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Effect of Shear Reinforcement on Flexural Strengths of Normal Weight and Palm-Kernel Shell Reinforced Concrete Beams

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Abstract
The focus of this research is to investigate the effect of shear reinforcement on flexural capacities of reinforced Normal Weight Concrete (NWC) and Palm Kernel Shell Concrete (PKSC) beams. Ten beams were cast: five from PKSC and five from NWC. The beams were with shear reinforcement spacing of 50 mm, 100 mm, 150 mm, 200 mm and without shear reinforcement respectively. The beams were loaded with a point load at beam centre, and the results showed that the flexural capacity of the beams decreases as the spacing of the shear reinforcements increases. The ultimate loads of PKSC beams were lesser than that of NWC beams by 9.0%, 7.1%, 14.5%, 21 and 26.8% for shear reinforcement spacing of 50 mm, 100 mm, 150 mm, 200 mm and for beam without shear reinforcements respectively. The deflections of the PKSC beams were greater than that of the NWC, hence the PKSC beams had more plastic rotation capacity than the NWC beams. The study shows that reinforced concrete beams produced from 20% partial replacement of crushed aggregate by PKS have the potential of being used for structural purposes in low cost buildings.

Keywords: Palm Kernel Shell Concrete, Normal weight concrete, Palm kernel shell, Deflection, Shear reinforcement.

1. Introduction

Sustainable construction process is aimed at minimising the environmental and worker-related impacts

(CIB and UNEP-IETC, 2002). Construction is the broad process/mechanism for the realisation of human settlements and the creation of infrastructure that supports development. This includes the extraction and beneficiation of raw materials, the manufacturing of construction materials and components, and the construction project cycle from feasibility to deconstruction of built environment (CIB and UNEP-IETC, 2002). The continuous development in construction and neglecting the environmental needs lead to negative impact on the environment and its surrounding (Ling and Gunawansa, 2011; Abidin, 2010). Since the discovery of crude oil in the southern part of Nigeria in the 70s, and its accompanied petrol-dollars, a rapid development in construction sector has been observed in Nigeria, which increases the level of per capita energy consumption (Okusami, 2019). The worldwide building construction sector consumes approximately 40% of energy produced in the world (Perez-Lombard *et al*, 2008). Sustainable buildings enhance quality of life, work productivity, and create healthy environment. Therefore, sustainable construction or green buildings has been identified as the response of the building construction sector to the challenge of sustainable

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development (Hoffman and Henn, 2008). The sustainable construction commonly uses green materials, reduces energy consumption, saves water, preserves indoor air quality, and many more (Safinia *et al*, 2017).

Agricultural wastes have started becoming a major problem if not properly managed. The majority of construction and agricultural wastes, however, are considered inert and can potentially be used as construction materials (Kabir *et al*, 2016). In Nigeria, the use of the conventional materials such as sand and granite drastically reduce the natural stone deposit and this has damaging effect on the environment causing ecological imbalance (Short and kinniburgh, 1998; Alengaram *et al.,* 2008). The use of waste materials in construction contribute to conservation of natural resource and the protection of our environment (Abdullah 1996; Ndoke, 2006; Osei and Jackson, 2012). Because of its low density, PKS can be used to produce Light Weight Concrete (LWC). Light Weight Aggregate concrete is not a new invention in concrete technology; it has been used since ancient times (Shafigh *et al.*, 2010).

From literature, many researches have been conducted on the possibility of using agricultural waste ashes as partial replacement for cement in the construction industry. Researches have been carried out on partial replacement of cement with Bamboo Leaf Ash (Dwiveldi *et al.*, 2006), partial replacement of cement with Rice Husk Ash (Chungsangunsit *et al.*, 2007), partial replacement of cement with Palm Fruit Ash (Olonode, 2010), partial replacement of cement with Locust Bean Pod Ash (Adama *et al*, 2013), partial replacement of cement with Cassava Peel Ash (Salau *et al.,* 2012), partial replacement of cement with Corn Husk Ash (Adesanya and Raheem, 2009) and partial replacement of cement with Corn Cob Ash (Akinwumi and Aidomojie, 2015). Also Busari, *et al.*, (2018) carried out research on the possibility of using Bamboo Straw Ash to improve the Index Properties of Lateritic Soil. Also, some researches have been carried out on partial replacement of normal weight aggregate with Oil-Palm-Boiler Clinker (Chai, *et al.*, 2017) and partial replacement of normal weight aggregate with Oil Palm Shell (Aslam, *et al.*, 2017). Shafigh *et al* (2017, PP 04) investigated the use of Oil-palm-boiler clinker (OPBC) as coarse aggregate instead of conventional coarse aggregates to produce a greener concrete, for this purpose, normal weight coarse aggregates was substituted with dry OPBC aggregates up to 75% (by volume) in a high strength normal weight concrete.

Azunna (2019), investigated the use of palm kernel shell as a partial replacement for coarse aggregate in concrete. The results show that for a replacement of 10% and 25% of PKS gave 4.78 N/mm^2 and 4.44 N/mm^2 compressive strengths respectively. The flexural behaviour of NWC and PKSC under-reinforced concrete beams produced from 30 grade concrete were investigated by Alengaram (2008). The beams were tested under two-point loading for flexure until failure occurred. It was observed that the moment capacity of PKSC beams was higher than NWC beams by about three percent. Also, the mode of failure observed in PKSC was ductile compared to the brittle failure of NWC beams. The PKSC beams exhibited higher deflection under constant load until failure, compared to NWC beams that failed in brittle manner without warning.

Alengaram, *et al* (2011) studied the shear behaviour of PKSC beams prepared using palm kernel shell (PKS) as lightweight aggregate (LWA). PKSC beam was able to produce twice flexural and shear cracks compared to NWC beam, and tension stiffening between the tensile cracks of PKSC enhanced flexural rigidity and dowel action. Mo *et al*

(2014) studied the effect of steel fibre on the toughness characteristics such as flexural toughness, fracture parameters and compressive toughness of steel fibre oil palm shell concrete (SFOPSC). The addition of steel fibres significantly increased both the fracture energy and flexural toughness of the SFOPSC up to 16 times. The compressive toughness of SFOPSC specimens with 0.75% steel fibre was 6 times higher than the specimens without fibres, and an increase of up to 178%, 88% and 41% for splitting tensile, flexural and direct tensile strengths, respectively.

Słowik (2014) investigated the shear failure mechanism and shear capacity of reinforced concrete beams without transverse reinforcement, and found that the shear span-to-depth ratio and a beam size are important parameters which significantly affect the failure mode of the investigated beams. Acheampong *et al* (2016) investigated the influence of beam depth with varying longitudinal reinforcement without shear reinforcement. Test variables were longitudinal reinforcement ratio (ρ_w varying from 1 to 2%) and effective depth of beams (varying from 120 to 265 mm) with average compressive strength (f_{cu}) = 30.3 MPa and shear span to effective depth (a_v/d) = 2.5. All tested beams failed in shear failure modes and were influenced by the beam depth and amount of longitudinal reinforcement.

2. Methodology

The PKS which was used as aggregates were obtained from a palm kernel oil production site along Ondo Road, Akure Nigeria, while the fine aggregate was sourced from borrowed pit in Akure metropolis and the coarse aggregate sourced for the quarry along Akure-Owo road. In this investigation, the PKS were washed with detergent and flushed with portable water (warm) to remove dirt, oil film coating and other impurities which could be detrimental to the concrete.

The concrete mix ratio for this study was 1:1½:3. The PKSC beams were produced with 20% replacement of crushed granite by palm kernel shell (PKS) as coarse aggregate. The grade of concrete used for the production of the PKSC beams was 8.4 N/mm², while that of the NWC beams was 10.4 N/mm² respectively. Total number of ten beams were cast, five for PKSC beams, while the remaining five beams were NWC beams. One beam each for PKSC and NWC beams were without shear reinforcement, while the remaining four beams each for PKSC and NWC beams were with shear reinforcement spacing of 50 mm, 100 mm, 150 mm and 200 mm respectively. Table 1 shows reinforcement details for beam types while the beam sections are shown in Figs. 1-5. Two type of beams were designed for testing: beam without shear (W) and beam with shear reinforcement (S).

Table 1: Beam details

Beam ID	b (mm)	h (mm)	Length mm	Shear rein. Spacing (mm)	Top/bottom/links reinforcement.
$B1_{NCS}$	100	150	1000	50	Y10T/C, Y8L
$B2_{NCS}$	100	150	1000	100	Y10T/C, Y8L
$B3_{NCS}$	100	150	1000	150	Y10T/C, Y8L
$B4_{NCS}$	100	150	1000	200	Y10T/C, Y8L
$B5_{NCW}$	100	150	1000	W	Y10B

$B1_{PKS}$	100	150	1000	50	Y10T/C, Y8L
$B2_{PKS}$	100	150	1000	100	Y10T/C, Y8L
$B3_{PKS}$	100	150	1000	150	Y10T/C, Y8L
$B4_{PKS}$	100	150	1000	200	Y10T/C, Y8L
$B5_{PKW}$	100	150	1000	W	Y10T

Where b and h are breadth and height

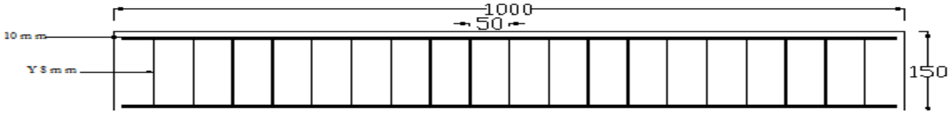

Figure 1: Details of B1NCS and B1PKS beams

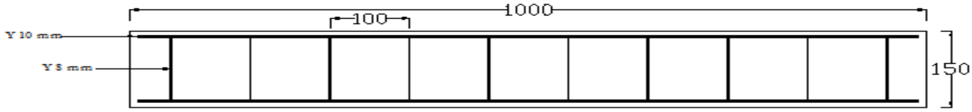

Figure 2: Details of B2NCS and B2PKS beams

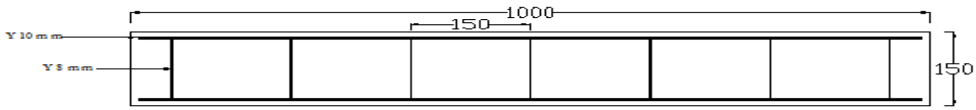

Figure 3: Details of B3NCS and B3PKS beams

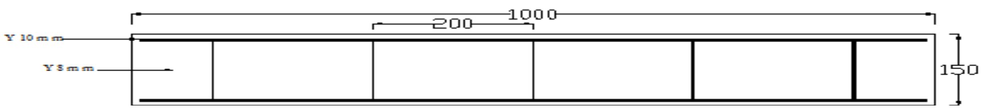

Figure 4: Details of B4NCS and B4PKS beams

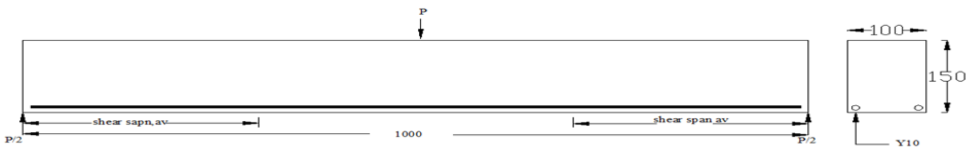

Figure 5: Details of B5NCW and B5PKW Beams

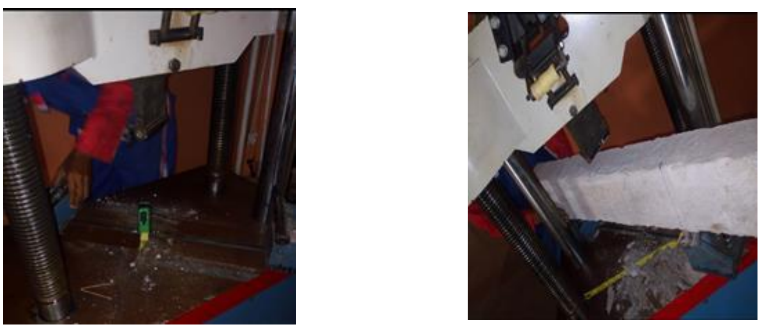
(a): The Universal Testing Machine *(b): Beam Setting-Up*

Figure 6: Experimetal set-up for all beams type.

The beams were cured by covering them with wet jute bags. The beams were subjected to a Point Load at the centre using Universal Flexural testing machine with a capacity of 300kN (Figure 6). The effective length of each beam was kept at 750mm measured from the center of each support. The flexural strength test set-up was carried out in accordance with BS EN 12390-5(2000). The application of load was done at constant rate and deflection was measured at the beam centre. The beams were loaded until the ultimate load capacity of the beam was reached. These procedure was repeated for all beams type.

3. Result and Discussion

The results of the flexural tests carried out on the beams are presented below.

3.1 Determination of concrete density

The density of the NWC was determined to be 2500 kg/m^3 while that of PKSC with 20% replacement of granite by PKS was 24100 kg/m^3 respectively. This shows that PKSC is lighter by 3.6% when compared with that NWC.

3.2 Test on beams

The beam's description, the ultimate failure load, load at first crack and flexural capacity are presented in Table 2. Figure 7 shows beam set under point load at the centre, while the bending stress can be determined by Eq. 1.

$$F_r = \frac{3FL}{2bd^2} \qquad Eq.1$$

Where; F= is the load at the fracture point, L =is the length of the support span, b= is the breadth and d =is the depth.

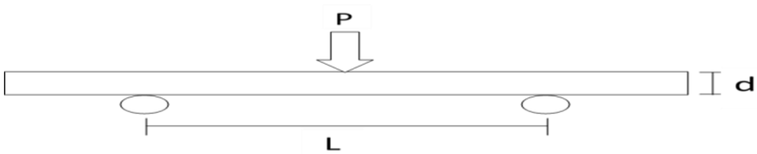

Figure 7: Typical loading of beam at the center with a point load

The results of flexural tests carried out on the beams are presented in Table 2. From Table 2, it can be seen that the ultimate loads for the PKSC beams are lower than that of the NWC beams. This may be attributed to the higher roughness of the surface of granite aggregates and thus a better aggregate interlock and better bonding of the aggregates with the cement paste.

From Table 2, the ultimate loads of the beams decreases as the spacing of the shear reinforcements increases. For beams produced from NWC, the ultimate load was 105.1 kN, 97.63 kN, 70. 46 kN, 67.5 kN and 50.16 kN for shear reinforcement spacing of 50 mm, 100 mm, 150 mm, 200 mm and for beam without shear reinforcements respectively. For beams produced from PKSC, the ultimate load was 96.37 kN, 91.17 kN, 61.56 kN, 55.79 kN and 39.57 kN for shear reinforcement spacing of 50 mm, 100 mm, 150 mm, 200 mm and for beam without shear reinforcements respectively. From

Table 2, there were decrease of ultimate loads of PKSC beams when compared with that of NWC beams by 9.1%, 7.1%, 14.5%, 21 and 26.8% for shear reinforcement spacing of 50 mm, 100 mm, 150 mm, 200 mm and for beam without shear reinforcements respectively. Therefore, the more closely the shear reinforcement spacing, the closer the ultimate load of PKSC to that of the NWC.

Figure 8, shows the effect of shear reinforcement on the flexural capacity of the two types of beams, that is, decreasing the shear reinforcement spacing, resulted in higher flexural capacity of the beams.

Table 2: Experimental load at first crack and failure load

Type	Shear Spacing	Max Force	Load at First Crack	L	b	d	Flexural capacity (F_r)(N/mm²)
	(mm)	kN	kN	(mm)	(mm)	(mm)	
NWC With Varying Shear Spacing							
$B1_{NCS}$	50	105.01	78.28	750	100	150	48.815
$B2_{NCS}$	100	97.63	70.62	750	100	150	35.23
$B3_{NCS}$	150	70.46	52.08	750	100	150	33.8
$B4_{NCS}$	200	67.6	49.15	750	100	150	25.08
$B5_{NCW}$	WS	50.16	37.31	750	100	150	10.33
PKSC With Varying Shear Spacing							
$B1_{PKS}$	50	96.37	71.76	750	100	150	45.585
$B2_{PKS}$	100	91.17	63.07	750	100	150	30.78
$B3_{PKS}$	150	61.56	49.15	750	100	150	27.895
$B4_{PKS}$	200	55.79	41.64	750	100	150	19.785
$B5_{PKW}$	WS	39.57	29.06	750	100	150	7.965

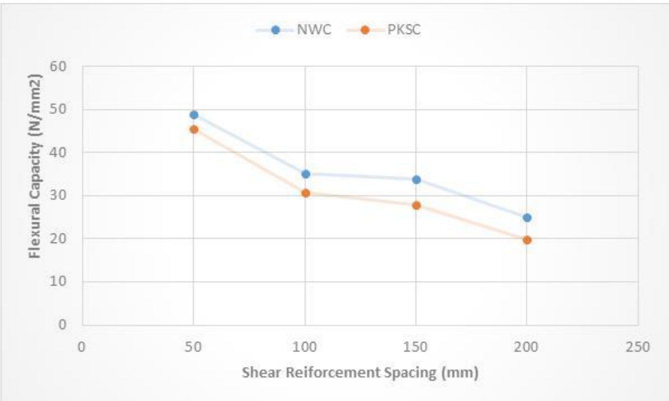

Figure 8: Flexural Capacity for PKSC and NWC beams

Using the equations of the Bristish Standard (BS 8110-1, 1997), the ultimate loads of the experimental beams were estimated. The results of the experimental and estimated ultimate loads for NWC and PKSC beams are presented in Table 3. The estimated loads for beams $B5_{NCW}$ and $B5_{PKW}$ were 22.29 kN and 16.48 kN respectively, while the experimental loads were 50.16 kN and 39.57 kN respectively. This shows that for beams without shear reinforcements, the equations of BS 8110-1 (1997) underestimated the ultimate load of reinforced concrete beams to the tune of 55.6% and 58.4% for NWC and PKSC beams respectively. Also for beams $B1_{NCS}$, $B2_{NCS}$, $B3_{NCS}$, and $B4_{NCS}$, there were understimation of the ultimate loads by 49.4%, 45.5%, 24.5% and 21.3% respectively. For beams $B1_{PKSC}$, $B2_{PKSC}$, $B3_{PKSC}$, and $B4_{PKSC}$, there were understimation of the ultimate loads by 47.6%, 44.7%, 18.0% and 9.6% respectively. It can be seen that the percentage error in the estimation of the ultimate loads increases with reduction in the shear reinforcement spacing.

Table 3: Experimental and estimated load capacity for beams

Beam ID	Experimental load	Estimated load
	P_{AUL} (kN)	**P_{EUL} (kN)**
$B1_{PKS}$	96.37	50.45
$B1_{NCS}$	105.01	53.17
$B2_{PKS}$	91.17	50.45
$B2_{NCS}$	97.63	53.17
$B3_{PKS}$	61.56	50.45
$B3_{NCS}$	70.46	53.17
$B4_{PKS}$	55.79	50.45
$B4_{NCS}$	67.6	53.17
$B5_{PKW}$	39.57	16.48
$B5_{NCW}$	50.16	22.29

3.3 Deflection Characteristics of Beams

Deflections of the experimental beams are presented in Table 4. Deflections at the ultimate loads were 15.9 mm, 13.5 mm, 11.5 mm, 7.5 mm, and 6.0 mm for PKSC beams at loads of 96.37 kN, 91.17 kN, 61.56 kN, 55.79 kN, 39.57 kN and 15.93 kN respectively, while the deflections at the ultimate loads were 14.5 mm, 13 mm, 10 mm, 6 mm, and 5.0 mm for NWC beams at the ultimate loads of 105.01 kN, 97.63 kN, 70.46 kN, 67.6 kN, 50.16 kN and 29.66 kN respectively. The deflections of the PKSC were greater than that of the NWC even at lesser ultimate loads, hence the PKSC beams had more plastic rotation capacity than the NWC beams.

Table 4: Deflection of PKSC and NWC Beams

Shear Spacing(mm)	Load(kN)		Deflection(mm)	
	PKSC	NWC	PKSC	NWC
$B1_{PKS}$ /$B1_{NCS}$	96.37	105.01	15.9	14.5
$B2_{PKS}$ /$B2_{NCS}$	91.17	97.63	13.5	13
$B3_{PKS}$ /$B3_{NCS}$	67.6	70.46	11.5	10
$B4_{PKS}$ /$B4_{NCS}$	55.79	61.56	7.5	6.0
$B5_{PKW}$ /$B5_{NCW}$	39.57	50.16	6.0	5.0
$B6_{PKP}$ /$B6_{NCP}$	12.06	20.66	3.1	3

From Figure 9, deflections increase with increase in the ultimate loads. Similarly increase in load capacity occurred as a result of decreased shear reinforcement spacing, therefore decreasing the shear reinforcement spacing for both type of beams also lead to increase in deflections. Figure 10 shows the effect of shear reinforcement spacing on the deflections of both NWC and PKSC beams.

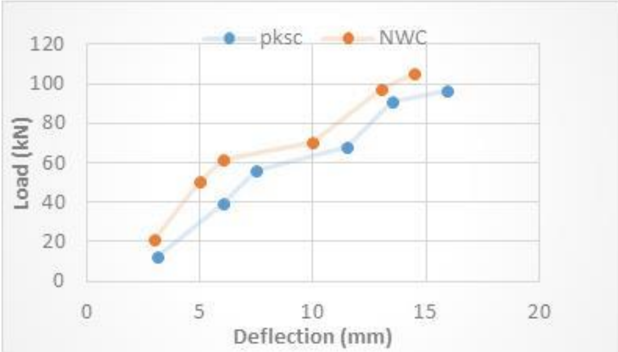

Figure 9: Load-Deflection graph for PKSC and NWC Beam

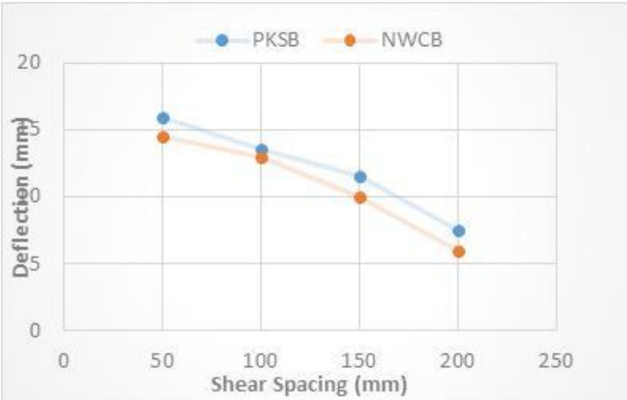

Figure 10: Effect of shear link spacing on deflection of PKSC and NWC Beams.

4. Conclusion

From the results and discussions above, the following conclusions can be made:

1. PKSC beams produced by 20% replacement of NWA with PKS was 3.6% lighter than NWC beams.
2. PKSC beams behaved similarly to that of the NWC beams.
3. Decreasing the shear reinforcement spacing in both types of beams resulted in the increase in the flexural/load bearing capacity of the beams.
4. Depending on the spacing of the shear reinforcements, decrease of ultimate loads of PKSC beams when compared with that of NWC beams was between 9.1% and 26.8%.
5. With proper choice of shear reinforcement, PKSC beams can be used for structural purposes in low cost housing units.

5. Recommendation for Future Research

Research should be conducted on the effects of cement grade, concrete grade and percentage area of tension reinforcements on the ultimate load of PKS reinforced concrete beams.

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