STRUCTURAL BEHAVIOR OF REINFORCED CONCRETE BEAMS WITH CRUSHED PALM KERNEL SHELL AS COARSE AGGREGATES

[1]*Fapohunda, Christopher, [2]Ikponmwosa, Efe, and [2]Osekita, Ifeoluwa
[1]Department of Civil Engineering, Federal University, Oye-Ekiti, Ekiti State, Nigeria.
[2]Department of Civil and Environmental Engineering, University of Lagos, Nigeria.
Tel. 08066020802

Abstract

Any waste material that is found to be appropriate for use for structural concrete will not only serve as efficient means of waste disposal but also an innovative way of converting waste to wealth. This paper presents the results of the investigation conducted to assess the structural behaviour of reinforced concrete beams made with palm kernel shell as replacement for coarse aggregates. The properties investigated are: workability, density and mechanical properties of concrete specimens containing palm kernel shell as partial replacement of coarse aggregates using a mix ratio of 1:2:4 and water cement ratio of 0.65. The percentage replacement of coarse aggregates was varied from 0% to 100% by weight at intervals of 25%. For the density and compressive strength tests, 150 x 150 ×150 mm cube specimens were used, while 2370 x 225 x 225 mm reinforced beam specimens were cast for the flexural strength test according to BS EN 12350:2000. The test specimens were moist and air cured for 28 days. The findings of the study showed that the increase in the percentage replacement of coarse aggregates with PKS in concrete resulted in: (i) reduction in the workability to 95% at 100% PKS replacement with coarse aggregates (ii) varying densities with no particular trend but fall within the normal weight concrete and lightweight concrete classifications of between 1368.89 and 2586.67 kg/m^3 (iii) reduction in the compressive strength of the specimens of up to 73.75% at 100% replacement level, and (iv) increase in the ratio of tensile to compressive strength from 0.08 - 0.15 respectively from 0 – 100% replacement levels, and (v) also the beam specimens containing PKS as partial replacement of coarse aggregates exhibited flexural failure.

Keywords: *Compressive strength, Crack pattern, Deflection, Density, Ultimate Moments.*

1.0 INTRODUCTION

Generation of wastes – industrial, agricultural, construction, etc. - is one of the things that accompany human civilization through his many-sided industrialization processes. The use of such waste materials, if found suitable, in the production of structural concrete without compromising its strength, will help in the conservation of natural resources and the protection of the environment (Ramezanianpour, 2009). This is more so in most developing countries, especially in Nigeria, where there are infrastructural deficiency and acute shortage of decent housing owing to prohibitive material cost (FEC, 2010; and Anyim, 2012). For the peculiar case of the riverine areas, especially in the Niger Delta of Nigeria (Bayelsa State and Rivers State), coarse aggregates such as coarse aggregates or gravel are not readily available due to the geological formation of the area. For any construction work carried out in these areas, coarse aggregates are being sourced from far distances. This places a great cost strain on construction budget, considering the distance from where the aggregates are to be transported before they get to the point of use. However in this area (Niger Delta) lies one major cash crop: palm tree, in which Nigeria is the 5th largest producer in the world (Figures 1 and 2).

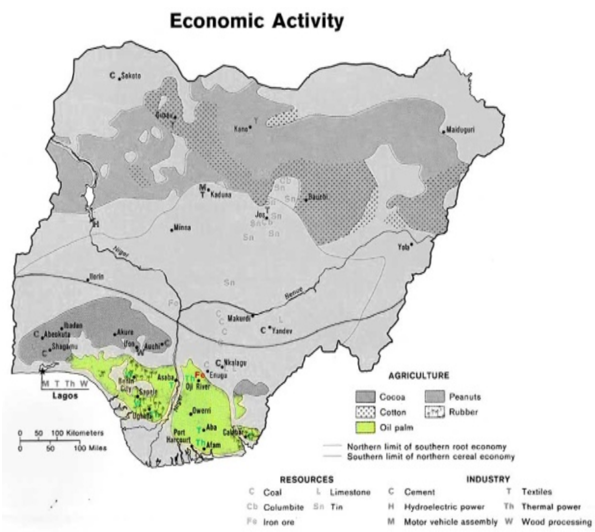

Figure 1: Map of Nigeria showing areas where Palm Oil is grown (http://www.indexmundi.com/compare)

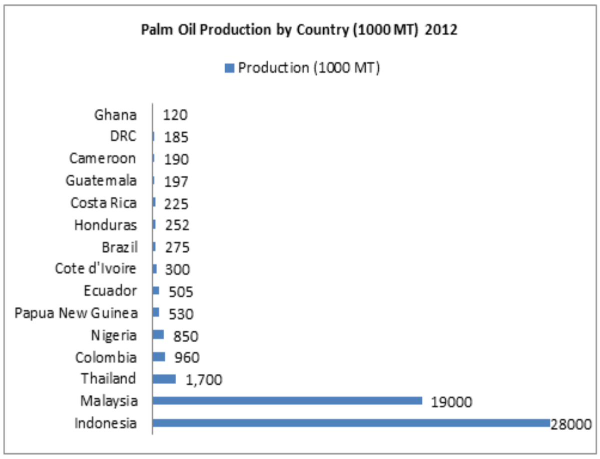

Figure 2: Palm oil productions by country (http://www.indexmundi.com/compare)

Considerable amount of wastes in form of palm kernel shell (PKS) are generated during oil extraction. About one and half million tonnes of oil palm shell (PKS) are generated as solid waste annually in Nigeria (Ndoke, 2006). Improper disposal of these wastes either through open burning or dumping has raised serious environmental issues like pollution and health hazards. However, the current trend in structural engineering materials and concrete construction is finding ways whereby wastes – industrial, agricultural, etc. - could be processed or transformed or made fit for adaptation as structural materials. The efforts of researchers in relation to palm kernel shell for structural concrete is to achieve this aim. It has however been found out that the particle sizes range of PKS is of such that it can be used as aggregates in the production of concrete (Alengaram, *et al.*, 2010a) with fly ash and silica fume as part of the binding materials, and especially as lightweight aggregate concrete. Successful attempt was also made by Alengaram, *et al.*, (2010b) to investigate the structural behavior of reinforced PKS foamed concrete beams having silica fume and fly ash as part of its binder flexural and shear capacities of the beam specimens found to be similar to the conventional concrete beams. It is thus necessary to investigate to what extent and how economical can PKS be used, either partially or wholly as aggregates in the production of structural concrete in Nigeria. The use of cheaper building materials without loss of structural performance is very crucial to the growth of developing countries (Zemke and Woods, 2009). Although some earlier works, Abdullah, (2003), Ata *et al.,* (2006), Teo *et al.,* (2006), Olutoge, (2010), Daniel, (2012), and Ikponmwosa *et al.,* (2014) on the use of PKS as replacement for coarse aggregates in concrete production but the flexural or bending characteristics of such concrete under loads have not been given due prominence. The present study therefore investigates the flexural behavior of reinforced concrete beams containing PKS as coarse aggregates.

2.0 MATERIALS AND METHODS

2.1 Materials and Concrete mix

In order to conduct this investigation, the following materials namely: cement, coarse aggregates, fine aggregates, water, and foaming agent were used.

Cement. The cement was Ordinary Portland Cement (grade 32.5) produced to satisfy the requirements in BS EN 197-1 (2000) and NIS 444 (2014).

The Coarse Aggregates. For the coarse aggregates, coarse aggregates chipping obtained from quarry with sizes ranges from 4.75mm to 20mm was used.

Fine aggregate. As fine aggregates river sand which was obtained from Ogun river basin in Nigeria was used. The sand was dried and sieved through sieve 2.36 mm and treated in accordance with BS EN 12620:2002+A1 (2008)

The Palm Kernel Shell (PKS). The PKS used as replacement of the coarse aggregates were collected from local source (Ibafo, in Ogun State, Nigeria). They were thoroughly washed with hot water and detergent so as to remove oil from its surface so as not to hinder the bonding in concrete. After this was done, the PKS was then rinsed in clean water, and dried.

Water. Portable tap water was used for mixing the concrete

For the purpose of this investigation, a mix ratio of 1: 2: 4 and a water-cement ratio of 0.65 by weight were adopted. The mix ratio was adopted bearing in mind the domain of the likely use of PKS for concreting where supervision by experience engineer for quality control and assurance might not be present. The coarse aggregates constituent of the concrete mix was replaced with PKS up to 100% at the interval of 25%. The mix without PKS served as the control.

2.2 Experimental Procedures

2.2.1 Preliminary Tests

The relevant preliminary investigations carried out on both the fine, coarse aggregates and the palm kernel shell to determine the physical properties were: specific gravity, dry density, bulk density and moisture content. Also mechanical analysis was carried out on the sand, the coarse aggregates and the palm kernel shell to determine the particle size distribution by using the sieve analysis in accordance with BS EN ISO 17892-1 (2014).

2.2.2 Workability Test

The workability of the concrete specimens were assessed through the slump tests in accordance with BS 12350: Part 2 (2000).

2.2.3 Density and Compressive Strength Test

Investigation of the density and compressive strength development were performed in accordance to BS 12350: Part 6 (2000) and

BS EN 12390-3 (2009). A total number of 60 concrete cube specimens, 150 x 150 x150 mm were used to determine the density and compressive strength tests of the concrete for this study. The cube specimens were cured in moist water and tested at 7, 14, 28, 56 and 90 days. The specimens were allowed to dry for about 2 hours before testing. The compressive strength characteristics of each cube were determined in 3 replicates per age on a 600kN Avery Denison Universal Testing Machine at a loading rate of 120kN/min and the values of the crushing load were averaged and used to evaluate the mean strength for each batch. The cubes were weighed on the Avery weighing machine prior to testing, and the values obtained were divided by the volume to compute the density of the specimens.

2.2.4 Tensile Strength Tests

Splitting tensile strength was used to determine the tensile strength of the concrete used for this study using 300 x 150 mm cylinder concrete specimens in accordance with the provision of BS 12390: Part 6 (2009) also at same curing method and age as the cubes. The splitting strengths were determined on the 600 kN Avery Denison Universal Testing machine at a loading rate of 120 kN/min until failure. The splitting tensile strength (T_s) was then calculated, equation (1) :

$$T_s = \frac{2P}{\pi l d} \qquad (1)$$

where: T_s = splitting tensile strength (N/mm^2), P = maximum applied load (in Newtons) by the testing machine, l = length of the specimen (mm), d = diameter of the specimen (mm). a total number of fifteen (15) cylinder specimens were used for this study.

2.2.5. Flexural Strength Tests

In order to assess the flexural response of the concrete mix, fifteen (15) numbers of 2370 x 225 x 225 mm reinforced concrete beam specimens were cast and cured and then tested. The beams were designed in accordance with BS 8110 (1997), the current code of practice in use in Nigeria. Details of the beam are shown in Figure 3. The beams were reinforced with minimum area of reinforcement (0.13% bh, b = breadth of beam, h = depth of beam) in accordance with BS 8110 (1997). The reinforcement for the beams consisted of two 10-mm-diameter hot-rolled, deformed bars having the yield and ultimate stresses of 488.10 N/mm^2 and 689.81 N/mm^2 respectively. For shear reinforcement, 8mm-diameter hot-rolled, deformed bars with yield and ultimate stresses of 475.42 N/mm^2 and 666.90 N/mm^2 respectively were used. The cover was 30 mm while the spacing for shear reinforcement was 125 mm to satisfy the requirement of the standard limiting the spacing for shear reinforcement to a value less than 0.75 of the effective depth (0.75 x 182 = 136.50 mm). The coarse aggregates constituent of the concrete mix was replaced with PKS at interval up to 100% at the interval of 25%.

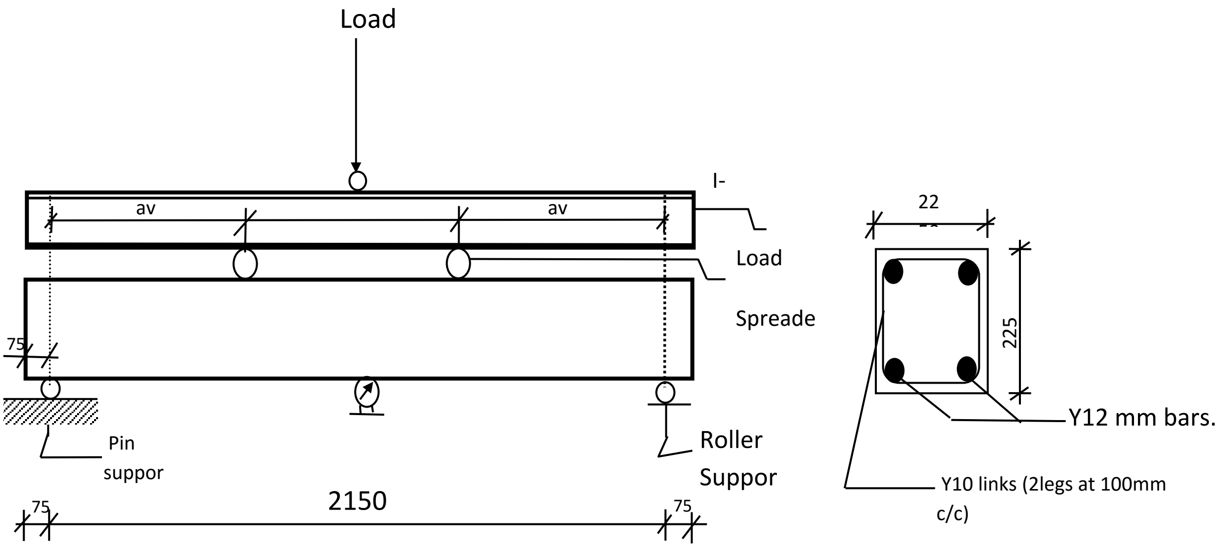

Figure 3: Details of reinforced beam element

The moulds were adequately cleaned and oiled to ensure that there were no left over debris of concrete in the moulds before casting and to facilitate easy demoulding. Adequate compaction was ensured during the process of concrete by thoroughly vibrating the poured concrete. After 24 hours, the concrete beams were demoulded and cured with damp jute bags for 28 days before being tested. The reinforced concrete beam specimens were using the third point loading arrangement (Figure 4). A dial gauge was placed under the beam at the mid-span to measure the deflection at regular intervals of loading. The load at which the first visible crack was noticed was recorded; so was the load at which failure occurred. The test was terminated when a little increase in load led to a very large deflection.

Figure 4: Experimental setup for the beam specimens

3.0 RESULTS AND DISCUSSIONS

3.1 Preliminary test on the aggregates for characterization

The results of the preliminary investigations are presented in Table 1 and the particles size plots are shown in Figure 5.

Table 1: Summary of the physical properties of the materials used

PHYSICAL PROPERTY	CEMENT	SAND	COARSE AGGREGATES	PKS
Fines Content (% Passing Through 600µm Sieve)	99.5	-	-	
Uniformity Coefficient (C_u)	-	5.91	1.95	4.06
Coefficient Of Curvature (C_c)	-	1.06	1.84	1.54
Specify Gravity	3.15	2.62	2.65	1.17
Dry Density (Kg/m^3)	-	1605.60	1742.89	599.93
Bulk Density ((Kg/m^3)	1297.79	1667.74	1749.52	642.35
Moisture Content (%)	-	3.87	0.38	7.07

It can be seen from table 1 that the observed values of weight parameters like density, specific gravity showed that PKS is lighter than the gravel used. Lightness of PKS means than more volume of PKS per unit weight replaced with gravel will be required. Table 1 also showed values of the coefficient of uniformity ($C_u = \frac{D_{60}}{D_{10}}$) and coefficient of curvature ($C_c = \frac{D_{30} \times D_{30}}{D_{60} D_{10}}$) computed from the results of the sieve analysis conducted for the PKS and coarse aggregates to respectively, 4.06 and 1.54; 1.95 and 1.84. These values gave a positive index of good quality for concrete production (Jackson and Dhir, 1990) since (state the Jackson's corresponding values). Also from Figure 5, it can be observed that the sand, coarse aggregates and palm kernel shell are well-graded particulate materials, thus all the aggregates, including the palm kernel shells are suitable for concrete production.

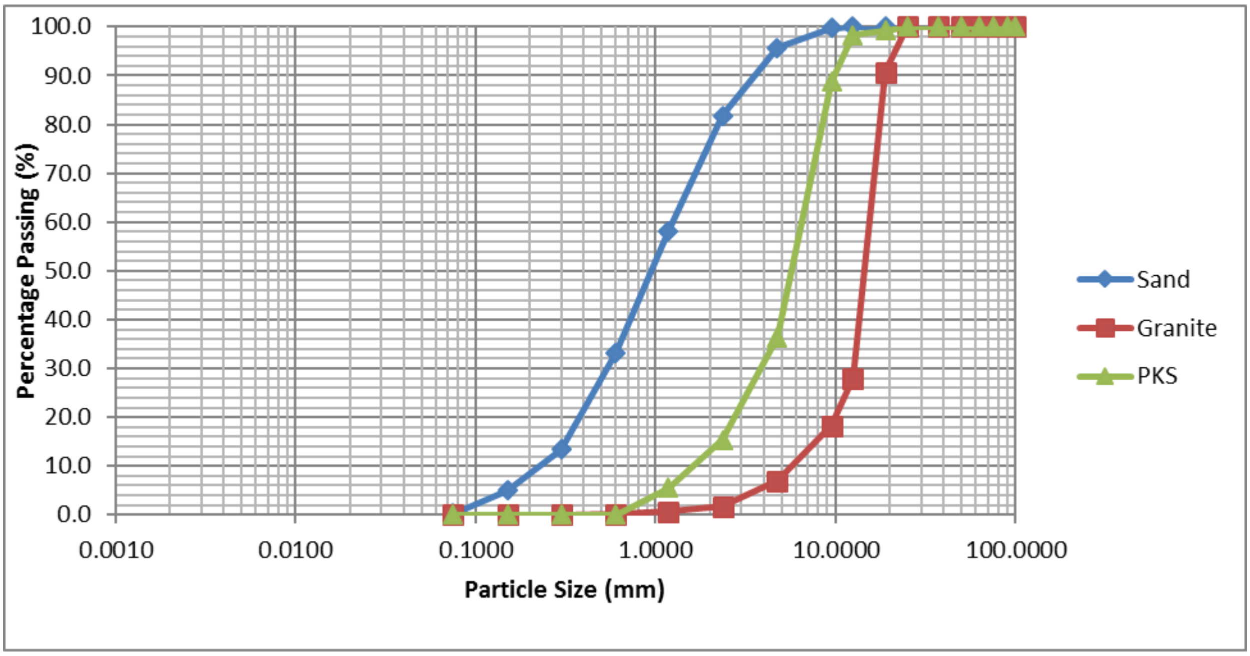

Figure 5: Particle Size Distribution Curves for Sand Coarse aggregates and PKS

3.2 Concrete Workability

Workability properties for the specimens with PKS were assessed through the slump and the compacting factor tests. The results of the workability tests through the slump test are presented in Figure 6. All the specimens except the control showed true slump. This could be attributed to the high water-cement ratio of 0.65 for the mix proportion used throughout the investigation. It can however be seen that the slump decreased as the percentage of the palm kernel shell in the mix increased. This trend was also replicated in the compacting factor test. The values of the compacting factors were: 0.95, 0.93, 0.92, 0.89, and 0.87 respectively for 0, 25, 50, 75 and 100% coarse aggregates replacement with PKS. These compacting factor values of between 0.80 and 0.90 obtained for the specimens suggested of concrete with medium to low workabilities (Neville, 2003, Gambhir, 2013).

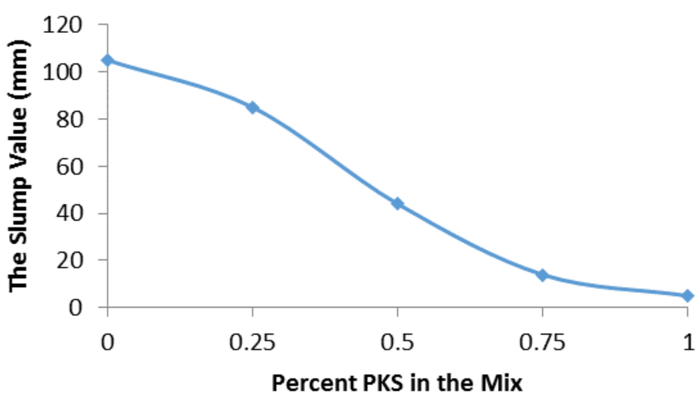

Figure 6: Slump value of fresh mix per percentage replacement

At the 100% PKS, the observed slump was very low (about 5 mm) because the mix became harsh. This reflects a less workable mix at 100% coarse aggregates replacement with PKS. This clearly indicates that to make the concrete workable at this replacement a water-reducing agent such as a 'super plasticizer' may have to be used (Mannan, 2001).

3.3 Density and Compressive Strength of PKS Concrete

The results of densities and compressive strengths of the concrete mix at all the replacement levels of PKS are presented in Table 3 and Figure 7. It can be seen that the density reduced as percentage of PKS in the mix increased. The range of densities for PKS concrete for 28 days was between 1588.15 for 100 % coarse aggregates replacement with PKS to 2587 kg/m^3 for the specimens without the PKS (that is, the control). However, the densities of mix containing up to 25% PKS can be classified as the normal weight concrete, while the densities for the mix containing PKS beyond 25% can be classified as the lightweight concrete (Falade *et al.*, 2011).

Table 3: Density and Compressive Strength of PKS Concrete at the Curing age (days)

% PKS in the Mix	Density (kg/m^3)				Compressive Strength (N/mm^2)			
	7	14	21	28	7	14	21	28
0	2477.04	2536.04	2560.99	2586.67	17.70	19.82	21.21	22.02
25	2091.85	2103.70	2118.52	2136.30	13.76	15.87	16.80	18.31
50	1816.30	1848.89	1934.81	1940.74	11.85	12.85	13.98	14.74
75	1534.81	1564.44	1573.33	1588.15	8.88	9.87	10.41	11.29
100	1368.89	1389.63	1404.44	1460.74	4.89	5.41	5.57	5.78

The results obtained from the compressive strength test are presented in Figure 7. It can be observed that the compressive strength of the specimen increased with the curing age at all the replacement levels. This is an indication of undisturbed strength-forming hydration process. However, the compressive strength decreased as the amount of palm kernel shell in the concrete increased. The reason for this reduction in compressive strength with PKS can be deducted from Table 1. From the table, the moisture content of PKS was higher than that of the coarse aggregates. The effect of this is to progressively increase the total water-cement ratio as the percent replacement of coarse aggregates with PKS in the mix increased.

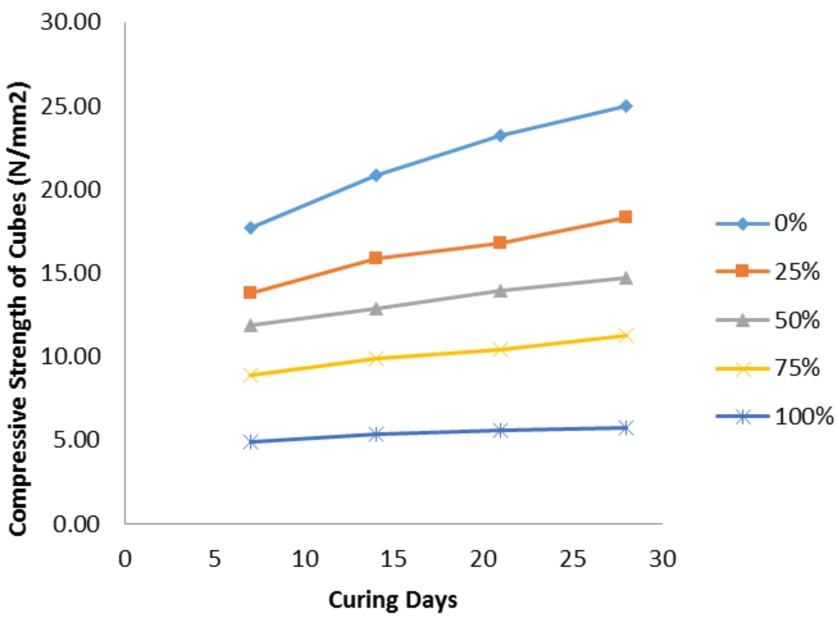

Figure 7: Effect of PKS on the compressive strength of concrete

Since high water-cement ratio results in low strength (Neville, 2003), the observed strength reduction is consistent with the prosperities of the materials. Another reason is the fact that PKS was found to be lighter than the coarse aggregate it replaced (Table 1). All other things being similar, it was found out that the compressive strength of concrete increased with density and vice versa (Espino, 1966). Thus the resultant reduction in densities as the PKS in the mix increased, subsequently led to reduction compressive strength. The compressive strength developed for 25%, 50%, 75%, and 100% coarse aggregates replacement with PKS respectively represented 18.31, 14.74, 11.29 and 5.78N/mm^2 of the control. Although, there was progressive reduction in compressive strength, the strength development at 25% replacement met the requirements for use as structural lightweight concrete (ACI, 2003), which is 17 N/mm^2 at 28 days curing age.

3.4 Tensile Strength Test

In practice, concrete is not usually expected to resist direct tension because of its low tensile strength. However, the determination of tensile strength of concrete is necessary to determine the load at which the concrete members may crack (Neville, 2003). The results of the 28-day tensile strength of the specimens at all the replacement levels are presented in Table 4.

Table 4: Splitting Strength per PKS replacement

% PKS in Mix	Tensile Strength, F_t (N/mm^2)	Compressive* Strength, F_c (N/mm^2)	Reduction in F_c (%)	Ratio of $^{Ft}/_{Fc}$
0	1.50	22.02 (18.72)	-	0.08
25	1.25	18.31 (15.56)	16.85	0.08
50	1.00	14.74 (12.53)	33.06	0.08
75	1.00	11.29 (9.60)	48.73	0.11
100	0.75	5.78 (4.91)	73.75	0.15

* Equivalent cylinder strength (Atis, 2005)

The equivalent cylinder compressive strength, derived from 0.85 compressive strength (Atis, 2005), is in parenthesis.

It can be seen from the table that the split tensile strength decreased with PKS. But from the consideration of the ratio of tensile strength to compressive strength, it can be seen that the ratio of tensile strength to compressive strength increased with PKS. However, up to 50% replacement levels, the ratio fell short of about 10% usually recorded for the normal concrete. It was not until the replacement exceeds 50% that the ratio reflects an improved tensile performance.

3.5 The Flexural Test of Reinforced Concrete Beams

The flexural issues examined in this study are: crack pattern and propagation, deflection, failure loads, failure modes and ultimate bending moments. They are discussed below.

3.5.1 Crack and Failure Pattern

The crack width and crack pattern were observed throughout the test period by measuring, marking and photographing the formations on the beams. It was observed that for the 0% - 25% PKS composition, the initial cracking occurred at about 50 -60% of the ultimate load, whereas for PKS composition of 50% and above, it was noticed that the initial cracking occurred at about 70-88% of the ultimate load. This reveals that for lower percentage of PKS composition, the first crack occurs at a smaller percentage of the ultimate load and always appears close to the mid-span of the beam. The number of cracks between loading points also increased as the PKS content increased ranging from 5 cracks for 0% PKS to about 15 cracks for 100% PKS. The cracks forming on surface of the beams were in most cases approximately vertical, suggesting failure to be in flexure. It was also noticed that wider cracks appear beneath the beams but narrower as the crack propagates into the beam. Most of the cracks appeared within the middle third of the beam distance between the points of load application and 92 to 107 mm. The summary of the failure pattern is presented in Table 6.

Table 6: Load-Deflection behaviour of reinforced concrete beams with PKS

% PKS in the Mix.	**At first Crack**		**Failure**		**Failure Modes**
	Load (kN)	Deflection (mm)	Load (k~~K~~N)	Deflection (mm)	Failure by flexure
0	65	4.74	85	8.00	Cracks visible within the middle third, flexural failure
25	55	6.25	65	8.65	Cracks visible within the middle third, flexural failure
50	40	5.45	50	11.10	Cracks visible within the middle third, but wider in width, flexural failure
75	35	5.35	45	12.00	Cracks wider and more in number within the middle third, flexural failure
100	25	5.25	35	13.20	Numerous and wider cracks within the middle third, flexural failure.

3.5.2 Deflection and Failure Loads

The deflection pattern of the beam specimens at all replacement levels are shown in Figure 8. It can be observed that the deflection increased as the percentage of coarse aggregates replaced with PKS increased.

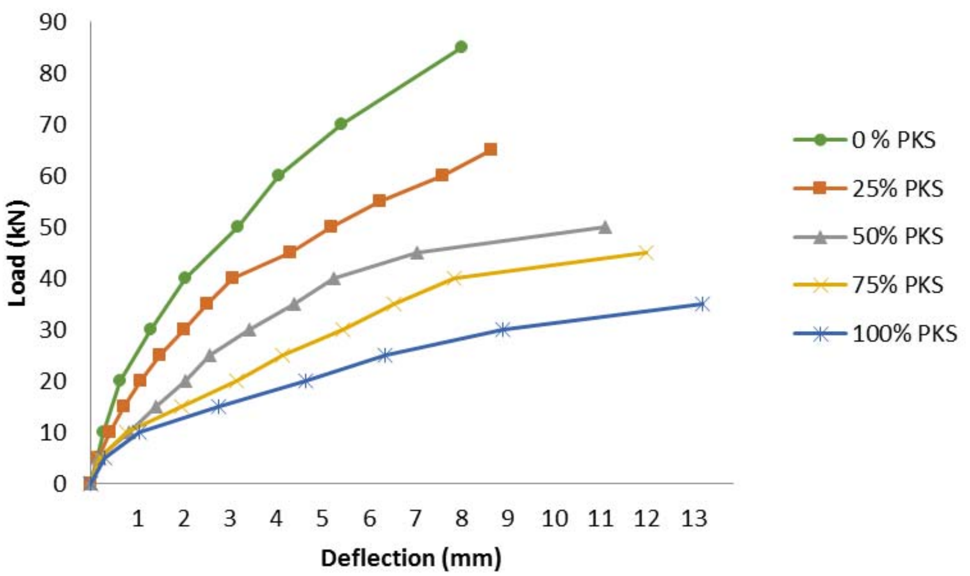

Figure 8: Load-Deflection Curve

The observed increase in deflection with PKS may be connected to the fact that PKS concrete has been found to have lower modulus of elasticity which has been attributed to its low stiffness and density (Mannan and Ganapathy, 2004 and Mahmud, *et al*., 2009), which tend to tend to produce larger deflections. Also, the failure load decreased as the percentage of replacement of coarse aggregates with PKS increased. This can be attributed to reduction in compressive strength as percent replacement of PKS in the mix increased. The slope of the load-deflection curves were observed to be fairly linear until yielding of the reinforcement took place.

3.5.3 Ultimate Bending Moments

A comparison between the experimental ultimate moments and the theoretical design moment using the rectangular stress block analysis as recommended by BS 8110, $M_T = 0.156 f_{cu} b d^2$ are shown in Table 7. The maximum experimental bending moment was calculated for the mid span of the beam; M_E = (PL/3), using the load at the first crack, shows that both theoretical and experimental bending moments were reduced as the level of coarse aggregates replacement with PKS increased, Table 7 (figures in parenthesis represent the percent reduction relative to the control). This may due to the strength-reducing influence of PKS concrete specimens (Table 4), from where the strength reduction relative to the control (0%) were 16.85%, 33.06%, 48.73% and 73.75% respectively at 25%, 50%, 75% and 100% coarse aggregate replacement with PKS. Also the experimental moment's values were higher than the theoretical values resulting in higher capacity ratios. The reason may not be unconnected to the fact that, in the determination of the theoretical bending moments using the BS 8110 equation, only the materials properties of concrete came into the equation. But in the experimental environment, both the concrete and the reinforcement were active in providing the bending resistance.

Table 7: Comparison between experimental and theoretical ultimate bending moments

% PKS in the Mix	Cracking Load (KN)	Theoretical Bending Moments (KN.m) [M_T]	Experimental Bending Moments (KN.m) [M_E]	Capacity Ratio M_E/ M_T
0	65	26.17	46.58	1.78
25	55	21.76 (16.85%)	39.60 (14.99%)	1.82
50	40	17.52 (33.05%)	28.80 (38.17%)	1.64
75	35	13.42 (48.72%)	25.20 (45.90%)	1.88
100	25	6.87 (73.75%)	10.00 (78.53%)	1.46

From the results, it can be deducted that, for PKS concrete beams, BS 8110 can be used to obtain a conservative estimate of the ultimate moment capacity.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made based on the current experimental results:

The use of PKS as partial replacement of coarse aggregates in the concrete resulted in specimens with reduced workability

The use of PKS as partial replacement of coarse aggregate resulted in concrete with densities in the range of lightweight and normal weight concrete. A replacement value of up to 25% resulted in normal weight concrete

Increasing the percentage of PKS in the mix resulted in reduced compressive strength, with the replacement value of up to 25% only producing a compressive strength that meet the requirement for use as structural lightweight concrete.

All PKS reinforced concrete beams (partial or wholly) showed the typical structural behavior in flexure and yielding of the reinforcement occurring before crushing of the compression concrete in the pure bending zone. The flexural strength of the beams reduced as the PKS content increased at the rate of 18.44% per interval of increase for theoretical bending moments and 19.63% per interval of increase for the experimental bending moments.

The design of the reinforced PKS concrete with the BS 8110 can therefore give a conservative moment resistance capacity for a singly reinforced beam.

One of the findings from this investigation is the fact that the workability reduced with increasing addition of PKS in the mix. This is significant especially as the capacity of the concrete (from such mix) to develop adequate compressive strength may have been inhibited. It is possible that some of the mixing water necessary to sustain the strength-forming hydration process may have been entrapped or absorbed by the PKS. Thus the effects of water-reducers in concrete containing PKS to make it more workable, on its structural properties is necessary and thus recommended for further investigation. Also, the results of this investigation showed lower flexural response with increase in PKS, thus its use in the present time can be limited to short-span structural member where relatively lower flexural moments are expected to be induced by the applied loads.

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