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FEASIBILITY OF USING PERIWINKLE AND PALM KERNEL SHELL ASH AS CEMENTITIOUS MATERIAL IN MASONRY

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ABSTRACT
High costs for construction materials, depletion of natural aggregates, and increasing global emissions have led to a need for a feasible material to replace cement in some instances. This study investigated whether eco-friendly sandcrete hollow blocks (SHBs) can be manufactured and strengthened according to standard engineering properties. Periwinkle shell ash and palm kernel shell ash were substituted for cement and fine aggregates in masonry at 0%, 5%, 10%, and 15%, respectively. SEM-EDX analysis and compressive strength tests were used to select the most effective additive blend. PKSA (Palm Kernel Shell Ash) 5% mixture achieved the highest compressive strength of 1.02 N/mm^2 after 28 days, exceeding the control strength of 0.82 N/mm^2 and meeting ASTM C90-15 (2015) standards. A hybrid sample containing 5% PKSA and 5% PWSA (Periwinkle Shell Ash) had the lowest compressive strength of 0.74 N/mm^2 at 28 days, whereas a hybrid sample containing 10% crushed palm kernel shell and 15% periwinkle shell achieved the highest compressive strength at 1.2 N/mm^2. Despite its structural strength, Silicon (Si) at 52.85% and Calcium (Ca) at 25.34% contributed to its high concentration. A hybrid blend of 10% PKS and 15% PWS has emerged as the top-performing sample for SHB modifications, meeting necessary engineering standards and promising sustainable building materials in the future.

Keywords: Palm kernel shell ash, periwinkle shell ash, sandcrete hollow blocks, concrete, masonry.

INTRODUCTION
In recent years, the construction industry has undergone a significant transformation, driven by a global commitment to sustainability and environmental responsibility (Awolusi et al., 2021). This shift has spurred researchers, engineers, and construction professionals to explore cutting-edge materials and construction methods to achieve a record-breaking structural and durability performance without mitigating the environment. Among the array of construction materials, sandcrete hollow blocks (SHBs) have gained significant attention due to their versatility, cost-effectiveness, and potential for aligning with environmentally-friendly principles (Akinyemi et al., 2020; Akpokodje et al., 2021; Coffie et al., 2019).

The utilisation of agricultural waste materials in sandcrete block production represents a sustainable construction approach. Various agricultural waste products, such as rice husk ash (RHA), sawdust, bagasse ash, coconut shell ash (CSA), bamboo fibre, sugarcane bagasse fibre, and wheat straw ash (WSA), offer unique advantages for enhancing the properties of sandcrete blocks (Afolayan et al., 2017; Christopher et al., 2018; Salman et al., 2022; Ubachukwu et al., 2021). These waste materials can serve as lightweight aggregates, cement replacements, or reinforcements,

improving structural performance and durability and reducing environmental impact. Crushed palm kernel shells (CPKS), derived from agricultural waste, have garnered attention as a noteworthy component in the quest for sustainable construction materials. These shells possess promising attributes, including their use as lightweight aggregates and a natural composition rich in minerals (Afolayan et al., 2017; Christopher et al., 2018; Salman et al., 2022; Ubachukwu et al., 2021).

Crushed periwinkle shells (CPWS), sourced from marine environments, present another compelling natural material under consideration. Their incorporation into SHB production holds promise due to their distinctive composition, which includes calcium carbonate (Ikeagwuani et al., 2020; Joshua et al., 2013; Nduka et al., 2019).

Palm kernel shell ash (PKSA), a by-product of palm kernel shell combustion, extends the realm of possibilities for enhancing SHB properties. According to Anosike and Oyebade (2012) and Anosike (2021), PKSA can serve as a supplementary cementitious material, reducing the reliance on traditional cement and thus lowering the environmental impact associated with SHB production. In addition, the Periwinkle shell ash (PWSA), obtained through combustion, also offers an alternative source for improving SHB properties.

The primary objective of this research is to investigate the feasibility and effectiveness of incorporating crushed palm kernel shells, crushed periwinkle shells, palm kernel shell ash, and periwinkle shell ash into producing eco-friendly sandcrete hollow blocks.

Comprehensive analysis of the mineralogical properties of these materials and their impact on sandcrete hollow block and compressive strength would propel the construction practice and industry toward a brighter future of more sustainable construction materials. Through an evaluation of their appropriateness as partial substitutes for conventional cement, this research endeavours to reveal the complete capabilities of these additives in sandcrete hollow block production. The ultimate objective is to advance the development of more sustainable construction materials, paving the way for a more promising future in construction practices.

MATERIALS

The materials used for this research include Periwinkle shell, periwinkle ash, palm kernel shell and palm kernel shell ash, cement, and fine aggregate (sand).

Crushed Periwinkle Shell

The periwinkle shells were locally procured in Akure and subjected to a grinding process to attain a fine homogenous powder used in the research.



Figure 1: Periwinkle shell before crushing

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Periwinkle Shell Ash

The periwinkle shells illustrated in Figure 1 above, were subjected to a heat treatment process at 800^{o}C for 30 minutes to attain an amorphous pozzolanic state, transformed into ash utilised in the research.

Crushed Palm Kernel shell

Palm kernel shells were locally sourced in Akure and subjected to a grinding process to produce a finely powdered form.

Palm kernel Shell Ash

The palm kernel shells as seen in Figure 2 were subjected to a calcination process at a temperature of 800^{o}C for 30 mins to achieve fine ash with amorphous pozzolanic properties, utilised in the research.



Figure 2: Palm Kernel shell before crushing

Cement

The cement used in this research was Dangote cement, obtained from a local retail facility in Akure, Ondo state, Nigeria.

Fine Aggregate

The fine aggregate used was sourced from river sand in Akure, and the same was tested to ensure it was able to pass through the sieve size 425µm, which was the requirement according to British standards.

METHODS

The research procedure was in accordance with NIS 978:2017 (2017) for the production of hollow sandcrete blocks. The batching process employed a mix ratio of 1:6 (cement to sharp sand), with precise measurements conducted by weight. Consistency was maintained with a uniform water/binder ratio of 0.5 applied to all mix proportions.

The first stage involves partial replacement of the fine aggregate (Sharp sand) with either crushed palm kernel shell or crushed periwinkle shell at varying percentages of 0% (control sample), 5%, 10%, 15%, 20%, and 25%.

The second stage involves partially replacing cement with either crushed palm kernel shell (CPKS) or crushed periwinkle shell (CPWS) at varying percentages of 0%, 5%, 10%, 15%, 20%, and 25%. Table 1 below is the mix constituent adopted for this research.

Table 1: Mix Constituents for research

Batch No	Mix Composition sample	Description
1	Control	Cement and sand mixed in the ratio (1:6)
2	5% CPKS	5% replacement of Sand with CPKS
3	10% CPKS	10% replacement of Sand with CPKS
4	15% CPKS	15% replacement of Sand with CPKS
5	20% CPKS	20% replacement of Sand with CPKS

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Batch No	Mix Composition sample	Description
6	25% CPKS	25% replacement of Sand with CPKS
7	5% CPWS	5% replacement of Sand with CPWS
8	10% CPWS	10% replacement of Sand with CPWS
9	15% CPWS	15% replacement of Sand with CPWS
10	20% CPWS	20% replacement of Sand with CPWS
11	25% CPWS	25% replacement of Sand with CPWS
12	5% PKSA	5% replacement of Cement with PKSA
13	10% PKSA	10% replacement of Cement with PKSA
14	15% PKSA	15% replacement of Cement with PKSA
15	20% PKSA	20% replacement of Cement with PKSA
16	25% PKSA	25% replacement of Cement with PKSA
17	5% PWSA	5% replacement of Cement with PWSA
18	10% PWSA	10% replacement of Cement with PWSA
19	15% PWSA	15% replacement of Cement with PWSA
20	20% PWSA	20% replacement of Cement with PWSA
21	25% PWSA	25% replacement of Cement with PWSA

EXPERIMENTAL TESTS

The need to ascertain the material mineral composition requires Microscopical Analysis (X-ray Fluorescence and Scanning electron microscope), as illustrated by (Goldstein et al., 2017). At the same time, the strength and durability performance was tested on the hardened sandcrete hollow blocks based on the compressive test.

Microscopical Analysis

X-ray Fluorescence (XRF) Analysis

Thermo Scientific ARL QUANT'X XRF spectrometer, which adheres to established standards ASTM E1621-22 (2022), was utilized. The powdered samples (periwinkle shell ash and palm kernel shell ash) were taken for XRD analysis. 1 to 2 grams of powdered sample were weighed into the sample holder and compacted with a glass slide to achieve an even surface. The sample holder was placed in the XRD multi-sample holder chamber, and the machine already calibrated progressed with the push of the "(SET)" button to start the analysis. The analysed samples were automatically saved into a directory folder and then uploaded to STUDIO SMART LAB II along with ICDD PDF-4 to perform an automatic or manual search. Finally, the analysis results were generated for reference purposes or printed out. This analysis revealed the elemental composition of the additives.

Scanning Electron Microscopy and Energy Dispersive X-ray (SEM-EDX) Analysis

The SEM-EDX analysis was conducted using the Phenom ProX equipment, which is pivotal for the detailed examination of the microstructure and elemental

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composition of selected additives following ASTM C1723-10 (2022). Sample preparation for SEM-EDX analysis began with carefully collecting representative samples (crushed periwinkle shell, periwinkle shell ash, crushed palm kernel shell, and palm kernel shell ash). Each sample was meticulously dried to eliminate moisture, ensuring optimal conditions for imaging and analysis. Subsequently, samples were mounted on SEM stubs using conductive adhesive tape and coated with a thin layer (approximately 10 nm) of conductive material such as gold or carbon through sputter coating. This coating process is essential to prevent charging effects during electron beam exposure, ensuring precise and reliable imaging during SEM analysis. Initial calibration involved aligning the electron beam and fine-tuning detector settings to achieve optimal imaging conditions. Operating parameters included an electron beam voltage typically set between 15-20 kV to ensure sufficient penetration and resolution. The spot size and working distance were adjusted accordingly, with magnifications ranging from 100x for broad views to 5000x or higher for detailed examination of microstructural features. For imaging, secondary electron detectors (SED) were utilised to capture high-resolution images of the sample's surface morphology, revealing details such as particle size, shape, and distribution. Backscattered electron detectors (BSED) provided compositional contrast, distinguishing between different phases based on atomic number differences. Elemental analysis was facilitated by the energy-dispersive X-ray spectroscopy (EDX) detector, which mapped and quantified the elemental composition across the sample. Spectra were collected from multiple points of interest to ensure representative data, enabling accurate elemental distribution and content determination. Analysis of the acquired images and EDX spectra was conducted using Phenom ProX software, allowing interpretation of the sample composition and identification of specific phases present.

Compressive Strength Test

Before subjecting the sandcrete block specimens to the compressive strength test, a curing process was initiated as specified according to BS 2028 (1996). This process entailed placing standard sandcrete blocks, measuring 450 mm x 225 mm x 225 mm (length x width x height), in a controlled environment for specific durations, typically 7 and 28 days, as outlined in ASTM C511-21 (2021). The electronic compression testing machine with a maximum capacity of 1500kN, was used. The sample was cured, and the hardened sandcrete block was placed in the machine between the metallic plate of the testing chamber, and the force that was able to crush the sandcrete block was recorded for each tested sample and analysed.

RESULTS AND DISCUSSION

Material Characterisation

Chemical Composition (X-ray Fluorescence Analysis)

The chemical composition of the periwinkle ash, as observed in Figure 3, shows that the sample has a significant presence of calcium oxide (CaO) at 85.138 % weight and a noticeable amount of MgO and Al_2O_3 which falls within the permissible range outlined by ASTM C618-23E1 (2023) for pozzolans.

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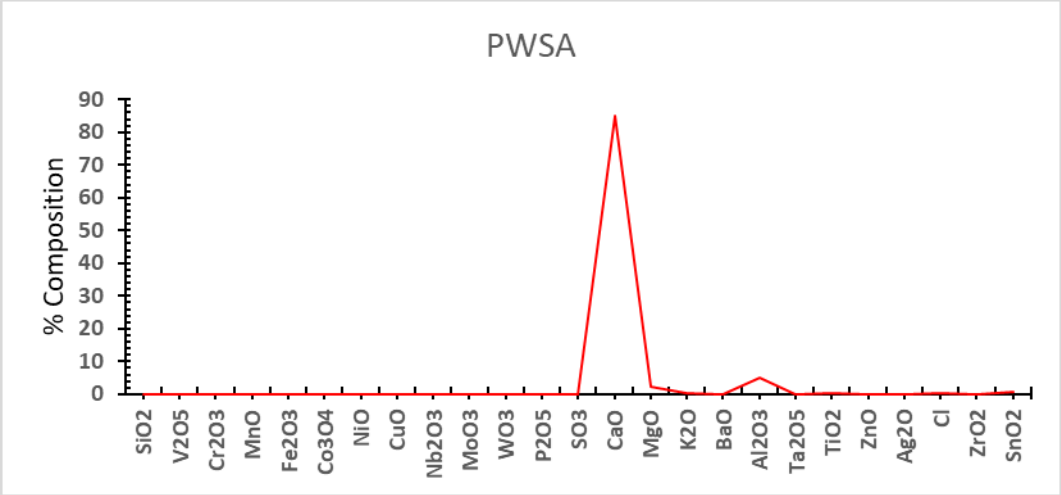


Figure 3: Elemental composition of Periwinkle shell ash

On the other hand, the chemical composition of palm kernel shell ash, as observed using X-ray Fluorescence (XRF), shows a high concentration of SiO_2 compared to other chemical compositions, as seen in Figure 4. The presence of silicon dioxide (SiO_2) at 38.691 wt.%, iron oxide (Fe_2O_3) at 14.725 wt.%, calcium oxide (CaO) at 19.340 wt.%, and aluminium oxide (Al_2O_3) at 12.918 wt.% falls within the permissible ranges for pozzolanic materials outlined by ASTM C618-23E1 (2023).

The high concentration of silicon dioxide in palm kernel shell ash improves the secondary strength gain in later days by reacting with free lime in the C-A-S-H (Calcium-alumino-silicate hydrate) reaction.

$$2(3CaO.SiO_2) + 6H_2O \rightarrow 3CaO.SiO_2.H_2O + 3Ca(OH)_2$$

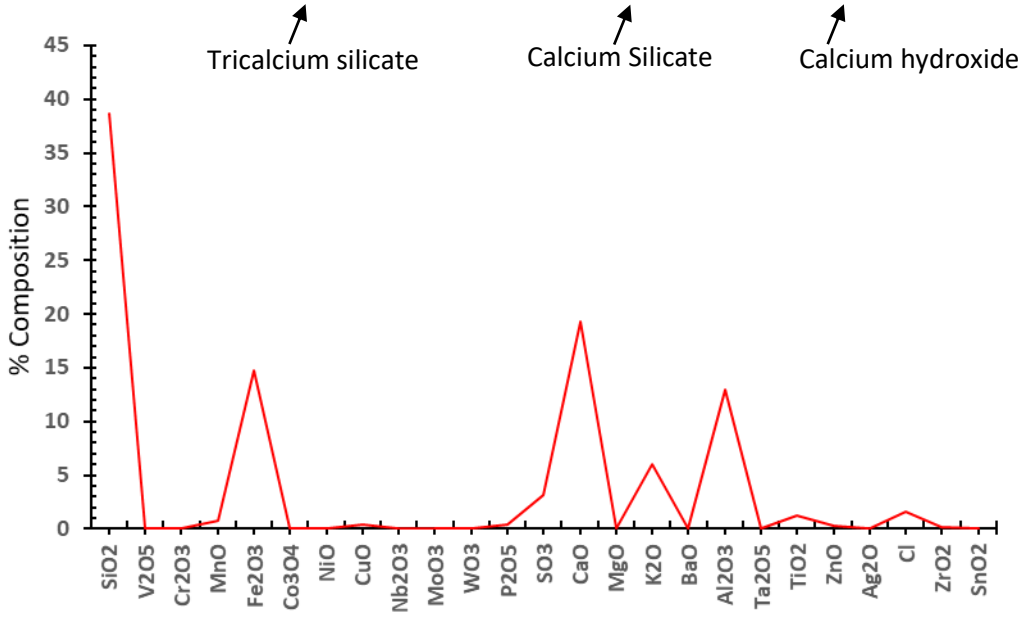


Figure 4: Elemental composition of Palm kernel shell ash

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Morphological Structure

The SEM analysis of the crushed periwinkle shell is categorised with angular particle morphology, as seen in Figure 5, with a rough surface texture that promotes a strong workability bond between the paste. The SEM analysis of the crushed palm kernel shell (CPKS) exhibits the polygonal shape of multi-sided shapes that make up the pattern, as seen in Figure 7. These patterns and shapes are responsible for solid bonds and high strength in mortar. A high magnification image shows that the primary constituent (material composition) of the crushed palm kernel shell is Silicon and Aluminium.

The dominant elements are carbon and nitrogen, with notable levels of silicon, aluminium, and organic compounds. The elemental composition for Figure 6 and Figure 8 were similar to the illustration explained in Figure 4 and Figure 3 for the ash composition of both the periwinkle shell ash and palm kernel shell ash.

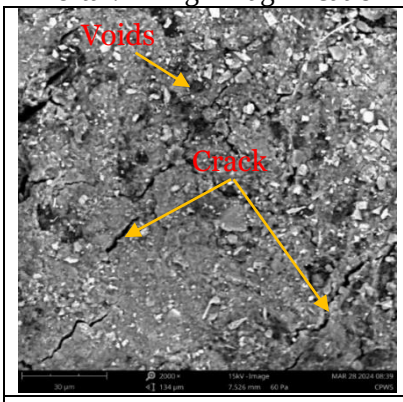


Figure 5: Crushed Periwinkle Shell (CPWS)

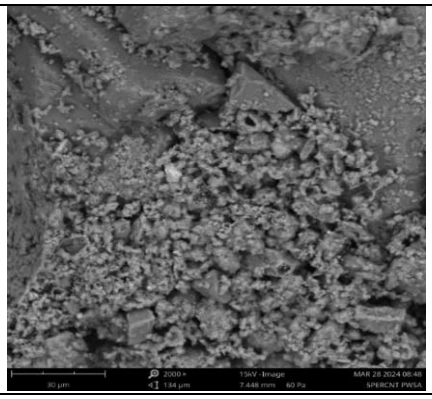


Figure 6: Periwinkle Shell Ash

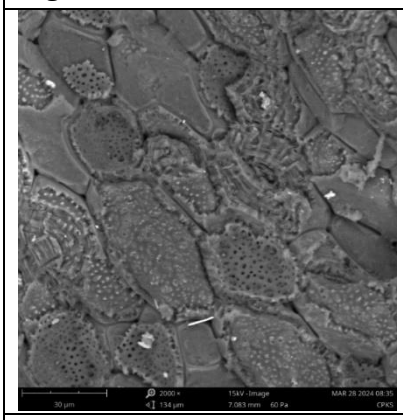


Figure 7: Crushed Palm Kernel Shell (CPKS)

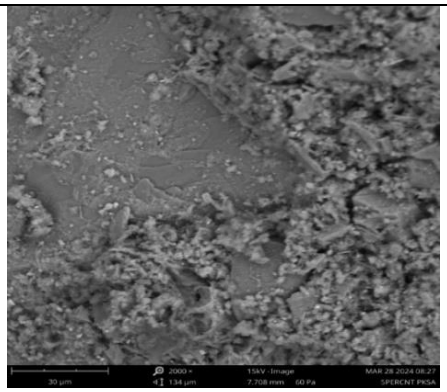


Figure 8: Palm Kernel Shell Ash

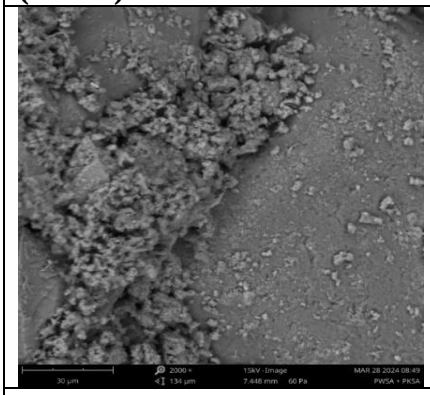


Figure 9: 5%PKSA5%PWSA Sample

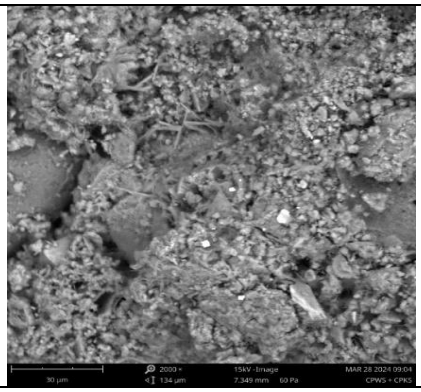


Figure 10: 10%CPKS15%CPWS Sample

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The SEM-EDX analysis of the 5% Palm kernel shell and 5% periwinkle shell ash, illustrated in Figure 9, shows high silicon and calcium elements and the material that supports a workable mortar due to its sparse sample distribution. The analysis of the 10% crushed palm kernel and 15% crushed periwinkle shell, as seen in Figure 10, promotes good strength due to the matrix arrangement and angular shape of the closely parked sample. This lattice arrangement improves the secondary strength with the formation of CASH (calcium silicon hydration), which improves the pozzolanic reactivity of mortar.

Compressive Strength

The compressive strength of sandcrete blocks was analysed with single-component additives and hybrid additive combinations (palm kernel shell and periwinkle shell ash) to evaluate the strength characteristics of the substitute materials (palm kernel shell or periwinkle shell).

As shown in Figure 11, mortar's compressive strength increases when the periwinkle shell is added up to 15% replacement but decreases after that.

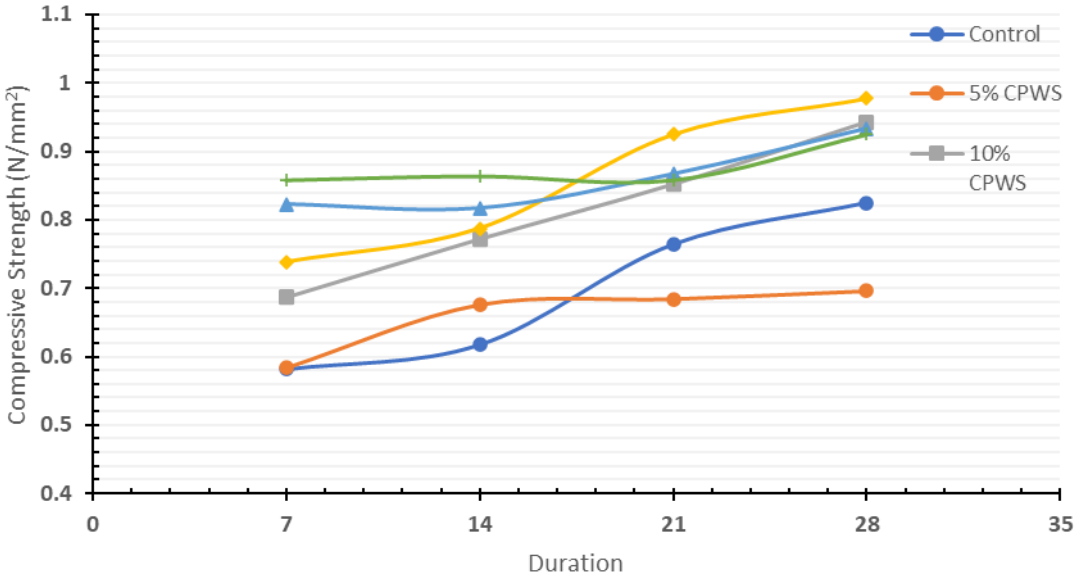


Figure 11: Analysis of compressive strength for crushed periwinkle shell

The increase in strength is due to the additional bonding provided by periwinkle shells. Nonetheless, too much periwinkle shell can reduce mortar's compressive strength. A sufficient amount of periwinkle shell should be added to the masonry to achieve maximum strength under compression. On the other hand, the periwinkle ash produces mortar with reduced compressive strength as the mortar hardens, as seen in Figure 12. The higher the periwinkle shell ash, the lesser the compressive strength of mortar produced.

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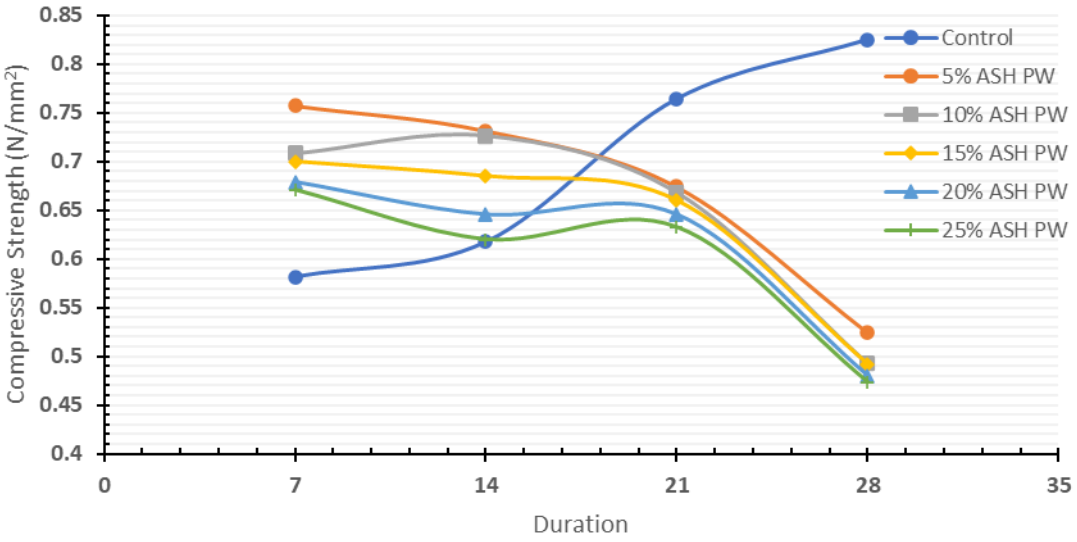


Figure 12: Analysis of compressive strength for periwinkle shell ash

Figure 12 and Figure 13 show a higher compressive strength when the palm kernel shell and its ash were used in mortar. According to Figure 12, with an addition of a palm kernel shell of 10%, the compressive strength increases and then begins to decrease. Similar features can be observed in palm kernel shell ash, except that the mortar reaches its maximum strength at 5% addition, and strength begins to decline with higher addition amounts.

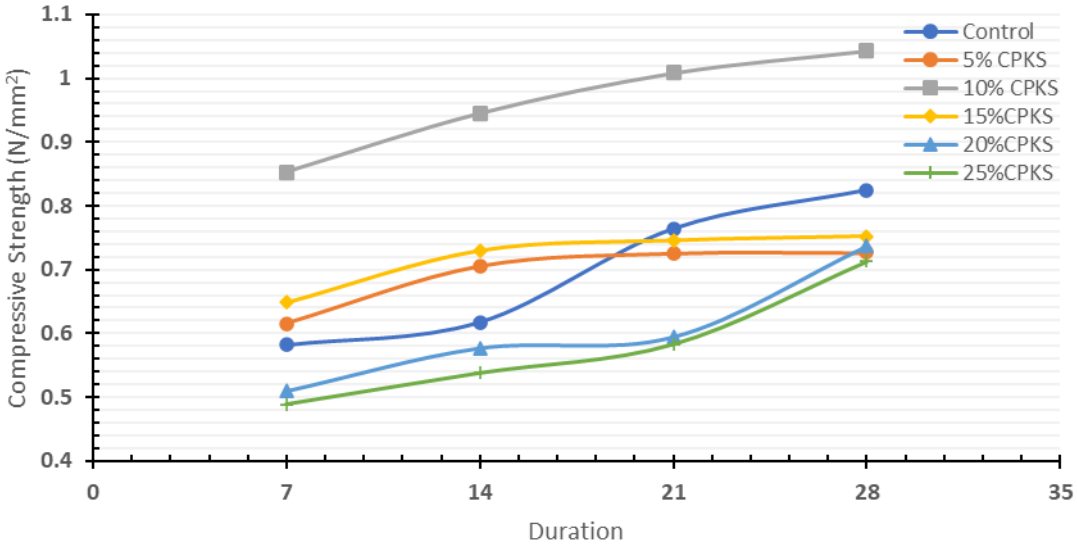


Figure 13: Analysis of compressive strength for crushed palm kernel shell

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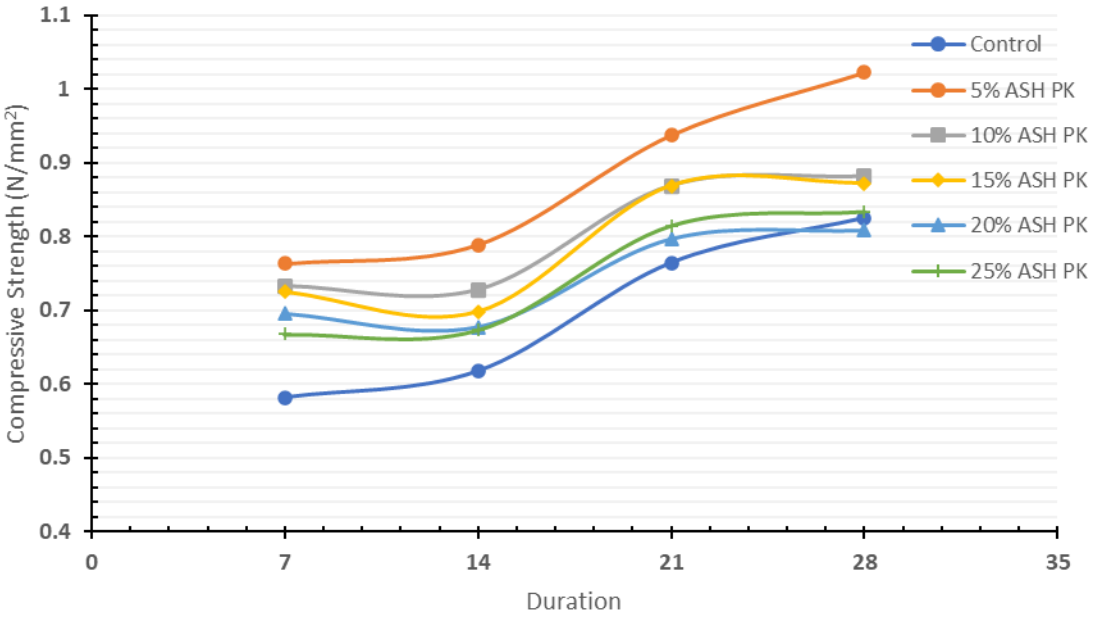


Figure 14: Analysis of compressive strength for palm kernel shell ash

There is an improvement in strength with the hybrid combination of samples (10% crushed palm kernel shell and 15% crushed periwinkle shell). There is notable higher compressive strength in the mortar compared to both the control sample and other hybrids of 5% palm kernel shell ash and 5% periwinkle shell ash) as seen in Figure 14, with a compressive strength of 1.2 N/mm^2 at 28 days.

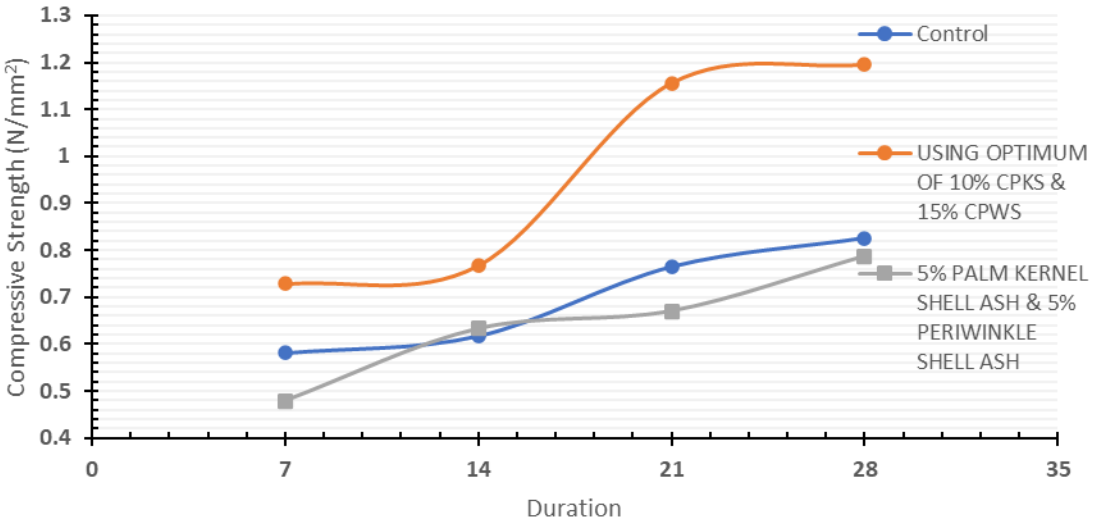


Figure 15: Analysis of compressive strength for 10% crushed palm kernel shell and 15% crushed periwinkle shell

Conclusively, Crushed Palm Kernel Shells (CPKS) demonstrated peak compressive strength at a 10% mixture, reaching 1.08 N/mm^2 after 28 days, as seen in Figure 13. Subsequent increases to 15%, 20%, and 25% diminished compressive strength. These aligns with ASTM C140/C140M-24 (2024) recommendations, highlighting

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10% as the optimal CPKS inclusion level. Periwinkle Shells (CPWS) exhibited optimal performance at a 15% inclusion rate, achieving a peak compressive strength of 0.98 N/mm^2 after 28 days, as seen in Figure 11. Higher concentrations (20% and 25%) resulted in slight reductions in compressive strength, consistent with BS 6073-1 (2018)'s suggestion of a 15% CPWS inclusion level. Palm Kernel Shell Ash (PKSA) displayed superior performance at a 5% mixture, peaking at 1.2 N/mm^2 after 28 days. Exceeding this proportion led to a gradual decline in compressive strength, aligning with ASTM C140/C140M-24 (2024)'s recommended 5% PKSA inclusion. Periwinkle Shell Ash (PWSA) showcased reduced compressive strength with increased ash concentration and, likewise, a reduction in strength as curing days increased. These findings underscore the critical role of precise dosage control and adherence to recommended inclusion levels in augmenting the structural integrity of SHBs.

CONCLUSION AND RECOMMENDATION

This study optimised an eco-friendly hollow block production system and strength characterisation using additives. In comparison to the control sample strength of 0.82 N/mm^2, the 5% PKSA mixture achieved the highest compressive strength of 1.02 N/mm^2 after 28 days. Based on comparisons with the control sample, the hybrid sample with 10% CPKS and 15% CPWS demonstrated the highest compressive strength of 1.2N/mm^2 compared with 0.82N/mm^2 for the control sample. The result obtained from this study demonstrated that using periwinkle shell ash composition resulted in reduced compressive strength and crushed periwinkle shells achieved optimal compressive strength of 0.98 N/mm^2 when 15% of the shells were replaced (% replacement).

Based on the research findings, it can be recommended to use crushed palm kernel shell ash provided the replacement is not more than 10%, whereas crushed palm kernel ash should be limited to 5% for optimal performance, while 15% is suitable for economical usage since it still has a higher strength than the control sample at this concentration.

Further research can be carried out on its water absorption and durability, pozzolanic reactivity over a long curing duration, and other curing methods.

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