

Comparative Strength Analysis of Normal Weight and Palm Kernel Shell Reinforced Concrete Beams for Sustainable Development

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Abstract

Reduction in self-weight of Palm Kernel Shell Concrete (PKSC) over Normal Weight Concrete (NWC), reduces the amount of cement needed for construction, this is accompanied by reduction in CO₂ emission associated with the production of cement: This will have reduction effect on the greenhouse, a major cause of climate change. This study carries out the comparative analysis of the strength characteristics of NWC and PKSC beams produced from four concrete mixes of 0%, 20%, 40% and 60% partial replacement of crushed granite by palm kernel shell (PKS). From each concrete mix, two beams were cast: one with shear reinforcement of 200mm spacing, while the other one without shear reinforcement, making total of eight beams. From the study, the PKS concrete beams were 3.6%, 11.24% and 15.64% lighter than the NWC beams for 20%, 40% and 60% partial PKS replacement. The study shows that reinforced concrete beams produced from 20% and 40% 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, Strength characteristic, Cement.

1. Introduction

The use of conventional natural materials, 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). Therefore the need to explore/investigate other forms of coarse aggregate to reduce the construction cost and preserve our natural deposits for sustainable development. Also, reduction in self-weight of Light Weight Concrete (LWC) over Normal Weight Concrete (NWC) translates to reduction in the sizes of structural members of reinforced concrete structures, which in turn, reduces the amount of cement needed for construction, this is accompanied by reduction in CO₂ emission associated with the production of cement: This have reduction effect on the greenhouse, a major cause of climate change.

Presently, agricultural wastes constitute major waste management and pollution problem, therefore the use of agricultural and industrial wastes in construction will help to reduce pollution. In his work, Abdullah, concluded that agricultural waste have advantages over conventional materials in low cost construction (1996). It was also noted that the use of waste materials in construction contribute to conservation of natural resource and the protection of our environment (Osei and Jackson, 2012). The palm

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kernel shell (PKS) is one of such agricultural produce that has caused management problem in some parts of the world.

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 and Jimoh, 2011), 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; Yinusa and Jimoh, 2014). 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).

The hard nature of palm kernel shell (PKS) has given it a great potential to be used as coarse aggregate in concrete, especially in the production of lightweight concrete. From literatures PKS when properly processed have shown to be effective as a construction material, however in the construction industry in Nigeria, the use of palm kernel shell as coarse aggregate are not common, which is due to lack of information on the potential of PKS to be used as coarse aggregate (Ndoke, 2006).

Light Weight Aggregate concrete is not a new invention in concrete technology; it has been used since ancient times (Shafigh *et al.*, 2012). The use of palm kernel shell as replacement for coarse aggregate can be termed light Weight Concreting (LWC) if the density of concrete produced from such aggregates falls between 1200 kg/m³ and 2000 kg/m³, while the use of the conventional aggregate can be termed Normal weight Concreting (NWC), since the density of the concrete produced from them is the range of 2000 kg/m³ to 2500 kg (Newman and Owen, 2003). The light weight concreting has great advantage of the reduction in the dead weight of a building. For small building units, the savings thus achieved may not be significant. But for multiple building units (as the case in an estate), any saving due to reduction in structural member sizes multiplied by the number of building units can represent a substantial saving in total construction cost of the building units. Hence, the present study therefore investigates the strength characteristic of slender reinforced concrete beams, with shear reinforcement spacing of 200mm, produced from 20%, 40% and 60% partial replacement of Normal Weight Aggregate (NWA) with Palm Kernel Shell Aggregate (PKSA) for structural application in low cost housing construction.

2. Methodology

The PKS which was used for this study was obtained from a palm kernel oil production site along Ondo Road, Akure Nigeria. 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 maximum size of the PKS

was 19mm, while that of the coarse aggregate (crushed granite) was 12mm. The maximum size of the sand used was 5mm.

The concrete mix ratio for this study was 1:1½:3. Concrete mixes were cast with varying percentages of PKS for the partial replacement of crushed granite at 0%, 20%, 40%, 60%, 80% and 100% respectively. The compressive test was carried out according to BS EN 12390-3 (2009), while the slump test was carried out according to BS EN 12350-2 (2009), to determine the workability of concrete. Concrete density was determined according to BS EN 12390-7 (2000). NWC (control cubes) and PKSC (partially replaced cubes) of 150x150x150mm, were then water-cured and its characteristic strengths determined at 7th, 14th, 21st and 28th days respectively.

2.1 Experimental Beam Details

Table 1 shows the reinforcement details for the beam types, while cross section of the beams is shown in Figures 1 and 2. Two type of beams were designed for testing: beam without shear reinforcement (W) and beam with shear reinforcement (S).

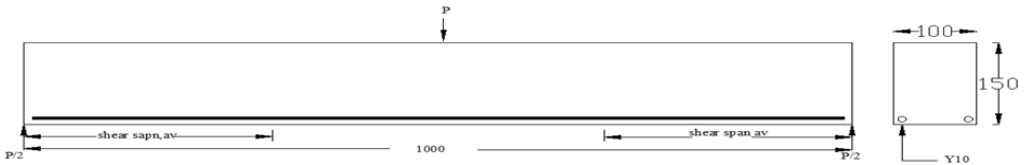


Figure 1: Detail of Beams B1NCW, B3PKW, B5PKW and B7PKW

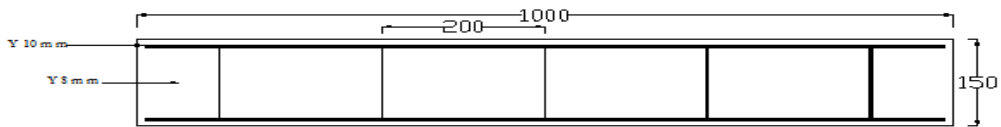


Figure 2: Detail of Beams B2NCW, B4PKW, B6PKW and B8PKW

Table 1: Beams detail

Beam ID	b (mm)	h (mm)	Length	Shear Reinf. Spacing (mm)	Bottom/top/links Reinforcement
Beam with 0% PKSA replacement of NWA					
B1 _{NCW}	100	150	100	-	Y10 B
B2 _{NCS}	100	150	100	200	Y10B/T, Y8L
Beam with 20% PKSA replacement of NWA					
B3 _{PKW}	100	150	100	-	Y10 B
B4 _{PKS}	100	150	100	200	Y10B/T, Y8L
Beam with 40% PKSA replacement of NWA					
B5 _{PKW}	100	150	100	-	Y10 B
B6 _{PKS}	100	150	100	200	Y10B/T, Y8L
Beam with 60% PKSA replacement of NWA					
B7 _{PKW}	100	150	100	-	Y10 B
B8 _{PKS}	100	150	100	200	Y10B/T, Y8L

Where:

b and h are breadth and height respectively.

B1_{N_{CW}} - beam from NWC without shear reinforcements.

B2_{N_{CW}} – beam from NWC with shear reinforcements at 200mm spacing.

B3_{PKW}, B5_{PKW} and B72_{PKW} are beams from PKS without shear reinforcements.

B4_{PKS}, B6_{PKS} and B82_{PKS} are beams from PKS with shear reinforcements at 200mm spacing.

2.2 Test procedure

The beams were subjected to flexural tests, using Flexural Testing Machine with 300 kN capacity. The beams were subjected to a point load at beams centre, with effective length of 750 mm. The flexural tests were carried out in accordance with BS EN 12390-5 (2009). The beams were loaded until collapse occurred.

3. Result and Discussion

The results of the tests carried out on aggregate, cement, fresh and hardened concrete is presented below.

3.1 Aggregate

From Figure 3, the coefficients of uniformity (C_u) of sand was determined to be 1.4 and while the coefficient of gradation (C_c) was determine to be 2.93. Since C_u is less than 4 and C_c is greater than 1 but less than 3, the fine aggregate is said to be well-graded. Table 2 gives the physical properties of the materials used in concrete.

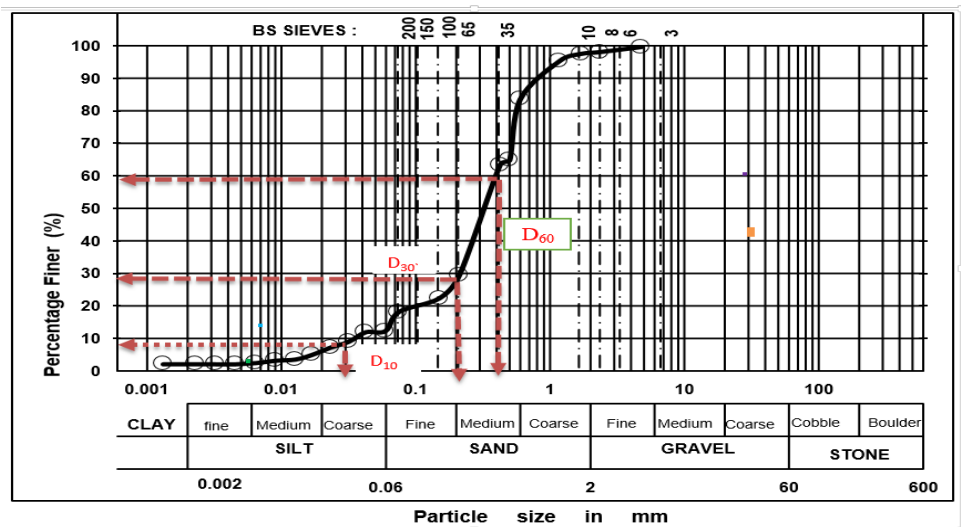


Figure 3: Particle Size Distribution of Fine Aggregate.

3.2 Cement

The cement type used in this study was Ordinary Portland cement of grade 32.5 conforming to BS EN 197-1 (2000). Some physical properties of the cement used are presented in Table 3.

Table 2: The experimental physical properties of aggregate

Properties	PKS	Granite	Sand
Maximum aggregate size(mm)	19	12	5
Shell thickness, mm	1-5.9	0	
Specific gravity , saturated surface dry	1.33	2.65	2.60
Aggregate impact value (AIV)	7.6	22.9	
Aggregate crushing value (ACV)	16.8	30.1	
24hour water absorption	18	0.68	
Moisture content	9.7	0	7%
uniformity coefficient C_u			1.4
coefficient of gradation C_c			2.93

Table 3: Test on Portland cement

Test	Average
Fineness Test (%)	2.2
Soundness (mm)	0.25
Initial Setting Time	30min
Final Setting Time	9hr18min

3.3 Reinforcement properties

The result of the tests carried out on the steel reinforcement used in this study is presented in Table 4.

Table 4: Strength of tested reinforcement

Reinforcement Bars Size (mm)	Yield Stress (N/mm ²)		
	Bar 1	Bar 2	Average
Y8	460	480	470
Y10	500	460	480

3.4 Tests on fresh concrete

The results of the slump test, indicating the workability of the concrete at 0%, 20%, 40%, 60%, 80%, and 100% replacement of NWA with PKSA are presented in Table 5.

Table 5. Concrete mix proportion for PKS replacement with coarse aggregate.

PR (%)	Cement kg	w/c	PKS Vol.	NWA kg	FN (kg)	SV (mm)	Type of slump	Degree of workability	Compaction factor
0	331	0.6	0	800	552	66	TS	medium	0.91
20%	331	0.6	160	640	552	60	TS	medium	0.89
40%	331	0.6	320	480	552	55	TS	medium	0.87
60%	331	0.6	480	320	552	50	TS	medium	0.83
80%	331	0.6	640	160	552	48	TS	low	0.79
100%	331	0.6	800	0	552	39	TS	low	0.77

From Table 5 and Figure 4, all the Specimens showed true slump, this could be as a result of the high water-cement ratio of 0.6 used for the mix proportion all through the research. It can however be seen (Figure 4), that the slump decreased as the percentage of the PKS in the mix increased as a result of high water absorption by the PKS. This trend of reduction was also repeated in the compacting factor test (Table 5).

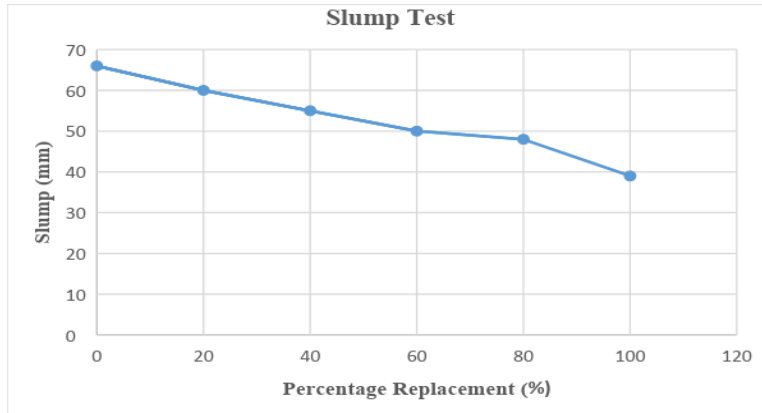


Figure 4: Slump test against percentage replacement

The compacting factor values between 0.80 and 0.90 obtained for the specimens suggested a concrete with medium to low workability (Neville, 1981). From Table 5, it can also be seen that 80% and 100% replacement showed low degree of workability, this occurred because the mix became harsh as a result of a high water absorption rate of the PKSA.

3.5 Tests on hardened concrete

3.5.1 Density

The relationship between densities of the NWC and the PKSC are presented in Table 6. From Table 6, based on the concrete density, concrete with 0%, 20%, 40% and 60% of partial replacement of NWA with PKSA can be classified NWC, while concrete with 80% and full replacement of NWA with PKSA can be classified as LWC.

Table 6: Experimental Air dry density of PKSC/NWC.

Type of concrete	Percentage of PKSA %	Air dry density of various mix Kg/m ³			
		7 days	14days	21 days	28 days
NWC	0	2083	2300	2360	2500
PKSC	20	1993	2071	2341	2410
PKSC	40	1978	2056	2210	2219
PKSC	60	1847	2038	2080	2109
PKSC	80	1782	1797	1799	1830
PKSC	100	1432	1438	1524	1781

3.5.2 Compressive Strength

The variation of characteristic strengths of concrete with curing age for concrete cubes with percentage replacement of NWA with PKSA at 0%, 20%, 40%, 60%, 80% and 100% respectively is shown in Figure 5. It can be observed that the characteristic strengths of the specimens increased with the curing age at all the percentage replacement of NWA with PKSA. This indicated an undisturbed strength-forming hydration process. However, the characteristic strength decreased as the amount of palm kernel shell in the concrete increases. The result of characteristic strength of the concrete cubes with age of curing is presented in Table 7.

Table 7: Summary of Compressive Strength Test Result with Age of curing

Percentage replacement	7day	14day	21day	28day
			(N/mm ²)	
0%	7.03	8.05	9.01	10.42
20%	6.05	6.99	7.9	8.39
40%	6.0	6.74	7.49	7.44
60%	5.56	6.88	7.02	7.12
80%	5.34	5.83	5.97	5.84
100%	4.16	4.49	4.47	5.00

From Figure 5, it can be seen that the characteristic strength of the control cubes were higher than the characteristic strengths of the concrete cubes with partial replacement of NWA with PKSA. The significant difference between the two types of concrete showed the effect of percentage replacement. The control cubes of NWC were seen to be higher than the PKSC by 19.48%, 28.6%, 31.7%, 43.95%, and 52.02% for 20%, 40%, 60%, 80% and 100% replacement at 28days of curing respectively. The effect of clay content present in the fine aggregate contributed to the reduced strength of the two types of concrete as both types of concrete did not meet the required specified standard. From the sieve analysis carried out, the percentage of clay in the fine aggregate was 18.26%, this was higher than the maximum percentage of 4% by weight of sand required by BS 882 to achieve better strength.

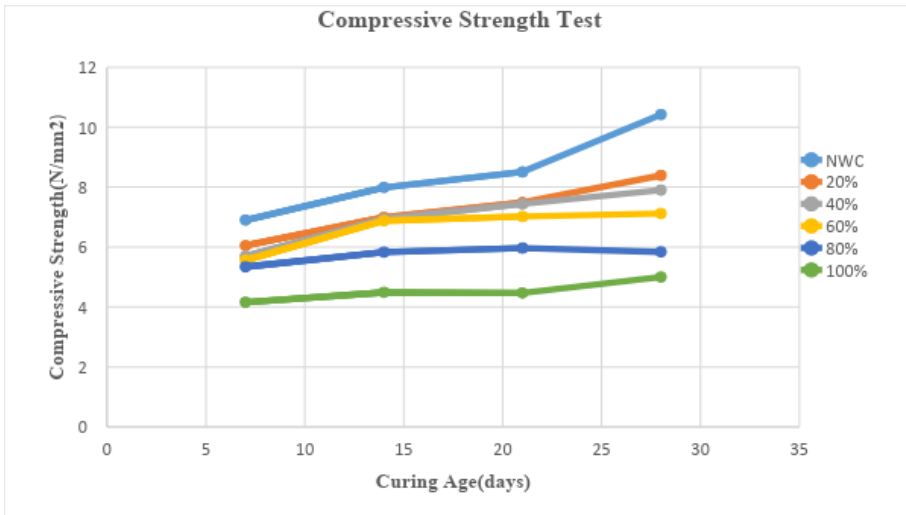


Figure 5: Comparison between the compressive strength of PKSC and NWC

3.6 Test on beams

Table 8, presents the results of flexural tests carried out the beams loaded with point load at the centre. The bending stress is given by Eq. 1.

$$F_r = \frac{3FL}{2bd^2} \tag{Eq. (1)}$$

Where; F = is the ultimate load, L = is the beam span, b = is the breadth and d = is the depth.

From Figure 6, the ultimate loads of the NWC beams are higher than that of the PKSC 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 than that of PKSA.

Table 8: Experimental load at first crack and failure load

Type	Shear Spacing (mm)	Max Force kN	Load at First Crack kN	L (mm)	b (mm)	d (mm)	Flexural capacity(Fr) (N/mm ²)
Beam with 0% PKSA replacement of NWA							
B1 _{NCW}		50.16	37.31	750	100	150	35.00
B2 _{NCS}	200	67.60	49.15	750	100	150	47.15
Beam with 20% PKSA replacement of NWA							
B3 _{PKW}	-	39.57	29.06	750	100	150	27.60
B4 _{PKS}	200	55.79	41.64	750	100	150	38.90
Beam with 40% PKSA replacement of NWA							
B5 _{PKW}	-	28.59	24.5	750	100	150	19.94
B6 _{PKS}	200	43.35	33.65	750	100	150	30.24
Beam with 60% PKSA replacement of NWA							
B7 _{PKW}	-	18.70	12.00	750	100	150	13.04
B8 _{PKS}	200	28.55	20.64	750	100	150	19.91

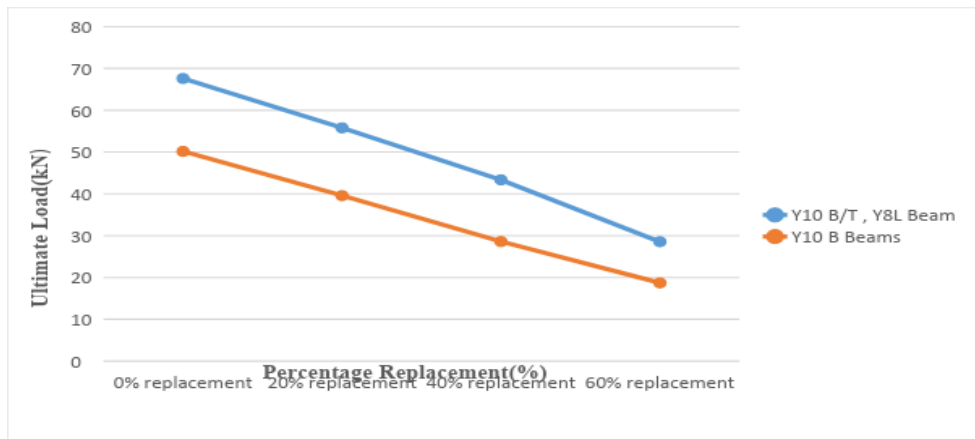


Figure 6: Effect of percentage increase of PKSA with ultimate load of beams

Table 9: Experimental and estimated load capacity for beams

Beam ID	Experimental Load	Compressive Strength (f_{cu})	Estimated Load (BS code 8110)
	P_{AUL} (kN)	(N/mm ²)	P_{EUL} (kN)
B1 _{NCW}	50.16	10.42	22.29
B2 _{NCS}	67.60	10.42	53.17
B3 _{PKW}	39.57	8.39	16.48
B4 _{PKS}	55.79	8.39	50.45
B5 _{PKW}	28.59	7.44	12.85
B6 _{PKS}	43.35	7.44	49.17
B7 _{PKW}	18.70	7.12	11.17
B8 _{PKS}	28.55	7.12	48.75

From Table 9, the experimental load for B2_{NCS} beam is 21% higher than the estimated load. While the experimental load at 20% replacement for B4_{PKS} beam was 9.57% higher than the estimated load. However the experimental load for B6_{PKS} and B8_{PKS} beams were 11.8% and 41.4% lower than the estimated load.

For beams without shear reinforcement, the B1_{NCW} beam was 125% higher than the estimated load. While for the B3_{PKW}, B5_{PKW}, and B7_{PKW} the experimental load was 140%, 122.5% and 67.4% higher than the estimated load respectively.

3.7 Deflection Characteristics of Beams

Table 10 presents the deflection of the beams. From Table 10, the beam deflection depends on the ultimate load, composition of the aggregates and the shear reinforcement.

Table 10: Deflection of PKSC and NWC Beams

Beams ID	Load (kN)	Deflection (mm)
B1 _{NCW}	50.16	6.0
B2 _{NCS}	67.60	7.0
B3 _{PKW}	39.57	5.0
B4 _{PKS}	55.79	6.5
B5 _{PKW}	28.59	4.5
B6 _{PKS}	43.35	6.0
B7 _{PKW}	18.70	2.8
B8 _{PKS}	28.55	4.2

From Figure 7, it can be seen that the higher the percentage of PKSA in the reinforced concrete beam, lower the ultimate load, and hence the deflection.

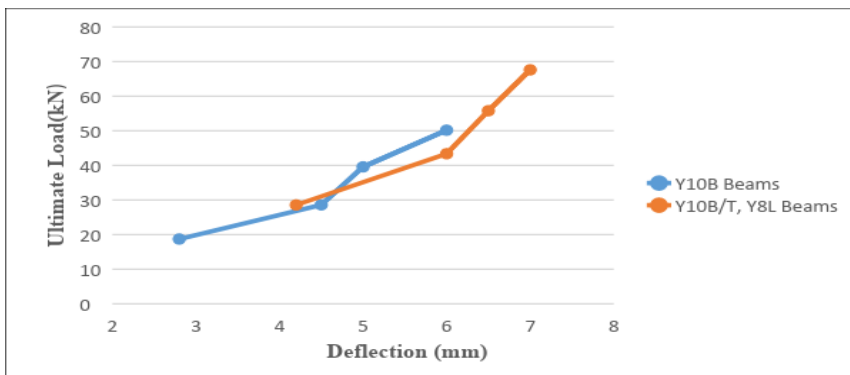


Figure 7: Load-Deflection graph for PKSC and NWC Beams

3.8 Influence of percentage replacement of PKSA with NWCA and shear reinforcement

From figures 8, B1_{NCW}, B3_{PKW}, B5_{PKW} and B7_{PKW} are beams without shear reinforcement, with 0%, 20%, 40% and 60% partial replacement of NWA with PKSA respectively. The ultimate loads are, 50.16 kN, 39.57 kN, 28.59 kN and 18.70 kN

respectively. These results show that there is reduction in the ultimate load by 21.11%, 43.00%, and 62.72% for beams B3_{PKW}, B5_{PKW} and B7_{PKW}, when compared with B1_{NCW}, with 0% PKSA.

Also from figures 9, B21_{NCS}, B4_{PKS}, B6_{PKS} and B8_{PKS} are beams with shear reinforcement, with 0%, 20%, 40% and 60% partial replacement of NWA with PKSA respectively. The ultimate loads are, 67.60 kN, 55.79 kN, 43.35 kN and 28.55 kN respectively. These results show that there is reduction in the ultimate load by 17.47%, 35.87%, and 57.77% for beams B4_{PKS}, B6_{PKS} and B8_{PKS}, when compared with B2_{NCS}, with 0% PKSA.

From the above, it can be seen that there is general increase in ultimate load with provision of shear reinforcement at 200mm spacing. For example, there is 34.77% increase of ultimate load of beam B2_{NCS} over the ultimate of B1_{NCW}, by the provision of shear reinforcement at 200mm spacing. Also due to provision of shear reinforcement at 200mm spacing, there is 41.00%, 51.63% and 52.67% for beams B4_{PKS} over B3_{PKW}, B6_{PKS} over B5_{PKW} and B8_{PKS} over B7_{PKW} respectively.

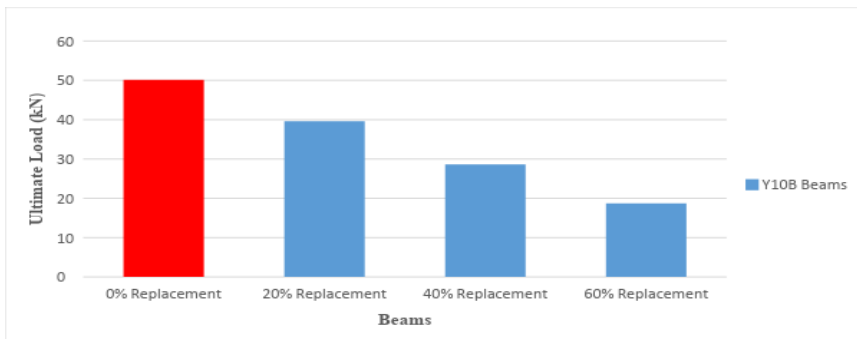


Figure 8: Ultimate loads decrease in beams (without shear) with increasing % content of PKSA.

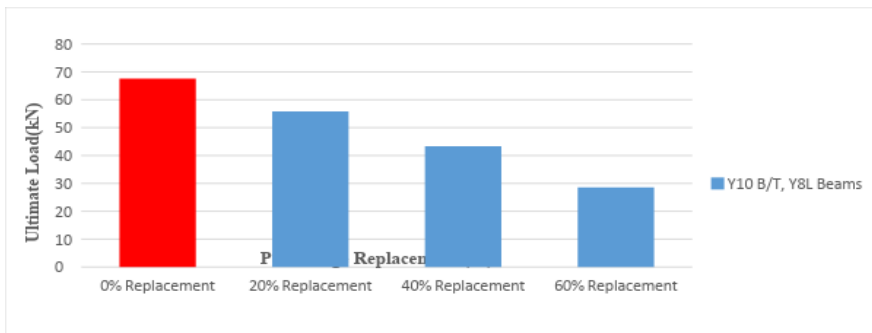


Figure 9: Ultimate loads decrease in beams (with shear) with increasing % content of PKSA.

4. Conclusion

The following conclusions are made from the results and the analysis thereof:

1. There is general decrease in the ultimate load the partial replacement of PKSA increases.

2. There is general increase in the ultimate load with the provision of shear reinforcement.
3. There is decrease in the percentage reduction of ultimate load with increase in the partial replacement of NWA with PKSA.
4. For beams B4_{PKS} and B6_{PKS} with shear reinforcement of 200mm spacing, there is reduction in the ultimate load by 17.47% and 35.87% when compared with beam B2_{NCS}, with 0% PKSA and shear reinforcement at 200mm spacing. This percentage reduction in the ultimate load can be reduced by the use higher concrete grade and by reducing the spacing of the shear reinforcement, so that such concrete mix can be used for structural purposes, especially in the low cost housing units.

5. Recommendation for Future Research

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

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