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Uncracked Palm Kernel Shell Effect on Compressive Strength of Concrete

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HIGHLIGHTS

- Grade C20 concrete was obtained for CC10,90 on the 28th day of curing.
- Grade C15 concrete was obtained for CC20,80 and CC30,70 on the 28th day of curing.
- A predictive model with a good coefficient of determination was formulated.
- The adequacy of the model was verified using a student's t-test.

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ABSTRACT

In recent times, the production of concrete has become a significant concern due to the rapid population growth and the depletion of raw materials. In this research, we investigated the use of Uncracked Palm Kernel Shell (UPKS) as a replacement for crushed granite in concrete production, with replacement percentages of 0%, 10%, 20%, 30%, and 100%. The concrete mix combined Ordinary Portland Cement with river sand and coarse aggregates (granite and UPKS). The properties of fresh concrete were assessed using the slump test, while the compressive strength test was conducted after curing the samples for 7, 14, 21, and 28 days. A total of 60 concrete cubes were cast for this study. Our findings indicate that the workability of concrete decreased as the percentage of UPKS replacement for granite increased. Additionally, the compressive strength of the concrete decreased with higher percentages of UPKS replacement. On the 28th day of curing, the control concrete achieved a strength of 28.59 N/mm². However, concrete containing 10%, 20%, 30%, and 100% uncracked palm kernel shells achieved average strengths of 20.74 N/mm², 18.22 N/mm², 15.31 N/mm², and 12.23 N/mm², respectively. This represents a 27%, 36%, 46%, and 57% decrease in strength compared to the control concrete. Our study reveals that concrete with 10% to 30% replacement of granite with uncracked palm kernel shell can produce eco-friendly lightweight grade 15/20 concrete, making it suitable for sustainable construction. The developed model was tested and found adequate for predicting the concrete properties.

1. Introduction

Concrete production has recently become a significant concern due to the rapid population growth and the decline in available raw materials [1-3]. Concrete is a widely used and preferred construction material due to its strength and versatility in forming different shapes and sizes [4,5]. It is defined as a composite material consisting of cement and coarse and fine aggregates [6].

The primary components of concrete are aggregates, which greatly contribute to its strength development [7]. Coarse aggregates, such as crushed granite and gravel, and fine aggregates, like stone dust and river sand, are commonly used in construction [8,9]. However, the extensive use of these materials has decreased availability and increased production costs [10].

Affordability is a major challenge in housing infrastructure, particularly in developing countries, where nearly 60% of the population resides in informal settlements due to the high cost of aggregates [11,12]. Engineers and researchers are exploring alternative materials for concrete production to address this issue and conserve natural resources. One such alternative is the uncracked palm kernel shell (UPKS), which is the intact shell of the palm fruit after processing for oil [13].

In rural Nigerian communities, UPKS is often considered waste and disposed of in landfills, leading to environmental challenges. However, studies have shown that waste materials like UPKS can be recycled into new raw materials to reduce environmental impact and resource depletion [13].

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Recent studies on lightweight concrete have focused on cracked palm kernel shells (PKS) as a replacement for traditional materials. Azuna [14] reported strength values of 4.78 N/mm^2 and 4.44 N/mm^2 at 10% and 25% granite replacement with palm kernel shell, but Eziefula and Opara [15] found that the strength of palm kernel shell concrete did not meet the standard requirements [16]. Fadele et al. [17] obtained a compressive strength range of 20-36 MPa for concrete made with PKS, while another study [18] reported a compressive strength of 30.2 N/mm^2 for 25% PKS replacement at 28 days of curing.

Shafigh et al. [19] used crushed oil palm shells as coarse aggregate in concrete production, resulting in 38% lower strength than the control mix after 28 days of curing. Oti et al. [20] replaced granite with palm kernel shells at different intervals and obtained compressive strength ranging from 12.71 N/mm^2 to 16.63 N/mm^2 at 28 days of curing. Additionally, other studies [21, 22] reported varying strengths for cracked palm kernel shell concrete in their respective investigations.

This research explores using an uncracked palm kernel shell (UPKS) to replace crushed granite to produce eco-friendly concrete. The goal is to lower the cost of housing construction in rural areas where UPKS is readily available and traditional coarse aggregates are expensive and scarce. Obtaining UPKS from dump sites in Odingene village, Enugu state, Nigeria, the study will conduct physical property tests, concrete slump tests, and compressive strength tests by relevant British and American standards (BS and ASTM). The findings will support the development of sustainable and affordable housing solutions for citizens at various governmental levels.

2. Materials and Methods

The uncracked palm kernel shell used for the research was obtained from Odingene village in Akpugo, Nkanu West, Enugu, Southeastern Nigeria. It was washed, air-dried, cleaned, and free from unwanted materials, with a maximum size of 20 mm. The control coarse aggregate was 20 mm crushed granite from Agbani aggregate depot in Enugu, Nigeria. The fine aggregates used were high-quality white sharp sand from a sand depot in Enugu, as shown in Figure 1.

A B C

Figure 1: (A)The un-cracked palm kernel shell, (B) crushed granite, (C) river sand

Figure 1 depicts the uncracked palm kernel shell (A), crushed granite (B), and river sand (C) used in the research. All aggregates were air-dried to a saturated surface dry condition to maintain the water-to-cement ratio. Table 1 presents the results of physical tests conducted on the materials, including water absorption, sieve analysis, relative density, bulk density, gradation coefficient (Cc), uniformity coefficient (Cu), and fineness modulus.

UPKS was used to replace crushed granite at various percentages, as specified in Table 2. Concrete was produced using 42.5 R grade Ordinary Portland Cement (BUA brand) purchased from a cement outlet in Enugu state, Nigeria. Good-quality water was used for mixing and curing the concrete samples. A concrete mix ratio of 1:2.2:4.5 with a 0.55 free water-to-cement ratio was used, targeting a characteristic design strength of 25 N/mm^2.

Table 1: Aggregates physical properties

Type of property	River sand	UPKS	Granite
Relative density	2.63	1.36	2.68
Water absorption (%)	0.82	0.78	0.65
Bulk density (Kg/m^3)	1700	740	1660
Coefficient of gradation, C_c	0.75	1.26	1.23
Uniformity Coefficient, C_u	3.8	1.59	1.81
Fineness modulus	3.02	1.96	2.59

The concrete types in Table 2 are clearly explained as follows:

- CC0,100: Concrete cubes containing 0% Uncracked palm kernel shell and 100% Granite, serving as the control sample.
- CC10,90: Concrete cubes containing 10% Uncracked palm kernel shell and 90% Granite.
- CC20,80: Concrete cubes containing 20% Uncracked palm kernel shell and 80% Granite.
- CC30,70: Concrete cubes containing 30% Uncracked palm kernel shell and 70% Granite.
- CC100,0: Concrete cubes containing 100% Uncracked palm kernel shell and 0% Granite.

Table 2: Concrete types

S/No	Concrete type
1	CC0,100
2	CC10,90
3	CC20,80
4	CC30,70
5	CC100,0

3. Mixing of Concrete

The concrete was batched by weight following the mix ratio. First, the coarse and fine aggregates were mixed and spread evenly on the laboratory's clean, hard floor. Next, the cement was uniformly spread over the mixed sand and coarse aggregate. The materials were repeatedly shoveled from one end to another and cut with a shovel to ensure thorough blending. Gradually, water was added to the mix, ensuring neither water nor cement could escape. The mixing process was repeated until the mixture achieved a uniform color and consistency.

4. Fresh Concrete Tests

4.1 Slump Test

The slump test was performed using Abram's slump cone apparatus, following the guidelines in [24]. This test assesses the filling ability of concrete. Slump tests were conducted on CC0,100 (control), CC10,90, CC20,80, CC30,70, and CC100,0 concretes. The cone was carefully filled with fresh concrete in three layers, with 25 blows for each layer. After filling, the cone was vertically removed, allowing the concrete to deform and settle on a flat metal tray. The height of the concrete was measured, and the difference in height between the cone and the concrete after removal was recorded.

4.2 Specimen Preparation for Strength Test

Various procedures were followed to prepare the concrete cubes for the strength test. Firstly, the inside of the 150 mm x 150 mm x 150 mm molds was oiled using a brush to lubricate them and facilitate easy de-molding. Molding, de-molding, and curing were carefully carried out during this process. The thoroughly mixed concrete was filled into the cubical molds in three layers using a mason's trowel. Each layer received 25 blows with the rammer at its weight to ensure proper compaction, following the guidelines in [25]. The concrete was evenly spread over the cross-section of the mold. The top of each mold was smoothed and leveled while the outside surfaces were cleaned. In total, 60 cubes were produced for this research. After 24 hours, the cubes were de-molded and placed in a tank for curing until they were ready for testing. Throughout the laboratory process, precautions recommended in [26] and [27] were taken into consideration.

4.3 Concrete Compressive Strength Test

The compressive strength of the concrete cube samples was determined using a compressive strength testing machine. The samples were cured for 7, 14, 21, and 28 days before testing. The testing machine met the requirements specified in the literature (BS EN) [28]. For each day of curing, triplicate samples of 150 mm x 150 mm x 150 mm concrete cubes were used for the test, following the guidelines outlined in (BS EN) [29]. A total of sixty (60) samples were crushed, as shown in Table 3.

Table 3: Number of samples crushed

Sample type	Curing ages	Replicates	Number of samples
CC 0,100	7, 14, 21, 28	3	12
CC 10,90	7, 14, 21, 28	3	12
CC 20,80	7, 14, 21, 28	3	12
CC 30,70	7, 14, 21, 28	3	12
CC 100,0	7, 14, 21, 28	3	12
Total			**60**

4.4 Model Development

Regression analysis is a statistical method used to develop empirical models for predicting dependent response variables based on independent variables. It explores the relationships between variables [30]. This relationship is expressed in mathematical form, as shown in Equation 1 [31].

$$Y = Q(X_1, X_2 \dots \dots \dots X_k) \tag{1}$$

Y is the dependent variable and X_K is the independent variable. Researchers normally conduct a statistical adequacy test to ensure laboratory values and predicted values have no significant difference.

The empirical correlation for this research was conducted using MS Excel spreadsheet regression. The empirical model for estimating concrete strength was developed following the standard linear-iterative approach described by Cindy and Robert [32]. The relationships between the variables were established, and a statistical t-test was performed at a 95% confidence level to test the validity of the empirical model.

5. Results and Discussion

5.1 Physical Properties

Table 1 presents the results of physical property tests conducted on the aggregates used in this research. The grading curves for the aggregates are shown in Figures 2, 3, and 4. According to the American Standard for Testing and Material (ASTM) and British Standard International, the results in Table 1 indicate that the aggregates meet the necessary requirements for use in concrete production.

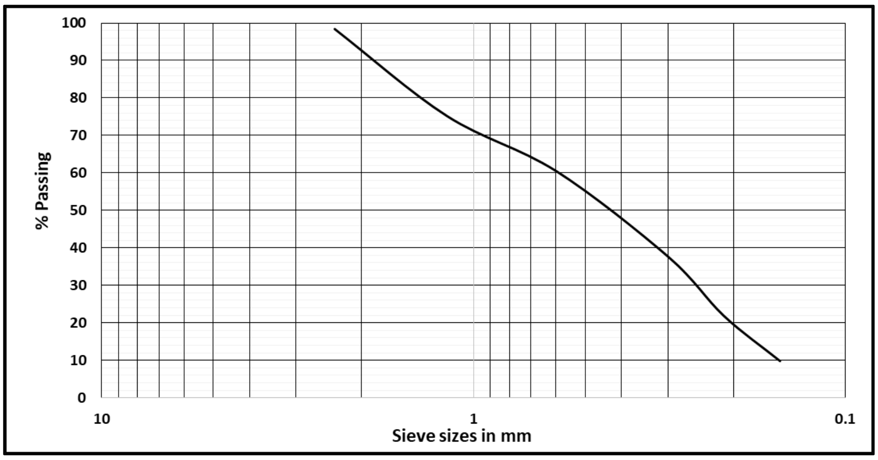

Figure 2: Grading curve of River sand

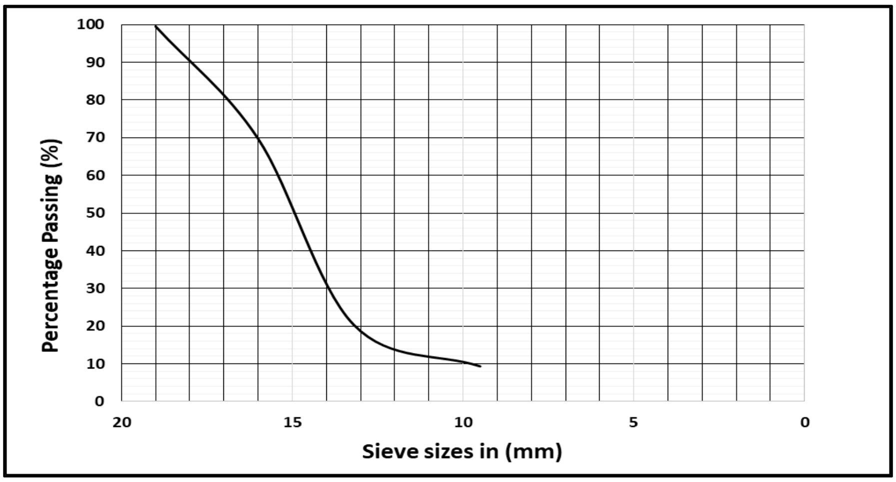

Figure 3: Grading curve of UPKS

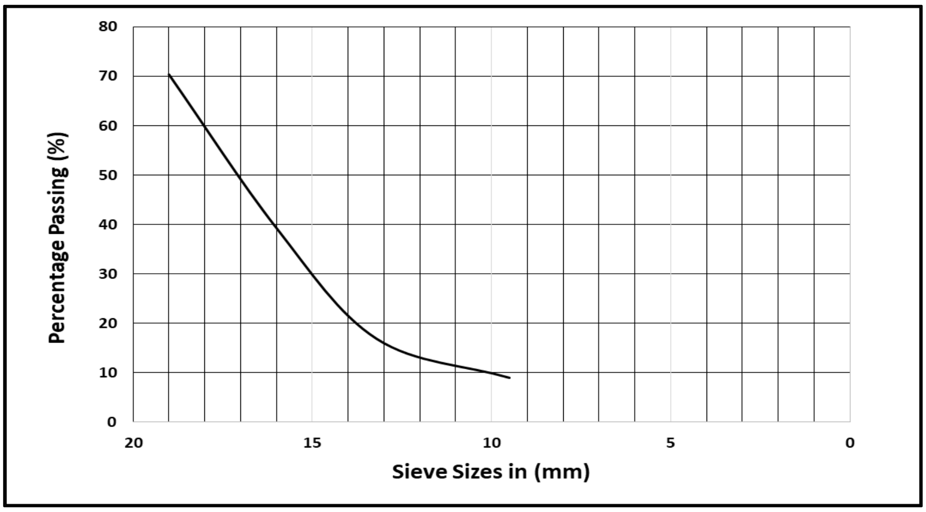

Figure 4: Grading curve of Granite

5.2 Fresh Properties

The results of the slump test are presented in Table 4. The CC 0,100 sample exhibited a better slump compared to the others. As the percentage of Uncracked palm kernel shells (UPKS) increased, the slump values also increased. The presence of UPKS in the concrete affected its rheological behavior, making it less workable. The slump values for all samples ranged between 20-50 mm. The low workability values of the concrete containing UPKS could pose challenges during the casting process in the field. To enhance workability, chemical admixtures like superplasticizers, such as sulfonated naphthalene formaldehyde condensate, can be added to the concrete.

Table 4: Fresh properties of samples

Sample	Slump (mm)	Degree of workability
CC 0,100	40	Low
CC 10,90	36	Low
CC 20,80	29	Low
CC 30,70	25	Low
CC 100,0	20	Very low

5.3 Strength of Concrete Cubes

Figure 5 illustrates the results of average concrete cube compressive strength at different replacement levels. The average cube strength increased over time, but the rates varied among the samples. According to [33], the 7th-day cube strength is approximately 60% of the 28th-day strength. In this research, the CC0,100 (control) sample had a 65% cube strength ratio from the 7th to the 28th day. For CC10,90, CC20,80, CC30,70, and CC100,0, the ratios were 47%, 40%, 36%, and 28%, respectively, indicating that concrete containing uncracked palm kernel has low early strength development. The CC0,100 sample consistently maintained the highest compressive strength values over time, while the strengths of the other samples (CC10,90, CC20,80, CC30,70, and CC100,0) increased with curing age but remained lower than the control at all testing ages. The increase in strength over time is attributed to the ongoing hydration process, leading to more calcium silicate hydrate forming, which enhances concrete strength [31]. On the 14th, 21st, and 28th day of curing, the CC0,100 sample achieved compressive strengths of 22.52 N/mm2, 26.81 N/mm^2, and 28.59 N/mm^2, respectively, representing 17.09%, 30.36%, and 34.70% increase compared to the strength gained on the 7th day. In contrast, the CC10,90, CC20,80, CC30,70, and CC100,0 samples exhibited compressive strengths of 20.74 N/mm^2, 18.22 N/mm^2, 15.31 N/mm^2, and 12.23 N/mm^2 on the 28th day of curing. Considering the 28th-day strengths, these samples showed a decrease of 27.46%, 36.27%, 46.45%, and 56.87%, respectively, compared to the CC0,100 sample. This reduction in strength can be attributed to the increase in the percentage of UPKS, leading to a higher volume of coarse aggregate since uncracked palm kernel shell is lighter than granite [34]. Nonetheless, the compressive strength of 20.74 N/mm2 achieved by the CC10,90 on the 28th day of curing surpasses the strength of C20 grade concrete, which is suitable for structural load-bearing works. Similarly, the strengths of 18.22 N/mm^2 and 15.31 N/mm^2 attained by CC20,80 and CC30,70 on the 28th day are higher than the C15 grade concrete. These strengths fall within the regular grades of concrete, making them excellent choices for various applications such as developing unreinforced foundations for houses, paving, residential flooring, and freestanding retaining walls.

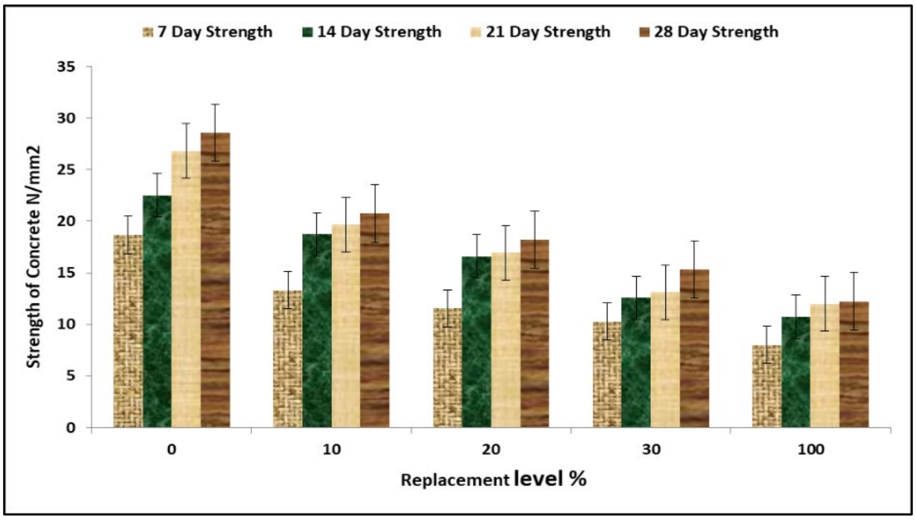

Figure 5: Average Compressive Strength of Concrete Cubes

5.4 The Model

The developed model for concrete compressive strength is presented in Table 2, where P represents compressive strength, Q1 represents curing age in days, and Q2 represents the percentage replacement level.

The regression analysis of the data indicated a significant linear relationship between the parameters (p = 0.0006). The R-square value of 0.7 reflects a high correlation level, meaning that the model can explain approximately 70% of the variation in the compressive strength. In comparison, the remaining 30% is attributed to random error or other factors.

The t-test analysis results are displayed in Table 5. If t Stat < t Critical two-tail or t Stat > t Critical two-tail, the null hypothesis is rejected, and the alternative hypothesis is accepted; otherwise, the null hypothesis is accepted. In this case, t Stat = -1.90, which is less than t Critical two-tail = 2.09, leading to the acceptance of the null hypothesis and rejection of the alternative hypothesis. Consequently, the model is deemed adequate, indicating that there is no significant difference between the laboratory concrete cube compressive strength results and the model-predicted concrete cube compressive strength results. Hence, the compressive strength of the concrete containing uncracked palm kernel shell (UPKS) can be reliably predicted using Equation 2.

$$P = 14.31 + 0.31Q1 - 0.10Q2 \quad (2)$$

Table 5: Statistical t-test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	16.33	32
Variance	30.24	1322.11
Observations	20	20
Hypothesized Mean Difference	0	
df	20	
t Stat	-1.91	
P(T<=t) one-tail	0.04	
t Critical one-tail	1.72	
P(T<=t) two-tail	0.07	
t Critical two-tail	2.09	

6. Conclusion

This research focused on examining the impact of uncracked palm kernel shells on the compressive strength of concrete. By using uncracked palm kernel shell as a substitute for granite at different replacement levels in the coarse aggregate, the following conclusions were drawn:

1) As the percentage replacement of granite with uncracked palm kernel shell increased, the workability of UPKS concrete decreased.
2) The compressive strength of UPKS concrete decreased with a higher percentage replacement of granite with an uncracked palm kernel shell.
3) The compressive strength of UPKS concrete increased with the curing age, showing improved strength over time.
4) Concrete samples with 10%, 20%, and 30% granite replacement with uncracked palm kernel shell (CC10,90, CC20,80, and CC30,70) achieved compressive strengths of 20.7 N/mm^2, 18.22 N/mm^2, and 15.31 N/mm2, respectively, after 28 days of curing. This indicates their suitability for developing grade 15/20 concrete.
5) The model developed to predict concrete compressive strength using UPKS was validated and found to be adequate, with a good coefficient of determination.

Authors contributions

Conceptualization, C. Ezenkwa; formal analysis, C. Ezenkwa. and T. Elogu; investigation, C. Ezenkwa. and T. Elogu; data curation, C. Ezenkwa. and T. Elogu; writing—original draft preparation, C. Ezenkwa. and T. Elogu; writing—review and editing, C. Ezenkwa. and T. Elogu. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data supporting this study's findings are available on request from the corresponding author.

Conflicts of interest

Not applicable.

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