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**Original Research Article**

# Mechanical Properties, Durability and Microstructure of Palm Kernel Shell Concrete Produced from Different Grades of Portland Limestone Cement

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## ABSTRACT

*The need for lightweight structures and to reduce environmental waste which leads to pollution has necessitated the utilization of agro-based materials as aggregates for concrete. Notable among these wastes is the Palm Kernel Shell (PKS). This study investigated the compressive and tensile strength, durability and internal structure of PKS concrete made with 32.5N and 42.5N grades of Portland Limestone Cement (PLC). A designed mix of Grade 20 culminating into a combined ratio of 1:1:1 for cement, sand and PKS batched by volume adopting a water-cement ratio (w/c) of 0.45. The compressive and tensile strengths of the concrete were tested, the durability of the concrete was determined using a water absorption test and Scanning Electron Microscopy (SEM) was conducted to correlate the test results. The outcome of investigations showed that PKS concrete from the cement of grade 42.5N has higher compressive and tensile strengths than grade 32.5N. Microstructural images from SEM showed non-uniformly distributed voids which are higher in concrete produced from 32.5N grade cement. Hence, the PKS concrete from grade 32.5N PLC absorbed more water than the concrete made from 42.5N PLC. Therefore, cement grade affects the strength, durability and microstructure of PKS concrete.*

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## 1. INTRODUCTION

Large-scale manufacturing of concrete utilizing regular coarse aggregates, stone deposits and other mining materials influences the climate, thus, increasing environmental pollution (Odeyemi et al., 2024). So, alternative waste materials such as rubber, fly ash, and palm kernel shell (PKS) for use as a replacement for aggregates in concrete are being investigated by researchers (Jones et al, 2012; Adam, 2014; Atoyebi *et al*, 2018). The use of waste materials in concrete helps in reducing environmental pollution, producing more sustainable concrete and decreasing cost. Agricultural waste materials like PKS have been suggested to be good aggregates in cement concrete production (Olanipekun *et al*, 2006; Odeyemi *et al*, 2019; Atoyebi *et al*, 2021; Odeyemi *et al*, 2021; Katte *et al*, 2022; Adazabra *et al*, 2023; Padavala *et al*, 2024). It has been proven in some research that PKS can be utilized in lightweight concrete, because of its high-impact resistance (Chin et al., 2020; Ogundipe *et al*, 2021). Various structures like dams, multistorey buildings, piers, etc. depend on the durability, strength, mixture, and microstructure of concrete. The properties of aggregate have a substantial impact on the structural performance and resilience of concrete. Aggregates with unsuitable properties will not produce strong and durable concrete. Neville, (2011) and Odeyemi *et al.* (2022) suggested that the water-cement ratio has effects on the water absorption of concrete, thereby influencing its durability.

PKS is obtained from the oil palm, a tree that is in high abundance in Nigeria. Infact, Nigeria is rated as the fifth largest producer of palm oil in the world (Eziefula *et al*, 2017). Ndoke, (2006) studied the influence of PKS as a fractional replacement for coarse aggregates in rural binder courses, and he concluded that it can safely replace 30% of coarse aggregates in asphalt concrete. Likewise, Azunna, (2019) investigated the use of PKS as a fractional substitute for granite in concrete and recommended up to 25% inclusion. Oyedepo *et al*, (2015) evaluated the efficiency of Coconut Shell Ash (CSA) and Palm Kernel Shell Ash (PKSA) as replacements for cement in concrete using a mix ratio of 1:2:4 and a water-binder ratio of 0.63. At 20 % replacement of cement with CSA and PKSA, maximum strengths of 17.26 N/mm$^2$ and 15.4 N/mm$^2$ were achieved respectively, while at 10 % substitution of cement with CSA, compressive strength of 20.58 N/mm$^2$ was achieved after 28 days. These results proved that the ashes of the wastes can be utilized for both lightweight and heavyweight concrete.

The research conducted by Chukwu (2017) on the properties of Palm Kernel Shell Concrete (PKSC) showed that on the 28th day, the concrete cubes had compressive strength ranging from 12.71 to 16.63 N/mm2, which was sufficient for lightweight concrete. (Alengaram *et al*, 2013) informed that the highest compressive strength of concrete containing PKS as aggregate at 28 days was 25 Mpa. (Teo *et al*, 2007) worked on lightweight concrete with PKS as aggregates and obtained compressive strength of 28.1 Mpa at 28 days. Yusuf and Jimoh (2011) evaluated different mixes of PKS concrete using 1:1.5:3 and 1:1:2 and a water-binder ratio of 0.5 in beams. The 28-day flexural strength gave 2.883 N/mm$^2$ and a deflection of 0.947 mm. The research conducted by Odeyemi et al. (2019) to determine bond and flexural strength in Self-Compacting Palm Kernel Shell (SCPKS) concrete wherein coarse aggregates content in concrete was replaced by 50% PKS for mix ratios of 1:2:4, 1:1.5:3 and 1:1:2 and a water-binder ratio of 0.5. The results revealed that the highest bond strength value of 5.56 N/mm$^2$ at 28 days was obtained in the mix of 1:1:2. The SCPKS concrete had the highest flexural strength at 6.88 N/mm$^2$ for the same mix. Their findings further show the applicability of PKS for concrete production. Saman Daneshmand (2011) studied the consequence of using PKS as aggregate on the workability and compressive strength of high-strength concrete. He found that the compressive strength of PKSC increased to 52.2 N/mm2 at 28 days.

Though studies had been carried out on the partial and full incorporation of PKS in concrete, investigations into the effect of cement grade on the properties of PKSC have not been carried out. Therefore, this research was aimed at bridging this gap by determining the mechanical, durability and microstructure properties of PKSC produced from grades of PLC. A concrete mix design for Grade 20 PKSC culminating into a 1:1:1 mix ratio for cement, sand and PKS was adopted.

## 2. MATERIALS AND METHODS

### 2.1. Materials

In this investigation, the materials used are PLC of grades 32.5N and 42.5N, fine aggregates, PKS as coarse aggregates and water. The Portland cement brands are Dangote 3X cement (42.5N) and Dangote Falcon (32.5N) meeting all the conditions of BS EN 197-1, (BS EN 197-1:2011, 2011). The initial and final setting times for grade 42.5N was 160 minutes and 315 minutes respectively, with a constituency of 32%. The grade 32.5N cement had 180 minutes and 345 minutes as initial and final setting times respectively, with a consistency of 33.6%. The fine aggregates used were river sand from Ilorin, Kwara state. The sand was medium-sized aggregate with a fine modulus of 2.73, sun-dried, sieved with a sieve of 4.75 mm and having a water absorption of 3%. The coarse aggregates are PKS as a full replacement, which was brought from Gbotako, Ondo State, Nigeria. The shells were washed in clean water and sun-dried before sieving with a sieve with an aperture size of 6.5 mm. Potable water conforming to the requirements of BS EN 1008 (BS EN 1008, 2002) was used for mixing the PKSC. A design mix for Grade 20 culminating into a mix ratio of 1:1:1 for cement, sand and PKS respectively with a water-cement ratio of 0.45 was used in this study. The resulting fresh concrete was dispensed into 100 x100 x 100 mm cubic moulds and 100 x 200 mm cylindrical moulds. 18 cube samples of 9 cubes for each grade and 18 cylinders of 9 cylinders for each grade were cast and left for 24 hours before demolding and curing for 7, 14 and 28 days with clean water conforming to BS EN 1008 (BS EN 1008, 2002).

### 2.2. Methods

#### 2.2.1. Tests on aggregates

The aggregates were tested for their coefficient of uniformity, coefficient of curvature, fineness modulus, specific gravity, and water absorption.

#### 2.2.2. Compressive strength test

The compressive strength of the PKSC specimens containing PLC of grades 32.5N and 42.5N was assessed. The tests were conducted following the procedures in BS EN12390-3 (BS EN 12390-3:2009, 2009) filling the 100 x 100 x 100 mm moulds with PKS concrete and each layer was compacted with 25 blows. After 24 hours, moulds were removed from the concrete cube samples before placing them in the curing tank containing water at ambient temperature for 28 days. Their strengths were obtained at intervals of 7 days with a computerized 1560 kN WAW-1560B compression testing machine having an accuracy of ± 1%.

#### 2.2.3. Tensile strength test

The tensile strength test was conducted on the PKSC samples with two different grades of Portland Limestone Cement (PLC). The concrete mix was poured into 100 x 200 mm cylindrical moulds. The test conformed to BS EN 12390-6 (BS EN 12390-6:2009, 2009), where a computerized 1560 kN WAW-1560B compression testing machine with an accuracy of ± 1% was used for the test.

#### 2.2.4. Water absorption capacity test

This test was conducted on the PKSC samples to determine their durability as prescribed in ASTM C1585 (ASTM C1585-20, 2020). The test involved measuring the rate of water absorbed by dry concrete cube specimens in 24 hours. Two concrete samples of different grades are cleaned and dried for 24 hours and weighed at the end of 28 curing days. Equation 1 was used in calculating the water absorption capacity of the samples.

$$\text{Water absorption capacity (\%)} = (W\_s-W\_d)/W\_d \times 100 \quad (1)$$

#### 2.2.5. Scanning electron microscope analysis

The microstructural properties of the PKSC were obtained using a Scanning Electron Microscope (SEM). The analysis was conducted as specified in ASTM C1723 (ASTM C1723-16, 2022). The SEM equipment produces high-resolution identification of elements with the aid of an energy-dispersive spectrometer. The samples used were taken from the innermost core of the crushed concrete cubes cured for 28 days and shaped into the appropriate size to fit in the specimen chamber of the SEM equipment. The samples were viewed at a magnification of 100 µm.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Materials Characterization

The properties of the sand and PKS used in this study are shown in Table 1. The specific gravity of the sand was 2.61 which met the requirement of ASTM C128 (ASTM C128-22, 2023) and the specific gravity of

PKS of 1.3 satisfies the requirement of ASTM C127 (ASTM C127-15, 2016). The water absorption of the sand is 3% which meets the requirements of BS EN 1097 (BS EN 1097-6:2000, 2000) and for the palm kernel shells, 0.67% meets the requirement of BS EN 1097 (BS EN 1097-6:2000, 2000). The 2.73 fineness modulus of sharp sand is less than the 3.10 specified by ASTM C136 (ASTM C136-06, 2015). The coefficient of uniformity of the PKS is 4.5, greater than the 4 specified by ASTMC33 (ASTM C33/C33M-18, 2023) and the sand's coefficient of uniformity is 6.6, which is greater than the 6 specified by ASTMC33 (ASTM C33/C33M-18, 2023). The coefficient of curvature of sharp sand and the shells are 1.92 and 1.85. Both values are less than 3, meeting the requirements of ASTM C33 (ASTM C33/C33M-18, 2023).

Table 1: Properties of sand and PKS

| Properties | Sand | PKS |
|---|---|---|
| Specific gravity | 2.61 | 1.3 |
| Fineness modulus | 2.73 | 0.87 |
| Coefficient of uniformity | 6.60 | 4.5 |
| Coefficient of curvature | 1.92 | 1.85 |
| Water absorption (%) | 3% | 0.67% |

### 3.2. Mechanical Properties

#### 3.2.1. Compressive strength

The compressive strengths of PKSC of the two grades of cement at 7, 14 and 28 curing days are presented in Figure 1. On day 7, the compressive strength of PKSC produced from grade 42.5N cement showed a higher early strength of 19.9 N/mm$^2$. This is higher than the 18.8 N/mm$^2$ of the PKSC from grade 32.5N cement. This trend continued till the 28th day, where PKSC from cement grade 42.5N and 32.5N had strengths of 28 N/mm$^2$ and 23 N/mm$^2$ respectively. This result expectedly showed grade PKSC from cement grade 42.5N has higher strength than PKSC from 32.5N cement grade. However, concrete produced from both grades of cement surpasses the minimum strength of 17 N/mm$^2$ applicable in residential and commercial structures (ACI CODE-318-19(22):, 2022).

#### 3.2.2. Tensile strength

The tensile strengths of the PKSC from the two grades of cement considered in this study at 7, 14 and 28 curing days are presented in Figure 2. The PKS concrete of grade 42.5N had a higher tensile strength of 2.29 N/mm$^2$ which is higher than the 2.12 N/mm$^2$ for PKS concrete produced from the cement of grade 32.5N. This trend also extended until the 28th day, where PKSC from cement grades 42.5N and 32.5N produced tensile strengths of 4 N/mm2 and 3 N/mm2 respectively. These results showed that PKSC from cement with grade 42.5N has a higher tensile strength than PKSC from cement grade 32.5N. Both grades surpassed the minimum tensile strength of 2 N/mm$^2$ specified in ASTM C330 (ASTM C330, 2006).

#### 3.2.3. Coefficient of water absorption

The results of the coefficient of water absorption are presented in Figure 3. The water absorption value of grade 32.5N is higher than grade 42.5N. Both grades do not meet the requirement of <3% specified by BS 6349 (BS6349-1:2000, 2003). This suggests that irrespective of the cement grade, PKS concrete should not be used in structures highly exposed to moisture since it will not be durable in such environments.

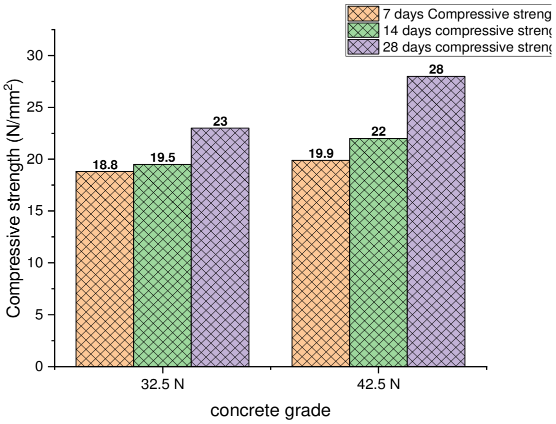


Figure 1: Compressive strength of PKS concrete

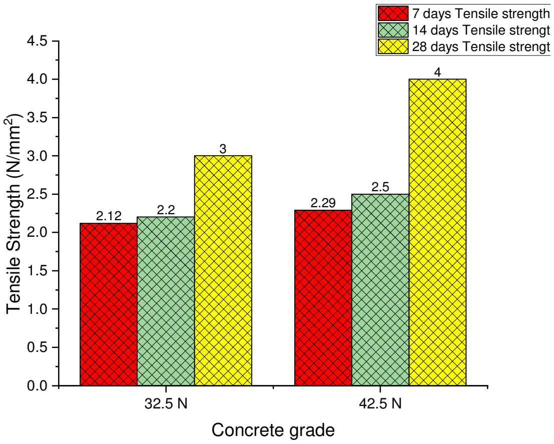


Figure 2: Tensile strength of PKS concrete

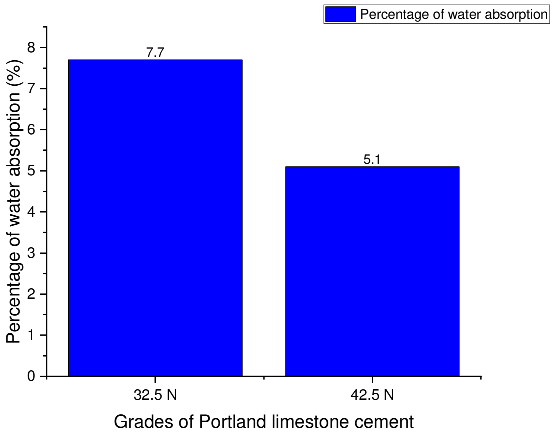
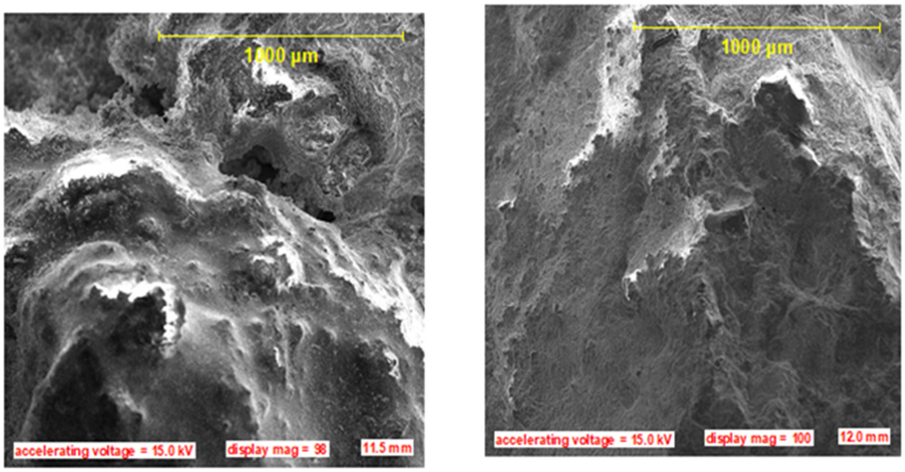


Figure 3: Water absorption of PKS concrete

### 3.3. Microstructure of Concrete Specimens

The apparent surface morphologies of the PKS concretes specimens (at 28 days of curing) examined by the SEM are presented in Figure 4. As observed from the micrographs, there are clear patterns suggesting the existence of non-uniformly distributed voids. The surface of the concrete produced from 32.5N cement grade has a weaker surface texture compared to the PKSC produced from 42.5N cement grade. In addition, the PKSC from 42.5N cement grade was seen to have a more stabilized surface in comparison with the PKSC from 32.5N cement grade. This contributed to the improved mechanical properties measured. Also, the extent of non-uniformly distributed voids which is greater in the PKSC from 32.5N cement grade contributed to its high porosity and a subsequent higher percentage of water absorption. These results are in agreement with the findings of Sumesh *et al.* (2019).



(a) (b)

Figure 4: SEM Images of PKS Concrete (a) 32.5N Cement Grade (b) 42.5N cement grade

## 4. CONCLUSION

The mechanical properties, durability and microstructure of palm kernel shell concrete were investigated in this study. From the outcomes of these investigations, the following conclusions were drawn:

a) The palm kernel shell concrete from grade 42.5N cement has higher compressive strength than that of grade 32.5N cement. However, the strength of PKSC produced from both grades of cement is suitable for structural purposes.

b) The palm kernel shell concrete from grade 42.5N cement has a greater tensile strength than the PKSC from grade 32.5N cement. However, the strength of the concrete produced from both grades of cement can be used for structural purposes.

c) The coefficient of water absorption of concrete samples from the cement of grade 42.5N is lower than the concrete samples produced from cement grade 32.5N at 28 days of curing. However, both concrete samples are not suitable for structures exposed to a high level of moisture.

The microstructure obtained from PKSC produced from 32.5N cement grade is more porous than those produced from 42.5N cement grade at 28 days of curing.

## 5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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