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RICE HUSK ASH AND PALM KERNEL SHELL IN CONCRETE: STRATEGIES FOR WASTE MINIMISATION AND STRENGTH ENHANCEMENT

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Abstract

This study explores the potential of rice husk ash (RHA) and palm kernel shell (PKS) as partial replacements for cement and coarse aggregate, respectively, in sustainable concrete design. Amidst the increasing global focus on environmental sustainability and the need to reduce the ecological footprint of cement production, agricultural waste by-products offer a promising alternative. A total of 25 concrete cubes were prepared with different mix ratios and tested for compressive strength and workability. Regression modelling was used to predict compressive strength based on the proportions of cement, sand, RHA, PKS, and gravel. The optimal mix (1:2:0:0:4) achieved a compressive strength of 24.375 N/mm², while the regression model showed moderate predictive ability with an R^2 of 0.435. The results confirm the feasibility of incorporating agro-waste into concrete design to improve strength and support eco-efficient construction.

Keywords: Rice Husk Ash (RHA), Palm Kernel Shell (PKS), Sustainable Concrete, Compressive Strength, Waste Valorisation, Regression Modelling, Cement Alternatives

1.0 Introduction

Concrete remains the backbone of modern infrastructure, yet its environmental cost, mainly from cement production, has prompted an urgent search for more sustainable alternatives. Cement manufacturing accounts for about 5% of global CO_2 emissions, significantly contributing to climate change. The environmental downside of concrete is primarily due to greenhouse gas emissions from cement production, which erodes the protective layer of the atmosphere that shields the Earth's surface from harmful ultraviolet radiation, thus leading to global warming. It is estimated that there is a 50% chance of global warming exceeding 1.5 °C. The annual global demand for cement and concrete is approximately 1.5 billion tonnes and 11.5 billion tonnes, respectively. Estimates suggest that 1.5 billion tonnes of greenhouse gases are emitted each year to satisfy cement demand. It is crucial

to decrease the reliance on traditional Portland cement by substituting some of it with supplementary cementitious materials of low carbon footprint.

In response, the partial substitution of cement and aggregate with agricultural waste materials has emerged as a viable strategy to reduce environmental impact and conserve natural resources.

In tropical regions such as Nigeria, the widespread availability of rice husks and palm kernel shells presents a unique opportunity for sustainable construction. Rice husk ash (RHA), rich in amorphous silica, exhibits pozzolanic properties that can improve the mechanical performance of concrete when used as a partial cement replacement. Palm kernel shell (PKS), a lightweight and durable by-product of palm oil processing, is an effective substitute for conventional coarse aggregates. Optimal replacement levels are crucial to achieving the desired mechanical properties. Continued research and standardization are necessary to harness the potential of these agro-waste materials in sustainable construction practices.
Tropical nations, including Nigeria, which use large amounts of agricultural waste management, can improve public and environmental health. Research on waste incorporation into building materials to create sustainable concrete has increased (Azunna, 2019). This is due to their availability and low environmental impact (Bahrami et al., 2016).

Empirical research has shown that RHA replacement between 10% and 25% can yield compressive strengths between 33 and 38.4 N/mm², while PKS has been validated as a structural-grade aggregate under BS 5328 standards. However, while individual studies provide valuable insights, comprehensive modeling of their combined effects remains limited. This study addresses this gap by formulating a regression-based predictive model for concrete compressive strength incorporating RHA and PKS. The results informed optimized mix ratios that achieve structural integrity and environmental sustainability.

Studies have demonstrated that incorporating RHA into concrete mixes improves compressive and flexural strengths. Nair et al. (2013) observed that RHA-high-strength concrete reduced density compared to conventional concrete while enhancing mechanical properties. Further research by Akeke et al. (2013) indicated that flexural strength marginally improved with 10% to 25% RHA replacement levels, suggesting that a 10% replacement is optimal for structural concrete applications.

1.1 Palm Kernel Shell (PKS) in Concrete

Oriola et al. (2022) investigated concrete mixes with 15% RHA as a cement replacement and varying PKS content (20% to 100%) as a substitute for crushed granite. The study found that both workability and density decreased with increasing PKS content. However, the compressive strength at 90 days remained satisfactory, decreasing from 27.8 N/mm² to 13.1 N/mm² as PKS content increased from 0% to 100%.

1.2 Combined Use of RHA and PKS in Concrete

The synergistic use of RHA and PKS in concrete has been examined to improve sustainability and performance. Oriola et al. (2022) combined 15% RHA with varying PKS content, observing that

although workability and density decreased with higher PKS levels, the compressive strength remained within acceptable ranges for structural applications. Similarly, a study on geo-polymer concrete incorporating palm kernel shell ash and rice husk ash showed that a 5% replacement of palm kernel shell ash increased compressive strength by approximately 5 MPa, while a 10% replacement of rice husk ash led to a 4 MPa increase. These findings imply that optimal proportions of these ashes can enhance the mechanical properties of geo-polymer concrete.

1.3 Environmental Implications

The construction industry greatly contributes to global CO_2 emissions, and incorporating agro-waste materials like RHA and PKS can reduce this impact. Research has shown that such practices improve concrete properties and support environmental sustainability by recycling waste and conserving natural resources.

The use of agricultural waste, including rice husk ash as a pozzolanic material, has been validated by several experts. These substances can produce more Calcium Silicate Hydrate (C-S-H) by reacting with the lime remaining after Ordinary Portland Cement has hydrated, increasing the concrete's compressive strength while reducing the amount of cement needed and the associated CO2 emissions (Raheem & Kareem, 2017; Alkamu et al., 2017; Tahomah et al., 2017; Joshua et al., 2017; Ogork and Danja, 2018; Tijani & Ajagbe, 2018). As a result, cement may be partially replaced by rice husk ash without compromising the required strength and durability.

Palm Kernel Shell (PKS), a waste product of the palm oil manufacturing process, has been found to have satisfied the requirements of BS 5328 in terms of its crushing value, impact value, density, specific gravity, and size, making it suitable for concrete production as a replacement for coarse aggregate. Using it as an alternative coarse aggregate lowers the cost of concrete, protects natural resources, and improves waste management, which results in a safer environment. It can also be used as an aggregate for the production of lightweight concrete (Oyejobi et al., 2019).

This paper presents the experimental optimisation of rice husk ash and palm kernel shell as partial replacements for cement and gravel, respectively, to enhance the strength of concrete. The aim is to promote sustainable construction by developing new concrete formulations that reduce the amount of cement and gravel used in production. This study was conducted to maximise the utilisation of rice husk ash and palm kernel shell, which may help mitigate environmental challenges and provide a cost-effective, sustainable solution for producing high-strength concrete. Additionally, it seeks to develop a model for predicting the compressive strength of concrete blocks made with rice husk ash and palm kernel shell.

2. Materials and Methods

2.1 Materials

The materials used in this research are limestone Portland cement (LPC), Palm Kernel Shell (PKS), Rice Husk Ash (RHA), fine aggregate (sand), and water. Each material was pretreated to meet the required standard. Rice Husk was burned for approximately 4 hours under a controlled burning process. The ash collected was sieved through a British Standard (BS) sieve size of 600µm. The palm kernel shell was pre-treated by washing with detergent, rinsed, air-dried, and then sieved using a 16.5 mm sieve and

retained on a 5 mm sieve. The aggregate size employed was chosen to avoid fine materials and shells with large surface areas and a high potential to absorb water. The fine aggregate used in this research was river sand, which was washed and air-dried before being sieved with a 5 mm BS 112 (1971) sieve to remove impurities and larger aggregates.

2.2 Methods

The various individual constituents for concrete production were used for the study, and the research materials were tested. The mix ratio was varied, as shown in Table 1, to determine the effect of each material. A constant water-cement ratio of 0.7 was used for this research. For each batch of the concrete mixes, the slump test was carried out to determine the workability of the concrete. This was to ensure adherence to the concrete slum design. Concrete cubes of 100 mm ×100mm × 100mm dimensions were cast and allowed to set for 24 hours for proper setting before curing in a concrete bath.

Table 1: Aggregate mix ratio

Constituents	Mix Proportion				
CEMENT	1	1	1	1	1
SAND	2	1.5	1	0.5	0
RHA	0	0.5	1	1.5	2
PKS	4	4	4	4	4

2.3 Compressive strength test

Twenty-five (25) concrete cubes were crushed using the hydraulic crushing machine. The failure load ratio to the cross-sectional area of the specimens was used to determine the compressive strength. The 7-day, 14-day, and 28-day strength results were recorded. Table 2 presents the mix proportions for concrete cubes of samples F11 to F54.

$$Compressive\ strength\ (N/mm^2) = \frac{P}{A} \quad ---------- \quad (1)$$

where $P = load\ at\ failure,$ $A = Cross-sectional\ are\ of\ specimen\ (mm)$

Table 2: Mix Proportion for Concrete Cubes

SAMPLE NO.	CEMENT	SAND	RHA	PKS	Gravel
F11	1	2	0	4	0
F12	1	1.5	0.5	4	0
F13	1	1	1	4	0
F14	1	0.5	1.5	4	0
F15	1	0	2	4	0
F21	1	2	0	3.2	0.8
F22	1	2	0	2.4	1.6
F23	1	2	0	1.6	2.4
F24	1	2	0	0.8	3.2
F25	1	2	0	0	4
F31	1	1.5	0.5	3.2	0.8
F32	1	1.5	0.5	2.4	1.6
F33	1	1.5	0.5	1.6	2.4
F34	1	1.5	0.5	0.8	3.2
F35	1	1.5	0.5	0	4
F41	1	1	1	3.2	0.8
F42	1	1	1	2.4	1.6
F43	1	1	1	1.6	2.4
F44	1	1	1	0.8	3.2
F45	1	1	1	0	4
F51	1	0.5	1.5	3.2	0.8
F52	1	0.5	1.5	2.4	1.6
F53	1	0.5	1.5	1.6	2.4
F54	1	0.5	1.5	0.8	3.2

2.3 Model Formulation

A regression model (Equation 2) was employed to identify the optimal compressive strength gain in concrete made from a mixture of cement, sand, RHA, PKS, and gravel.

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 \quad (2)$$

where Y = Predicted compressive strength

b_0 = $x_1, x_2, x_3, x_4, and\ x_5$ Regression constant

$b_1, b_2, b_3, b_4, and\ b_5$ = Input variables of cement, sand, RHA, PKS, and gravel, respectively
Coefficients that show the strength of the relationship between input variables (cement, sand, RHA, PKS, and gravel) and the outcome variable

3. Result and Discussion

3.1 Model Calibration

Data analysis for regression model equation calibration was performed using Microsoft EXCEL as shown in Table 3.

Table 3: Weight of aggregates for the different mix proportions and compressive strength

Sample No.	Weight by Mix Proportion (kg)					Total Weight (kg)	Compressive Strength (N/mm^2
	Cement	Sand	RHA	PKS	Gravel		
F11	0.239	0.478	0	0.956	0	1.673	9.375
F12	0.262857	0.394286	0.131429	1.051429	0	1.84	12.25
F13	0.264857	0.264857	0.264857	1.059429	0	1.854	14.375
F14	0.258857	0.129429	0.388286	1.035429	0	1.812	13.125
F15	0.322143	0	0.644286	1.288571	0	2.255	16.875
F21	0.262857	0.525714	0	0.841143	0.210286	1.84	16.625
F22	0.335714	0.671429	0	0.805714	0.537143	2.35	15
F23	0.289143	0.578286	0	0.462629	0.693943	2.024	8.5
F24	0.333857	0.667714	0	0.267086	1.068343	2.337	15.625
F25	0.372571	0.745143	0	0	1.490286	2.608	24.375
F31	0.273714	0.410571	0.136857	0.875886	0.218971	1.916	10.34125
F32	0.292429	0.438643	0.146214	0.701829	0.467886	2.047	6.52875
F33	0.285286	0.427929	0.142643	0.456457	0.684686	1.997	11.215
F34	0.327714	0.491571	0.163857	0.262171	1.048686	2.294	12.105
F35	0.336429	0.504643	0.168214	0	1.345714	2.355	11.94
F41	0.251857	0.251857	0.251857	0.805943	0.201486	1.763	4.095
F42	0.275143	0.275143	0.275143	0.660343	0.440229	1.926	7.475
F43	0.267857	0.267857	0.267857	0.428571	0.642857	1.875	9.0675
F44	0.282571	0.282571	0.282571	0.226057	0.904229	1.978	9.6225
F45	0.354571	0.354571	0.354571	0	1.418286	2.482	11.195
F51	0.232714	0.116357	0.349071	0.744686	0.186171	1.629	5.7
F52	0.263571	0.131786	0.395357	0.632571	0.421714	1.845	9.22625
F53	0.289714	0.144857	0.434571	0.463543	0.695314	2.028	9.125
F54	0.257714	0.128857	0.386571	0.206171	0.824686	1.804	12.305
F55	0.324143	0.162071	0.486214	0	1.296571	2.269	11.73

Table 4: Statistical results

SUMMARY OF OUTPUT

Regression Statistics	
Multiple R	0.65971
R Square	0.435218
Adjusted R Square	0.259297
Standard Error	3.391117
Observations	25

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	186.0933	37.21866	5.3941603	0.002973
Residual	21	241.4932	11.49968		
Total	26	427.5865			

	Coefficients	*Standard Error*	*t Stat*
Intercept	-14.4765	7.462893	-1.93979
Cement	0	0	65535
Sand	3.468284	3.933049	0.881831
RHA	0	0	65535
PKS	23.20961	7.49901	3.095023
Gravel	19.51159	6.106614	3.195157

From the result, we can deduce the constant coefficient of the model as follows

$b_0 = -14.4765,$ $b_1 = 0,$ $b_2 = 3.468284,$

$b_3 = 0,$ $b_4 = 23.20961,$ $b_5 = 19.51159$

Thus, the Regression model for predicting the compressive strength of the designed concrete cubes using Cement, sand, Rice Husk Ash, and Palm Kernel Shells is as stated in Equation 3.

$$\boldsymbol{C}ompressive\ strength = -14.4765 + 3.468284\,S + 23.20961\,PKS + 19.551159\,G \quad (3)$$

where $S = Weight\ of\ sand\ (Kg)$ $PKS = Palm\ kernel\ shell\ weight\ (Kg)$

$G = Weight\ of\ gravel\ (Kg)$

This equation implies that:

- The **regression constant** (−14.4765 N/mm²) represents the hypothetical base strength of the concrete mix in the absence of sand, PKS, and gravel.
- An increase in **sand** proportion increases compressive strength by **3.4683 N/mm²** per unit increase.
- Each unit of **PKS** increases the strength by **23.2096 N/mm²**, showing a significant contribution.
- **Gravel** enhances the strength by **19.5116 N/mm²** per unit, confirming its critical role in structural performance.

The variables cement and RHA did not have statistically significant coefficients in this model, likely due to multicollinearity or limited variance in those variables across the mix designs. Their exclusion from the final model was based on the regression output indicating coefficients effectively equal to zero.

3.2 Verification of Result

The correlation coefficient (r) between the measured and the predicted compressive strengths. Table 5 shows the result of the measured CBR and the predicted CBR using the formulated model.

Table 5: Measured and Predicted Compressive Strength (N/mm^2)

S/N	Samples	Predicted Value (N/mm^2)	Measured value (N/mm^2)
1	F11	9.36976789	9.375
2	F12	11.29428305	12.25
3	F13	11.03106485	14.375
4	F14	10.00432936	13.125
5	F15	15.43078174	16.875
6	F21	10.97247438	16.625
7	F22	17.03307345	15
8	F23	11.8065592	8.5
9	F24	14.8833899	15.625
10	F25	17.18575617	24.375
11	F31	11.54896657	10.34125
12	F32	12.46324203	6.52875
13	F33	10.96121979	11.215
14	F34	13.77487552	12.105
15	F35	13.53081475	11.94
16	F41	9.033979563	4.095
17	F42	10.39367526	7.475
18	F43	8.942687847	9.0675

S/N	Samples	Predicted Value (N/mm^2)	Measured value (N/mm^2)
19	F44	9.393216405	9.6225
20	F45	14.42630861	11.195
21	F51	6.843466391	5.7
22	F52	8.890664611	9.22625
23	F53	10.35128463	9.125
24	F54	6.8465439	12.305
25	F55	11.38382413	11.73

The compressive strength predicted values were close to the measured values, though they predicted higher and lower values in some cases, as shown in Figure 1.

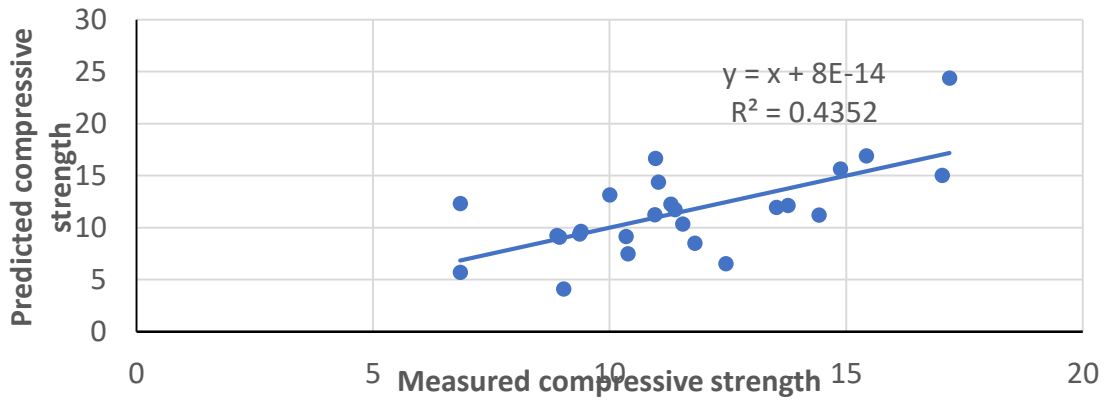

Figure 1: Predicted compressive strength against measured compressive strength

The graph of predicted compressive strength obtained from the model equation against experimental value measured from the laboratory (Figure 1). The model achieved an R^2 value of 0.435, indicating a moderate correlation between the independent variables and the measured compressive strength. Although not highly predictive, the model offers a useful approximation for mix optimization in sustainable concrete design.

4. Conclusion

This study has shown that incorporating rice husk ash and palm kernel shells into concrete mixes can improve compressive strength and support sustainable construction efforts. The data indicate that a concrete mix without RHA or PKS but with a high proportion of gravel achieved the highest strength (24.375 N/mm²). However, mixes that included RHA and PKS demonstrated notable performance and environmental advantages, especially when fine aggregates were reduced.

The regression model developed demonstrated a moderate predictive ability ($R^2 = 0.435$), suggesting that although further refinement is required, the model shows promise for guiding mix design in contexts prioritising cost efficiency and sustainability. Notably, the best results were obtained when sand and PKS were used in reduced

proportions, emphasising the importance of controlling the mix ratio.

Overall, this research highlights the potential of reusing agricultural waste in civil engineering. The results advocate for wider use of RHA and PKS as sustainable components in concrete and emphasise the need for further research to develop industry standards and expand model applicability across various construction contexts.

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