Malaysian Journal of Civil Engineering 30(2):269-281 (2018)

INVESTIGATION ON THE FLEXURAL STRENGTH OF PALM KERNEL SHELL CONCRETE FOR STRUCTURAL APPLICATIONS

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Abstract: An increase in the cost of conventional aggregate and the resulting environmental ecological imbalance has propelled research in the use of organic and industrial wastes as alternatives. The use of palm kernel shell concrete (PKSC) for structural applications such as beams is yet to be explored, mainly as a result of fewer research in the flexural strength of PKSC. This study investigates the flexural strength of palm kernel shell concrete (PKSC) for structural applications such as beams. Standard 150 x 150 x 150mm cube size and 100 x 100 x 500mm prisms of PKSC samples were casted at 1:1:2 mix ratio at water cement ratio of 0.5, and tested at age of 7, 14, 21 and 28 days according to BS EN 12390 – 3 (2002) and BS EN 12390 - 5 (2000). Method of batch by volume was adopted. At 28 days, the results show that the PKSC beam can support a load of 3981N with a deflection and flexural strength of 0.947mm and 2.883N/mm^2 respectively. Also, the theoretical values of flexural strength and deflection compares well with the experimental values. A power equation in the form $y = ax^n$ relating flexural strength with compressive strength produced a R^2 value of 0.94 and relative predictive error of 0.028, the latter compares well with ACI 363 (1992) minimum value of 0.026 for power equations.

Keywords: *Palm kernel shell concrete, flexural strength, compressive strength, density, beams.*

Article history:
Received 1 June 2017
Received in revised form 12 Dec 2017
Accepted 15 April 2018
Published online 30 June 2018

1.0 Introduction

One of the most essential materials in construction industry is concrete. Normal weight concrete (NWC) are produced with the use of Normal Weight Aggregates (NWA) such as gravel and crushed stones. The versatile use of concrete has made its demand and importance keep increasing daily, which has impacted on the environmental ecological balance. Also, the rising cost of the conventional aggregate has called for a concern. Alternative materials are being sought in the use of natural organic materials and industrial by product as Lightweight Aggregate (LWA) in place of Normal Weight Aggregate (NWA) in the production of Lightweight Concrete (LWC).

Lightweight concrete (LWC) has been in used in most developed countries, but it is just getting attention and relevance in developing countries. Lightweight concrete offers some advantages, which include lower density, as it reduces the dead load and low cost. Also, it has low thermal conductivity, in the form of providing thermal insulation four times greater than normal clay brick wall (Alengaram *et al*., 2008) and better fire resistance, sound absorption, superior anti-condensation properties and frost resistance. The natural raw materials for the production of LWA include expanded clay, vermiculite, shale, perlite and slate, and industrial by-product are sintered pulverized-fuel ash (fly ash), sintered slate and colliery waste, foamed or expanded blast-furnace slag (Shafigh *et al*., 2010).

Palm kernel shell is waste obtained after the removal of the edible oil from palm fruit. There are two kinds of oil in palm nut; one is palm oil, which remain in outer core of the nut and the other is palm kernel oil which is extracted from the inner core, known as palm kernel. Palm kernel is covered by a hard endocarp called palm kernel shell and is alternatively known as oil palm shell. Figure 1 shows palm kernel shell in various sizes.

Figure 1: Palm kernel shell of various sizes

Yusuf *et al*. (2016), in their study on PKSC noted that PKS is a lightweight aggregate used in the production of concrete for light traffic roads, concrete elements and grade 20 structural concrete at $1{:}1^1/_2{:}3$ and richer nominal mixes, and at water/cement ratio of 0.5. According to Alengaram *et al*. (2013), palm kernel shell is an organic material with many pores and has high water absorption within the range of 14 – 33%. They reported that the density of PKS concrete was in the range of 1703 to 1790 kg/m^3. They also noted that the workability of PKS concrete is influenced by the proportion of PKS used, water-cement ratio and sand content and that higher proportion of PKS content reduces the workability and compressive strength of PKSC.

The British Code, CP 110:1972 specified the minimum strengths of reinforced lightweight concrete and normal aggregate as 15N/mm^2 and 20N/mm^2 respectively. Oyejobi *et al*. (2012), conducted research on the suitability of palm kernel shell as lightweight aggregates and reported that palm kernel shell has a great potential to be used as replacement for coarse aggregate in concrete. They reported the density of Palm kernel shell concrete (PKSC) to be in the range of 300-1860kg/m^3 and at a nominal mix of 1:1$^1/_2$:3, the 28 - day compressive strength of PKSC is 20 N/mm^2. However, according to Yusuf and Jimoh (2014), PKS concrete produced at 1:2:4 and 1:4:8 nominal mixes fall below this specifications at the same age. It was reported that compressive and flexural strengths of PKSC improve with age of curing.

Many research works have focused on the application of PKSC as floor slabs, walk ways and foot bridges but very few works have been conducted in the use of PKSC as structural elements such as beams. To design a structural element, there is need for clear understanding of the modes of failure such as its response to loads and stress analysis of the elements. Extensive knowledge on the maximum stress in palm kernel shell concrete before it yields would provide structural designers the knowledge of ultimate limit strength of palm kernel shell concrete when used as a flexural member, to be incorporated in design.

This paper is aimed at investigating flexural strength of PKSC for structural applications. The objectives are to (i) characterize PKS as coarse aggregate in concrete production, (ii) determine the compressive and flexural strength of palm kernel concrete at 1:1:2 mix proportion and water-cement ratio of 0.5 at 7 14, 21 and 28 days, (iii) develop flexural – compressive strength relationship and (iv) determine the theoretical value of the flexural strength of PKSC and compare with the experimental results.

2.0 Materials and Method

Palm kernel shell (PKS) was sourced locally from Arandun town, Irepodun local government, Kwara State, Nigeria. PKS was washed with detergent to remove coated palm oil and mud particles which can have effect in the chemical reaction of hydration, and thoroughly rinsed with water to remove any film of detergent. It was then properly sun dried in an open space. The fine aggregate (sand) was sieved through a BS sieve size of 4.75mm in compliance with the British standard (BS 812 - 103.1:1985) so as to ensure separation of coarse aggregate such as stones that are present from the fine aggregate. The physical properties of sieve analysis, specific gravity, water absorption capacity, water content, aggregate impact value, surface area were determined for the aggregates in accordance with BS 812-103.1 (1985) and BS 812-109 (1990). Batching by volume method was adopted for the preparation of 1:1:2 mix proportion at water/cement ratio of 0.5. The workability of the freshly prepared PKSC was determined in accordance with BS 1881–102 (1983). Standard 150 x 150 x 150 mm size steel moulds were oiled and used in casting 12 samples of PKSC at 1:1:2 mix ratio at water/cement ratio of 0.5, and tested for compressive strength at 7,14,21 and 28 days according to BS EN 12390 – 3 (2002) specification. Also, 100 x 100 x 500 mm wooden prisms coated internally with formica, were used to cast 12 samples of PKSC at 1:1:2 mix ratio at water/cement ratio of 0.5 for the flexural strength test determination in conformity with BS EN 12390-5 (2000). Three PKSC cubes and three PKSC prisms were tested after 7, 14, 21 and 28 days for compressive and flexural strengths respectively, in accordance with BS EN 12390 – 3 (2002) and BS EN 12390-5 (2000). A statistical model was then proposed in predicting the flexural strength of palm kernel shell concrete from the compressive strength using Microsoft excel (2010). Statistical procedure was used in assessing the results obtained from the proposed equation. Mean, Variance, Standard error, Linear correlation coefficient (R^2), F - Test, T- Tests were then estimated for the flexural strength values obtained from the proposed equation.

3.0 Results and Discussion

3.1 Physical Properties of Aggregates

Palm kernel shell aggregate cannot be classified to have a definite shape. It can be irregular, flaky, angular or circular. The variance can be attributed to the mode of crushing the palm kernel fruit. The particle size distribution of PKS is presented in Figure 2 while Table 1 compares the physical properties of PKS with that of NWA. From Figure 2, PKS has a wide range of particles between 4.75 and 8mm and fineness modulus of 2.43. PKS aggregate satisfies the grading requirement for coarse aggregate as specified by BS 882:1992. The sand can be classified as medium grading fine aggregate, as it satisfies the BS 882:1992 requirement. The fineness modulus of the sand, falls within the range 4.75 – 40mm specified by ASTM C33 (2008) for fine aggregate. PKS apparent specific gravity was gotten to be 1.48 which falls within the specified range of 1.14 and 1.62 but lower than 2.69 specified for NWA. Hence, the quantity of concrete for a given mass of PKS will be affected. The specific gravity of sand was found to be 2.46. PKS thus, has lower specific gravity as compared with sand and cement. As a result, batch by volume will be more appropriate for the mix.

The water absorption capacity of PKS was found to be 18.7%, while that for sand was 2.25%. The water absorption of PKS is greater than that of normal weight aggregate. This is because PKS is an organic material with large presence of internal pores on its surface, which absorbs more water to increase the mass of PKS when soaked in water for 24 hours. More water contained in PKS in a saturated and surface-dry condition would have effect on the bond strength of the PKS, and the hydrated cement paste will thereby influence the strength of concrete. The water absorption capacity falls within the specified range of 14 – 33%.

PKS has a moisture content of 14%, which is in excess. This implies that saturated PKS will contribute 14% water to the mix, thereby, occupying a volume in excess of PKS. Aggregate is required to be in a basic state of saturated and surface-dry condition. Water absorption gives the water contained in aggregate in a saturated and surface-dry condition, while moisture content represents the water in excess, the sum of the water absorption and moisture content gives the total water content of a moist aggregate. The water absorption capacity of PKS is 18.7% as shown in Table 1. Therefore, the total water content of PKS is 32.7%, which is too high. This indicates that for a dry PKS aggregate, more quantity of water will be required and which needs to be put into consideration when designing the water-cement ratio so as to have a workable mix. The PKS can be soaked and leave in a saturated surface dry state before used in concrete production.

Also, PKS has AIV value of 5.63%, lower than that of normal weight aggregate value of 13.95. PKS can be classified as an exceptionally strong and hence a maximum value less than 10%. This means that PKS is a good shock absorbing material.

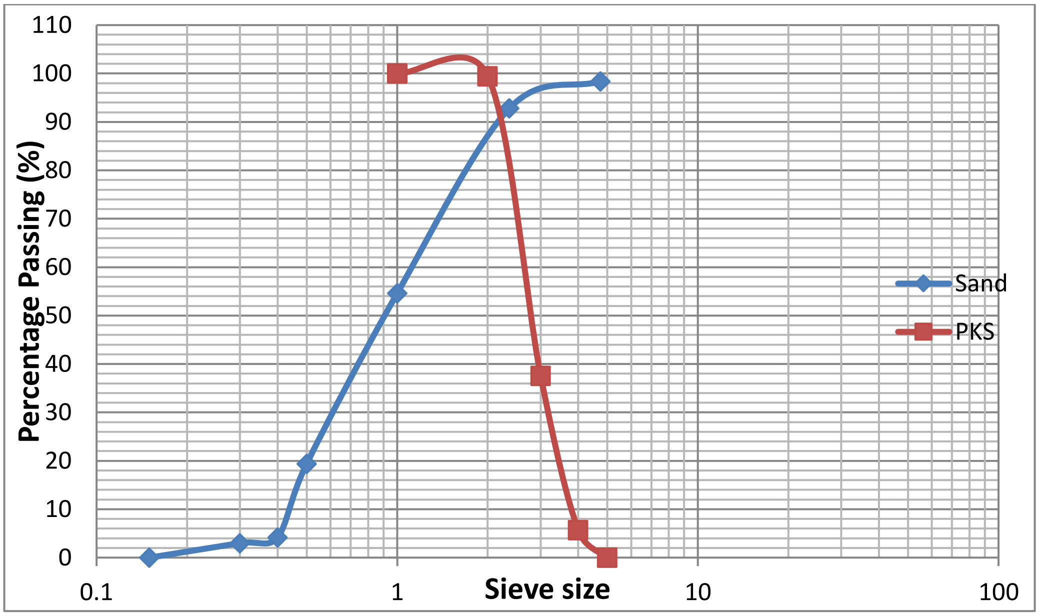

Figure 2: Sieve analysis of Sand and PKS

Table 1: Comparison of Physical properties of PKS and NWA

Physical Properties	*PKS*	*NWA*
Specific Gravity	1.48	2.61
Water Absorption 24h (%)	18.7	0.76
Moisture Content (%)	14	0.45
Aggregate Impact Value (%)	5.63	13.95

3.2 Mechanical Properties of PKSC

The results of the density test and Modulus of Elasticity (MOE) of PKSC at 7,14, 21 and 28 days age curing are presented in Table 2 while Tables 3 and 4 show the results of Compressive and Flexural strength of PKSC. From the results of Table 3, there is a gradual increase in strain, as the stress increases. Stress-strain relationship is a function of time. It can also be observed that, there is a gradual increase in the time of failure as the strain increases, which can be as a result of creep of PKSC. The batch by volume adopted is most appropriate for lightweight concrete such as PKSC, as it offers a reduction in the amount of PKS and increases the amount of fine aggregate in the concrete. Also, Modulus of elasticity depends on the density of aggregate. Like the compressive strength, the MOE of PKSC increases with age.

From Table 4, the deflection at 7 days is 0.982 and gradually reduces with increase in curing days to 0.947 at 28 days. This can be as a result of the high porosity and lower modulus of elasticity of PKS in the concrete leading to creep development. Creep increases the deflection of concrete with time. However, the flexural strength of PKSC beam increases with increase in days while its deflection decreases. At 28 days, the flexural strength value is about 18% of the compressive strength value. The results show that the PKSC beam can support a load of 3981N with a deflection and flexural strength of 0.947mm and 2.883N/mm^2.

Table 2: Density and Modulus of Elasticity of PKSC

Days	*Density (kg/m^3)*	*Modulus of Elasticity (N/mm^2)*
7	1870	410.234
14	1899 1925	451.114
21	1945	462.432
28		473.213

Table 3: Compressive strength, Strain and Time of Failure of PKSC

Days	*Compressive strength/Stress (N/mm^2)*	*Strain (%)*	*Time to Failure (secs)*
7	9.756	6.587	6.803
14	10.539	7.589	7.495
21	13.987	9.675	8.435
28	15.235	10.454	11.456

Table 4: PKSC Flexural Strength Test Result

Days	*Density (kg/m^3)*	*Force (N)*	*Deflection (mm)*	*Flexural Strength (N/mm^2)*
7	1786.300	3598.000	0.982	2.776
14	1899.400	3756.000	0.976	2.817
21	1901.200	3856.000	0.962	2.835
28	1932.101	3981.000	0.947	2.883

3.3 Relationship between Compressive strength and Flexural strength of PKSC

Figure 3 shows the relationship between compressive strength and flexural strength of PKSC. The experimental values of the flexural strength and the values obtained from the resulting model are compared in Table 5. The resulting power equation of the form $y = ax^n$ proposed to predict the flexural strength from compressive strength of PKSC produced R^2 value of 0.94. This indicates that there is a unique relationship between the compressive strength and flexural strength. The mean and variance of the experimental and the power model flexural strength values, are correspondingly 2.29 and 2.28 and 0.34 and 0.34. The experimental and power model values, therefore, compares reasonably well. The linear coefficient of correlation (R^2) is 0.94. The relative predictive error determine from equation (1) was evaluated as 0.028, and which compares reasonably well with 0.026 specified by ACI 363 (1992) for power model. However, Table 6 presents the outcome when the results obtained from equation relating flexural strength with the compressive strength was assessed using statistical procedures. Relative predictive error was determined with equation (1). The experimental and theoretical values of the flexural strength and deflections of the PKSC beams obtained from equations (2) and (3) were compared as shown in Tables 7 and 8, respectively.

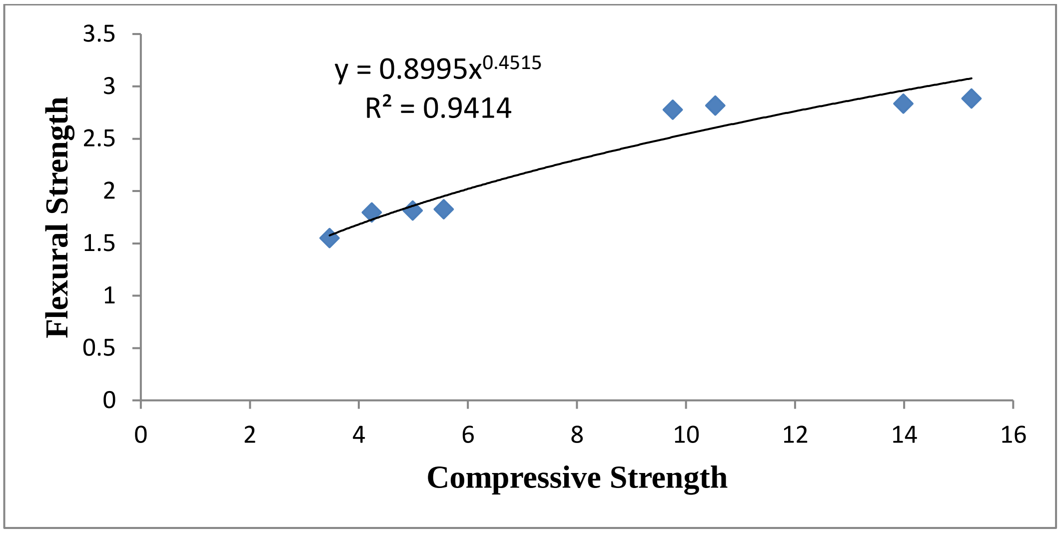

Figure 3: Relationship between Compressive and flexural strength of PKSC

Table 5: Comparison of Experimental Flexural Strength Results and Proposed Model

Experimental Compressive Strength (N/mm²)	*Flexural Strength (N/mm²)*		$\frac{fr_{exp}}{fr_{model}}$
	Experimental (fr_{exp})	*Proposed Model (fr_{model})*	
3.462	1.550	1.576	0.984
4.236	1.794	1.726	1.039
4.987	1.814	1.858	0.976
5.556	1.826	1.951	0.936
9.756	2.776	2.516	1.103
10.539	2.817	2.605	1.081
13.987	2.835	2.960	0.958
15.235	2.883	3.076	0.937

Table 6: Statistical Results

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.96038977
R Square	0.92234851
Adjusted R Square	0.909406595
Standard Error	0.174249749
Observations	8

F-Test Two-Sample for Variances		
	Variable 1	*Variable 2*
Mean	2.286875	2.2835
Variance	0.342572696	0.335156571
Observations	8	8
df	7	7
F	1.022127345	
P(F<=f) one-tail	0.488855064	
F Critical one-tail	3.78704354	

t-Test: Two-Sample Assuming Unequal Variances		
	Variable 1	*Variable 2*
Mean	2.286875	2.2835
Variance	0.342572696	0.335156571
Observations	8	8
Hypothesized Mean Difference	0	
df	14	
t Stat	0.011595531	
P(T<=t) one-tail	0.495455966	
t Critical one-tail	1.761310136	
P(T<=t) two-tail	0.990911932	
t Critical two-tail	2.144786688	

$$\text{RPE} = \frac{1}{n}\sum_{k=0}^{n}\left(\frac{f'}{f} - 1\right)^2 \quad (1)$$

where,
f ' = experimental value of flexural strength
f = predicted value of flexural strength
3.3 Experimental and Theoretical Flexural Strength and Deflection of PKSC beam

Table 7 and 8 present the comparison of the experimental and theoretical deflection and flexural strength of PKSC. The results of Tables 7 and 8 show that the theoretical value of flexural strength is about 58 to 62% of the experimental value of flexural strength. This implies that the theoretical equation can predict above 60% of the experimental results. Also, the theoretical deflection accounted for about 60 – 68% of the experimental result, implying that the theoretical deflection compares reasonably well with the experiment deflection.

$$fr_{theo} = \frac{6FL}{4bh^2} \quad (2)$$

$$\Delta_{theo} = \frac{FL^3}{48EI} \quad (3)$$

Table 7: Comparison of Experimental and Theoretical Flexural Strength of PKSC beam

Force (N)	*Experimental Flexural Strength (N/mm^2) fr_{exp}*	*Theoretical Flexural Strength (N/mm^2) fr_{theo}*
3598	2.776	1.619
3756	2.817	1.690
3856	2.835	1.735
3981	2.883	1.791

Table 8: Comparison of Experimental and Theoretical deflection of PKSC beam

Force (N)	*Experimental Deflection (mm) Δ_{exp}*	*Theoretical Deflection (mm) Δ_{theo}*	$\Delta_{exp}/\Delta_{theo}$
3598	0.982	0.585	1.679
3756	0.976	0.610	1.600
3856	0.962	0.627	1.534
3981	0.947	0.647	1.464

4.0 Conclusions

The following conclusions are drawn from the study

(i) The specific gravity and water absorption capacity of PKS are 1.48 and 18.7%, respectively. The former is lower than and the latter is higher than that of NWA, which implies that PKS is a lightweight aggregate with large pores. However, the AIV value of PKS of 1.27 makes it a better absorber of shock than NWA.
(ii) The density of Palm kernel shell concrete is in the range of 1587 – 1945 kg/m^3, which are less than maximum of 2000 kg/m^3 specified by British Standard for lightweight concrete.
(iii) The compressive and flexural strengths for batch by volume are higher than those for batch by weight, implying that batch by volume is more appropriate method of batching for lightweight aggregate concrete.
(iv) A power equation relating compressive strength and flexural strength in the form $y = ax^n$ produced R^2 value of 94% and relative predictive error of 0.028.
(v) The theoretical values of flexural and deflection of PKSC beam are in agreement with the experimental values.

5.0 Recommendations

(i) For PKSC to be successfully used for structural beams, the depth of the beam should be increased in order to reduce its deflection.
(ii) PKS should be kept in a saturated state before use in making concrete so as to enhance workability and cohesive mix.
(iii) More research work should be done on reinforced palm kernel shell concrete and palm kernel shell mix design for structural application.

6.0 Acknowledgement

This paper cannot be put together without the tremendous background information made available by various research workers, authors of excellent books and articles, which have been referred to and listed in the references. I Thank them all.

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