



## Utilization of Palm Kernel Ash and Shell as Sustainable Binders and Aggregates for Structural Block Production

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Article Info	ABSTRACT
<p><b>Corresponding Author:</b> Oladapo Babafemi Fakiyesi E-mail: <a href="mailto:bo.fakiyesi@unizik.edu.ng">bo.fakiyesi@unizik.edu.ng</a></p>	<p>In order to develop a block for structural purposes, this study investigates the use of Palm Kernel (PK) ash and sodium silicate as a binder to produce a six-inch block. The disposal of PK ash and shell, which are agricultural waste products from palm oil mills, is a hazard for the environment. The PK ash possesses pozzolanic qualities that make it possible to partially substitute cement and also play a significant role in the strength and durability of concrete. By using PK ash in concrete, the growing issues of cement scarcity and high cost will be lessened. Three different varieties of PK ash were created at various temperatures (350-7500 C) and used to replace up to 50% PC in order to explore the PK ash's ability to replace PC. In order to research the aggregate replacement potential of the PK shell, up to 100% of the coarse aggregate was replaced.</p> <p><b>Keywords:</b> Production, Structural Bricks, Palm Canel Shell, Sodium Silicate, Binder</p>

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### INTRODUCTION

Agricultural wastes can be used as a replacement material in the construction industry, especially in nations where agricultural waste discharge is abundant, to reduce the continuously rising demand for affordable and environmentally friendly construction materials while bolstering economic growth and competitiveness. For instance, the production of palm oil generates waste products such discarded fruit bunches, palm kernel ash, and palm kernel shells. Most often, these waste products are heaped up in open fields, which has a detrimental effect on the ecology. These palm kernel ash and shell might potentially replace some cement and aggregate, lowering construction costs and providing a practical method of waste disposal and resource conservation and several environmental benefits. Agricultural wastes have engineering potential and economic advantages when used as aggregate or cement replacement materials in bricks, particularly in low-cost, lightweight non-load bearing bricks when compressive strength is not a concern.

This is because, there has been a persistent challenge in many low- and middle-income countries is the rising cost and environmental burden of Portland cement and quarried aggregates. Cement production contributes materially to CO<sub>2</sub> emissions, while open dumping or burning of palm-kernel by-products (ash and shells) poses local air and

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land-use hazards. Converting these residues into supplementary cementitious materials (SCMs) and lightweight aggregates for masonry units offers a pathway to lower-carbon, cost-effective blocks (Kumar, & Srivastava, 2023; Mahmmod et al, 2024).

Palm kernel shell can be used as a lightweight aggregate for bricks manufacturing, according to earlier studies Alengaram et al (2010). Although palm kernel shell bricks' compressive strength satisfies the requirements for lightweight bricks, medium strength structural components are best served by bricks with a greater strength. Alengaram et al (2010). Another study's findings regarding the ductility behaviour of reinforced palm kernel shell bricks beams demonstrated that the ductile mode of failure found in palm kernel shell. Alengaram et al (2008). The work of another worker Mannan and Ganapathy (2002) reported on the engineering characteristics of palm kernel shell-infused bricks and showed that while palm kernel shell infused bricks have a lower modulus of elasticity when compared to conventional bricks, it still has enough strength to be accepted as structurally lightweight. In their report on a novel technique for creating high-strength, lightweight oil palm shell bricks, Shafigh et al.(2011) demonstrated that crushed oil palm shells can be used to create bricks with a significantly lower cement content while still having a strong physical bond with the hydrated cement paste.

Chemical and microstructural studies consistently show palm-kernel-derived ashes contain reactive silica and alumina with pozzolanic potential, supporting partial cement replacement (typically  $\leq 15\text{--}20\%$  by mass) without severe strength penalties and sometimes with improved later-age performance (Camiletti et al, 2013). Recent characterization confirms that properly calcined PKSA exhibits favorable  $\text{SiO}_2$  contents and low unburnt carbon, both prerequisites for reactivity (Das & Bhattacharjee, 2021). When used judiciously in sandcrete or concrete blocks, PKSA can reduce water absorption and refine pore structure due to filler and pozzolanic effects, though excessive replacement depresses early strength (Khan et al, 2017).

Beyond simple blending with cement, alkali activation using sodium silicate (often with NaOH) extends the utility of palm-oil-based ashes toward geopolymer binders. Studies on palm oil fuel ash (POFA)—a close relative of PKSA—show that sodium silicate-activated systems can achieve competitive strength and durability at ambient or mildly elevated curing, with mix design parameters (liquid/solid ratio and  $\text{Na}_2\text{SiO}_3/\text{NaOH}$  ratio  $\sim 2\text{--}3$ ) governing setting and strength development (Rashid & Masud, 2024). While most geopolymer data center on POFA or hybrid POFA-slag blends, the same alkali-activation principles apply to well-processed PKSA, indicating a credible route to low-cement or cement-free block binders using sodium silicate solutions (Alnahhal et al, 2024).

Decades of work demonstrate that PKS is a viable lightweight coarse aggregate producing concretes with densities typically  $< 2000 \text{ kg/m}^3$  and 28-day compressive strengths commonly in the 8–20 MPa range, depending on grading, pre-soaking, and mix proportioning (Gaikwad et al, 2025). For masonry units, these strengths are compatible with many non-load-bearing and some load-bearing block specifications when mixture designs are optimized. PKS tends to increase water absorption and reduce workability relative to crushed rock; pre-soaking shells, optimizing size ( $\approx 10\text{--}12 \text{ mm}$ ), and using mineral admixtures mitigate these effects and enhance bond with the mortar matrix (Liu et al, 2021). Partial replacement levels ( $\leq 30\text{--}50\%$ ) often balance density reduction and strength

retention; full (100%) replacement yields the lightest mixtures but may cap strengths below standard structural concrete, though still suitable for lightweight blocks (Thienel et al, 2020).

This paper's main objective is to describe the material characterization, compressive strength, chemical durability, and statistical modelling of palm kernel shell and ash-based bricks. In an effort to provide current information on palm kernel ash as partial cement substitutes and the usage of palm kernel as a replacement for aggregate, this article was written. The use of PK ash and shell as a replacement for cement and aggregate will help to ease disposal issues, which are a concern for the environment, and could possibly lessen the growing concerns of cement scarcity and high cost. Civil engineers and other professionals working in the built environment who require quick access to new generation bricks through the use of innovative technologies will find this article interesting.

## MATERIALS AND METHOD

### Materials

The components used to make palm Kernel matrix bricks using sodium silicate as a necessary material, amounts were weighed according to proportions, and mixing was carried out in accordance with IS specifications.

### Method

- a. Pattern Making  
Pattern was made from metal according to the dimension of brick of dimension 6 inches
- b. Pulverisation of Palm Kernel shell
- c. Grinding into Particulate of palm Kernel shell
- d. Sieving  
Palm Kernel shell with appropriate sizes of sieve.
- e. Casting  
Using the pattern, PKS was rammed and hammered 6 inches size using and binded with the help of sodium silicate.
- f. Curing  
Curing took place in ambient air for a selective period of 6 days, 13 days, and 27 days before the bricks were tested for 7 days, 14 days, and 28 days. After 48 hours, the molding started to change.

### Physical Properties

- a. Density
  - b. Capillary Water Absorption
  - c. Linear Shrinkage
- ### 3.4 Mechanical Properties

## RESULTS

Table 1 below is the data from hardness and toughness experimental process carried out in the fabricated bricks using 50% PK and 50% clay (Blend) on a varied silicate binder proportion. Each brick has a composition of 50 % clay and PK composition before the in 5 units of binder also expressed in percentage of volume of container used.

**Table 1:** Data from hardness and toughness experimental process

% percentage of Binder (Sodium Silicate	Hardness (BHN)	Toughness
5	73.4	3.20
10	78.6	2.90
15	82.4	2.00
20	85.2	1.60
25	83.8	1.80

The experimental data in Table 1 reveal a progressive increase in hardness as the percentage of sodium silicate binder rises from 5% to 20%, with peak hardness observed at 85.2 BHN before a slight decline at 25%. Conversely, toughness decreases consistently with higher binder content, dropping from 3.20 at 5% to 1.60 at 20%, suggesting a trade-off between hardness and toughness. This outcome aligns with the findings of Kuai et al, (2022), who reported that increasing sodium silicate concentration enhances densification and hardness but reduces ductility in composite systems. In contrast, Yolcu et al, (2022) observed that while higher binder content improved wear resistance in geopolymer composites, excessive addition weakened impact strength due to brittleness, which is comparable to the declining toughness trend in this study. In a related study, Febriana et al, (2024) noted that an optimum sodium silicate level exists—beyond which material brittleness outweighs strength gains—thus recommending moderation in binder dosage. Taken together, these studies confirm that while sodium silicate is effective in enhancing hardness, careful optimization is required to balance toughness for structural applications.

### Effect of varied Binder on Hardness and Toughness Mechanical Properties

The effects of varied binder influence on hardness and toughness mechanical property is depicted in figure 1 and 2. Figure 1 indicates an increasing effect on hardness as sodium silicon increases. This hardness increasing nature is depleted the 20% binder content in the bricks. The regression model is also developed from the plot indicating a 72.46 intercept and 0.548 slope. The  $R^2$  value is 0.83 which is a good fit considering that is above 0.5. Figure 2 indicates the relationship between the toughness and binder content in the bricks. From the graph, it indicates that increase in binder content in the bricks results in decrease in toughness mechanical property. This decrease is reversed beyond the 20% content which witnessed an slight increase. A regression model of  $Y=-0.82x +3.53$  was developed indicating an intercept of 3.53 and negative slope of -0.082. Also, a good  $R^2$  value of 0.8405 was recorded.

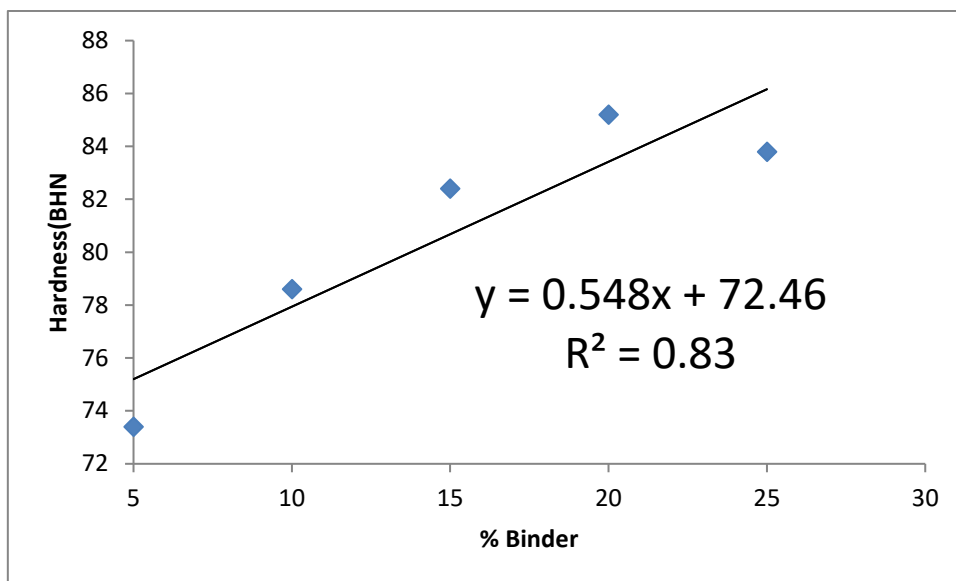


Figure1. Hardness versus % Binder

The regression analysis presented in the graph indicates a positive correlation between binder content and hardness, with an  $R^2$  value of 0.83, suggesting a strong predictive relationship. The linear equation  $y = 0.548x + 72.46$  implies that every 1% increase in binder content results in approximately 0.55 BHN increase in hardness. This finding agrees with Kuai et al, (2022), who reported that sodium silicate binder significantly enhances hardness by improving particle bonding and densification in composites. In contrast, Febriana et al, (2024) found that although hardness increased with higher sodium silicate levels, excessive binder addition beyond the optimum threshold caused microcracking, leading to reduced overall mechanical performance. In a related study, Cheng et al, (2023) observed that while binder increment enhances hardness, the relationship is nonlinear, as very high contents reduce structural balance due to brittleness. This is consistent with the slight dip in hardness at 25% binder content seen in the current study.

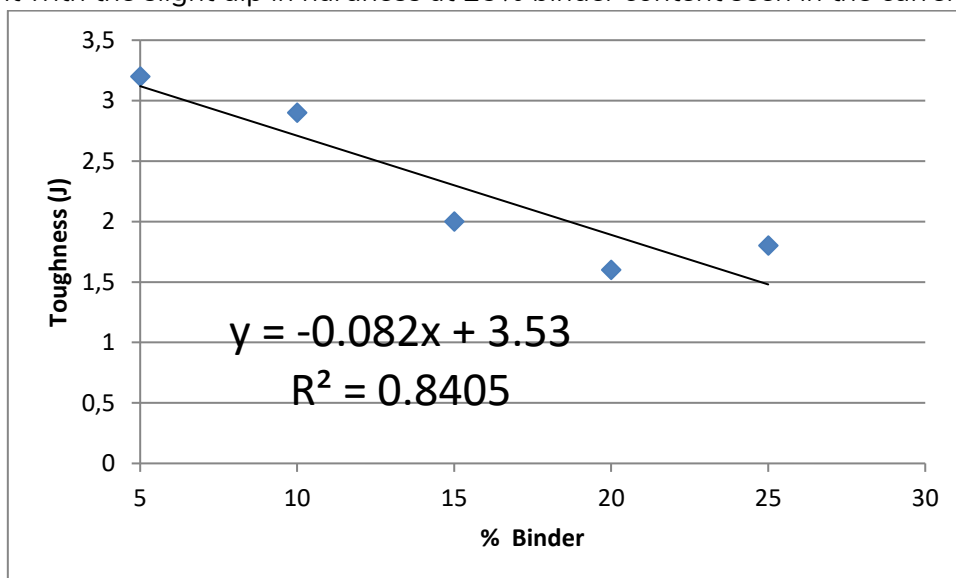


Figure2. Toughness versus % Binder

The regression analysis for toughness shows a clear negative correlation between binder content and toughness, with the equation  $y = -0.082x + 3.53$  and an  $R^2$  of 0.84, indicating strong predictive reliability. As sodium silicate binder increases, toughness drops sharply from about 3.2 J at 5% to around 1.6 J at 20%, confirming that higher binder content enhances brittleness. This finding agrees with Hossain et al, (2021), who reported that higher sodium silicate content in composites improves strength. In contrast, Pham et al, (2022) observed that moderate binder levels retained adequate toughness, but values beyond the optimum led to sudden fracture under load.

## CONCLUSION

Bricks were successfully produced using a blend of 50% palm kernel and 50% clay, bonded with varying proportions of sodium silicate as the binder. The study demonstrated that sodium silicate plays a critical role in influencing the mechanical behavior of the fabricated bricks. Notably, an increase in binder proportion by unit volume resulted in a corresponding improvement in hardness up to the 20% level. This trend was statistically validated by the developed regression model  $y = 0.548x + 72.46$ , with a strong coefficient of determination ( $R^2 = 0.83$ ), signifying a reliable predictive relationship between binder content and hardness performance. On the other hand, the study also revealed that as the binder content increased, the toughness of the bricks declined steadily within the same 20% range. This inverse relationship was expressed by the regression model  $y = -0.082x + 3.53$ , with an  $R^2 = 0.8405$ , indicating a strong negative correlation between binder content and toughness. These findings highlight a trade-off between hardness and toughness, implying that while higher sodium silicate levels enhance strength, they simultaneously increase brittleness. Thus, optimizing binder content is essential for achieving a balance in mechanical performance for structural applications.

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