete can be linked to the dense structure, low porosity, and strong interfacial bond typically associated with crushed stone aggregates. Concrete produced with Periwinkle Shells (PWS) showed a gradual decline in compressive strength as the replacement level increased. At 28 days, the concrete containing 10% PWS attained a compressive strength of 18.8 N/mm², while further increases in replacement levels reduced the strength to 16.5 N/mm², 15.0 N/mm², and 14.2 N/mm² for the 15%, 20%, and 25% mixes respectively. The reduction in strength may be attributed to the relatively porous and lightweight nature of periwinkle shells, which likely weakened the internal structure of the concrete. In addition, the shells may have produced weaker bonding within the interfacial transition zone between the aggregate particles and cement paste, thereby lowering the ability of the concrete to resist compressive loads.

A similar trend was observed in the Palm Kernel Shell (PKS) concrete mixes. The 28-day compressive strengths declined from 16.8 N/mm² at 10% replacement to 14.5 N/mm² at 25% replacement. Although the reduction in strength was evident, the decline occurred more gradually compared to the PWS mixes. This comparatively stable behaviour may be associated with the rough surface texture of palm kernel shells, which may have improved the mechanical interlocking between the shell particles and cement matrix. However, the lower stiffness and higher water absorption capacity of PKS relative to granite aggregate likely contributed to the observed reduction in compressive resistance at higher replacement levels. Interestingly, the concrete mixes containing combined PWS and PKS demonstrated better compressive performance than several of the single-shell mixes. The 10% combined replacement mix achieved a 28-day compressive strength of 19.3 N/mm², which was very close to the control value of 20.5 N/mm². Likewise, the 15% combined mix produced a strength of 18.7 N/mm² at 28 days. The improved performance observed in the blended shell concrete may be related to better particle distribution and improved aggregate gradation, which possibly reduced internal voids and enhanced stress transfer within the concrete matrix.

Despite this improvement at lower replacement levels, further increases in the combined shell content resulted in noticeable reductions in strength. The 25% combined mix recorded a compressive strength of 14.3 N/mm² at 28 days. This suggests that excessive replacement of conventional aggregate with lightweight shell materials adversely affects the density and structural integrity of the concrete. Overall, the compressive strength results indicate that shell replacement levels between 10% and 15% produced the

most satisfactory performance. Within this range, the concrete maintained reasonable mechanical strength while simultaneously promoting sustainable utilization of agricultural and marine waste materials. On examining the tested specimens, it was observed that both the PWS and PKS aggregate particles showed signs of fracture, which indicates that the periwinkle shell has a strong bond with the mortar as shown in Figure 7.



Figure 7: Bonding of PWS and PKS with mortar

Flexural Strength

The flexural test measures the modulus of rupture, which characterises the concrete's resistance to bending failure. It tests the ability of a short unreinforced concrete beam to withstand failure in bending. Figure 8 shows the result of the tested samples at 28 days.

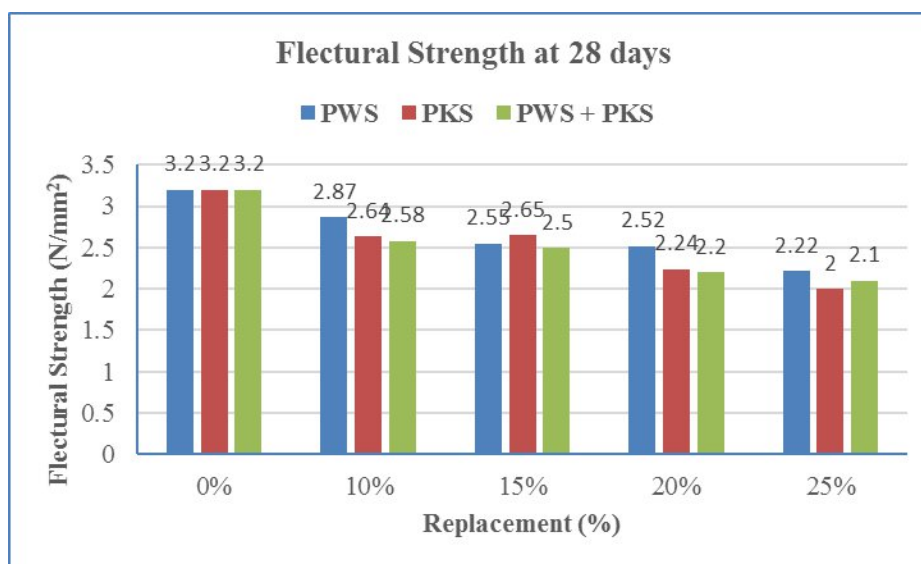


Figure 8: Flexural strengths of tested samples at 28 days

In Figure 8, the flexural strength results showed that all concrete mixed experienced progressive increases in strength with longer curing periods. This trend reflects the continuous improvement in the internal structure of the concrete due to ongoing hydration reactions. The control concrete achieved flexural strengths of 2.2 N/mm², 2.81 N/mm², and 3.2 N/mm² at 7, 21, and 28 days respectively. These values were higher than those obtained for all shell-modified concrete mixes, confirming the superior bending resistance of conventional concrete. Concrete incorporating Periwinkle Shells recorded 28-day flexural strengths ranging from 2.87 N/mm² at 10% replacement to 2.22 N/mm² at 25% replacement. The reduction in flexural strength as shell content increased suggests a decline in stiffness and bending resistance. However, the

relatively high value recorded at 10% replacement indicates that moderate incorporation of PWS may still produce structurally acceptable lightweight concrete.

Palm Kernel Shell concrete displayed similar behaviour. At 28 days, flexural strength values ranged from 2.64 N/mm² at 10% replacement to 2.0 N/mm² at 25% replacement. Interestingly, the 15% PKS mix produced a slightly higher flexural strength than the 10% mix. This can be attributed to the irregular surface texture of PKS, which enhances bonding at the interfacial transition zone (ITZ), and to improved aggregate packing at moderate replacement levels. These factors promote better stress transfer and delay crack initiation under flexural loading, explaining the temporary increase in flexural strength before the expected decline at higher replacement levels. The combined PWS and PKS mixes also demonstrated gradual reductions in flexural strength with increasing replacement percentages. The 10% combined mix achieved a flexural strength of 2.58 N/mm² at 28 days, whereas the 25% combined mix recorded 2.1 N/mm². Although these values were lower than those of the control concrete, they indicate that blended shell aggregates can still provide moderate resistance to bending stresses. The reduction in flexural strength observed in shell-modified concrete may be associated with increased internal voids, lower aggregate rigidity, and weaker interfacial bonding within the cement matrix. Even so, the performance of the 10–15% replacement mixes suggest that they may be suitable for lightweight construction purposes such as walkways, pavements, partition elements, and other non-heavy structural applications.

Splitting Tensile Strength:

The splitting tensile test evaluates the resistance towards the force that tries to split the specimen into two pieces. Specimens tested were of size 200mm×100mm and compressive testing machine was used for the test by placing the specimen horizontally with just a line of contact on to the jaw surface. It is method of determining the tensile strength of concrete using a cylinder which splits across the vertical diameter. Figure 9 is the graphical representation of the test results after 7, 21 and 28 days of curing.

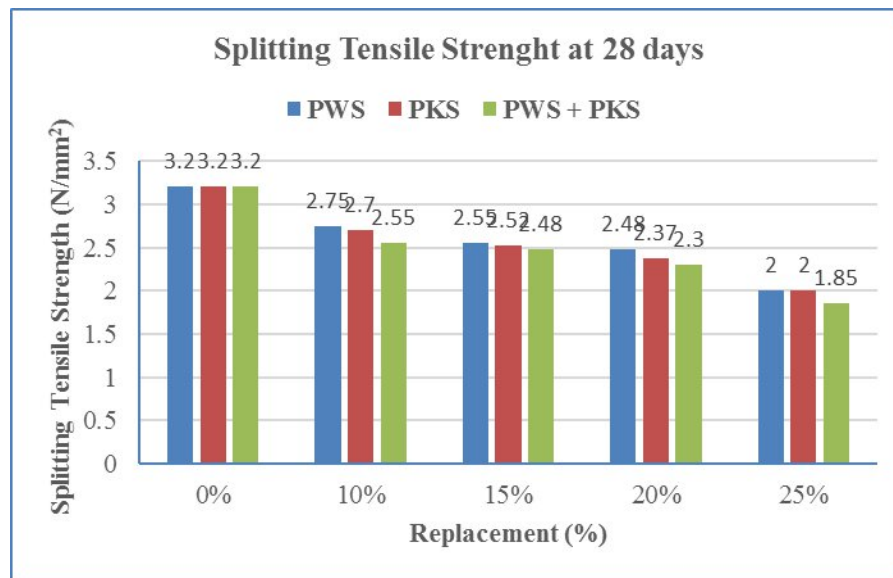


Figure 9: Splitting tensile strengths of tested samples at 28 days

From Figure 9, the splitting tensile strength results showed continuous improvement with curing age across all concrete mixes. The increase in tensile strength over time may be associated with progressive cement hydration and improved internal cohesion within the concrete structure. The control concrete recorded tensile strengths of 1.8 N/mm², 3.0 N/mm², and 3.2 N/mm² at 7, 21, and 28 days respectively. These values remained higher than those of all shell-modified mixes, confirming the stronger crack resistance and internal bonding characteristics of conventional concrete. For the Periwinkle Shell concrete, the 28-day tensile strength was reduced from 2.75 N/mm² at 10% replacement to 2.0 N/mm² at 25% replacement. The gradual

decrease in tensile strength with increasing shell content indicates that higher concentrations of PWS weakened the concrete's resistance to tensile cracking. This behaviour may be linked to the brittle characteristics of shell particles and weaker bonding between the shell aggregates and cement paste.

Similarly, Palm Kernel Shell concrete exhibited declining tensile strength as the replacement level increased. The 28-day values ranged from 2.7 N/mm² at 10% replacement to 2.0 N/mm² at 25% replacement. Although PKS concrete maintained moderate tensile performance at lower replacement levels, the reduction observed at higher percentages suggests that excessive shell incorporation may reduce the ability of the concrete to withstand tensile stresses and resist crack propagation. The combined PWS and PKS concrete mixes also followed a similar pattern. At 28 days, the 10% combined mix achieved a tensile strength of 2.55 N/mm², while the 25% mix decreased to 1.85 N/mm². Although the combined mixes did not surpass the best-performing individual shell mixes, the results demonstrate that blended shell aggregates can still provide acceptable tensile performance for lightweight and non-load-intensive applications.

The reduction in tensile strength observed across the modified mixes may generally be associated with increased porosity, weaker aggregate-cement bonding, and lower rigidity of the shell materials compared to conventional granite aggregate. Nevertheless, the relatively good performance recorded at lower replacement levels suggests that sustainable concrete incorporating shell waste can still satisfy the requirements of selected engineering applications.

Conclusion

This study demonstrates that incorporating periwinkle shells (PWS) and palm kernel shells (PKS) as partial replacements for conventional coarse aggregate significantly influences the mechanical properties of concrete. Strength development improved consistently with curing age across all mixes, but increasing replacement levels generally reduced performance compared to the control.

Compressive strength: The combined PWS + PKS mix at 10% replacement achieved a 28-day compressive strength of 19.3 N/mm², which is 94% of the control value (20.5 N/mm²). This indicates that moderate substitution can maintain structural performance, with 10–15% replacement emerging as the optimum range.

Flexural strength: Flexural resistance declined with higher shell content, yet the 15% PKS mix showed a slight improvement over 10%, suggesting that aggregate surface texture and packing effects can enhance crack resistance at moderate levels.

Splitting tensile strength: Splitting tensile strength also decreased progressively with increasing shell content, but the 10% combined PWS + PKS mix retained values above 2.5 N/mm² at 28 days, demonstrating acceptable crack resistance for lightweight and non-load-intensive applications.

Based on these results, mixes with 10% replacement are suitable for structural elements in lightweight construction such as non-load-bearing walls, walkways, and infill panels. At 15% replacement, the concrete may be applied in partitions, pavements, and other moderate-load elements. Beyond 15%, the progressive reduction in strength restricts use to non-heavy structural applications only.

Future research directions

To fully establish the viability of shell-based concrete, further studies should investigate long-term durability (including water absorption, porosity, and shrinkage), surface treatment of shells to improve bonding, and performance in higher-strength mix designs. Exploring these aspects will provide a more comprehensive understanding of the structural and sustainability potential of PWS and PKS aggregates.

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Conflict of interest: It is declared that the authors have no conflict of interest.

Ethical Statement: This study did not involve human participants or animals; no ethical approval was required. All research procedures adhered to relevant ethical guidelines and best practices for non-human and non-animal research.

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