FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 7 No. 6, December, 2023, pp 32 - 40
DOI: https://doi.org/10.33003/fjs-2023-0706-2082

MECHANICAL PROPERTIES OF PALM KERNEL SHELL ASH BLENDED CEMENT CONCRETE

*[1]Bilkisu Hassan Sada Amartey, [2]Kumator Josiphiah Taku, and [1]Yusuf Dada Amartey

[1]Department of Civil Engineering, Ahmadu Bello University, Zaria,
[2]Department of Civil Engineering, Joseph Sarwuan Tarka University of Agriculture, Makurdi

*Corresponding authors' email: bilkisuhs@yahoo.com

ABSTRACT

Chemical and agricultural process industries generate substantial amounts of industrial by-products annually, leading to environmental pollution and escalating waste disposal expenses for the industry. As environmental awareness grows and landfill space becomes scarce, there is a rising interest in researching waste materials utilization. Exploring alternative methods, instead of disposal aims to minimize pollutions impact on the environment. The application of pozzolanic materials in construction works is on the rise, and this trend is anticipated to persist in the coming years, driven by the depletion of natural materials essential for manufacturing construction materials such as cement. This study investigates the utilization of agro-waste ash as a supplementary cementitious material SCM, specifically palm kernel shell ash (PKSA) as a substitute material for ordinary Portland cement (OPC) in concrete. Specimens containing 5, 10, 15, 20, 25 and 30% palm kernel shell ash (PKSA) as replacement for cement in the concrete were prepared at a water/binder ratio of 0.65. The results showed that the samples incorporating binary blends of cement with 5 – 15% PKSA illustrated better strength properties at ages above 28 days of hydration than that of control sample without PKSA. The compressive strength obtained were 26.76MPa, 26.81MPa and 27.16MPa at 60 days, and 29.80MPa, 30.0MPa and 31.41MPa at 90 days for 5 – 15% replacement levels respectively. The tensile strength values obtained were 4.5MPa, 4.5MPa and 4.7MPa at 60 days and 5.2MPa, 5.2MPa and 5.4MPa at 90 days for 5 – 15% replacement levels. The flexural strength of the concrete obtained were 3.89MPa, 3.87MPa and 3.95MPa at 60 days hydration and 4.1MPa, 4.1MPa and 4.3MPa at 90 days hydration for 5 – 15% replacement levels. From the figures obtained for all the strength values the optimum replacement level of ordinary Portland cement with PKSA is 15% for achieving maximum effect on strength properties.

Keywords: Palm kernel shell ash, pozzolanic, blended cement, concrete

INTRODUCTION

The production of cement relies heavily on continuous exploration of non-renewable natural resources leading to a depletion of such resources while it contributes about 5% to 7% of the total harmful gaseous emissions to the atmosphere (Chen *et al.*, 2010). Indeed, the growing demand for cement driven by infrastructure and housing development poses a challenge to environmental health and sustainability. Balancing the need for essential infrastructure and housing with environmental considerations remains a critical aspect for ensuring long term sustainability. Also, the constant increase in the need to find beneficial use of wastes from industries and agricultural products in order to ensure that the environment is protected and energy is conserved have pushed researchers to look for substitute of cement as a binder in the construction industry (Sulaiman and Aliyu, 2020). In a bid to overcome these challenges, studies in recent times have been directed to the investigation of the behavior and performance of some industrial and agricultural wastes as supplementary cementitious materials (SCMs) (Fadele and Ata, 2016). In addition, considerable efforts are being made to the utilization of these SCMs which will lead to decreasing the cost of conventional construction materials and processes and improving their performance. Due to the high availability of such local waste materials their utilization in civil engineering works will go a long way to addressing the issues of environmental concerns caused by pollution and scarcity of landfills due to the abundance of these industrial and agro-wastes worldwide to utilize local natural waste and by-product materials (Sooraj, 2013).

Concrete, being one of the oldest manufactured construction materials globally, is integral to various structures. However, in Nigeria, the high cost of producing concrete and other construction materials poses a challenge, making it challenging for a majority of individuals to afford it. (Olutoge *et al*., 2012) hence the reduction of cement content in concrete can be used to reduce the cost. Reducing cement content in concrete can be achieved by utilization of SCMs like fly ash, blast furnace slag, natural pozzolans and biomass ash. This approach contributes to more sustainable concrete production. A Pozzolan is a powdered material, which when added to the cement in the mix reacts with lime, released by the hydration of the cement, to create compounds which improve the strength or other properties of the concrete or mortar (King, 2000). As a result, this study was carried out to investigate the pozzolanic potentials of palm kernel shell ash as a SCM by evaluating its effect on the compressive, tensile and flexural strengths development of concrete.

MATERIALS AND TEST METHODS

Materials

The materials used in this study were cement, palm kernel shell ash (PKSA), aggregates and water.

Cement

The cement used for this research was Dangote Portland limestone cement obtained from a local cement dealer in Samaru, Zaria, Kaduna state

Palm kernel shell ash (PKSA)

Palm kernel shell was obtained from a local palm oil factory in Omu-Aran, Kwara state, Nigeria. The shells were pre-cleaned by washing with detergent, air dried and then calcined in an aired electric oven at a temperature of 600^oC for four hours until it changed into ash. The ash was sieved through 150µm BS sieve. The physical properties and oxide composition of the cement and PKSA are presented in Tables 1 and 2 respectively.

Aggregates

Same type of fine and coarse aggregate was used throughout the experimental work. The fine aggregate was river sand and coarse aggregate was crushed rock both obtained from Rahusa block industry, Samaru, Zaria, Kaduna state, Nigeria. The physical properties of the aggregates are displayed in Table 3.

Water

The water used for mixing and curing the concrete was pipe borne water obtained from the taps in the Civil Engineering Department concrete laboratory. The water satisfies ASTM C1602; Standard specification for mixing water used in the production of hydraulic cement concrete.

Test Methods

Experiments were performed at the Concrete laboratory, Department of Civil Engineering, Ahmadu Bello University, Zaria, Kaduna state, Nigeria except oxide composition which was carried out at the Multi-User laboratory, Department of Chemistry, Ahmadu Bello University, Zaria, Kaduna state, Nigeria.

The fine and coarse aggregates were investigated based on ASTM C136-06 and ASTM C33-15 for grading and fineness modulus respectively, ASTM C128-15 for specific gravity and water absorption of fine aggregate, ASM C127-15 for specific gravity and water absorption of coarse aggregate, ASTM C29-09 for aggregate bulk density and BS 812-112 and BS 812-110 for aggregate impact and crushing values respectively.

The mix ratio used for the concrete mix was 1:2:4 mix ratio (one-part OPC/PKSA to two parts fine aggregate to four parts of coarse aggregates) with a water-cement ratio of 0.65. In addition to the control mix without PKSA (0% PKSA), various percentages of PKSA in Portland cement ranging from 5% to 30% in steps of 5% were used to produce the concrete specimens.

Slump test was performed in accordance with ASTM C143-00 and compacting factor test in accordance to BS EN 12350-4. Once the workability tests were carried out, the concrete specimens were then prepared by pouring the concrete into molds of 150 x 150 x 150 mm dimensions for compressive strength test, cylinders of 150 x 300 mm dimensions for splitting tensile strength tests and the flexural strength were measured by loading unreinforced concrete beams 150 x 150 mm with a depth of 300 mm. All specimens were compacted with a vibrating table and allowed to set for 24 hours, de-molded and cured in water for 3, 7, 14, 28, 60 and 90 days in the laboratory atmosphere prior to crushing. In addition to control cubes with 0% PKSA, three cubes were produced for each curing period and binder percentage replacement of 5% to 30% in steps of 5%. Tensile strength of concrete was investigated in accordance to ASTM C496-11 respectively. Compressive and Flexural strengths of concrete were performed as per BS EN 12390-3 and BS EN 12390-5 respectively.

RESULTS AND DISCUSSION

PKSA and Cement

The specific gravity and bulk density values obtained for the PKSA sample as displayed in Table 1 were far less than that of the Portland cement. In material characterization density values are not determined to measure the quality of a material but are rather used in calculations for mix design to determine the quantity of the materials. The results infers that more volume of PKSA will be needed to replace an equivalent mass of cement.

The fineness modulus of 85% obtained for the PKSA sample was 13% coarser than cement – from Table 1 this will improve better strength and durability in the cement/PKSA blends. Fineness of SCMs has substantial effect on the heat of hydration and subsequently rise in temperature in concrete specimens.

The oxides contained in both the cement and PKSA samples displayed in Table 2 reveals that the chemical composition of PKSA is like those of the cement used in this research but with varying amounts. For example, PKSA contained more of the oxides of SiO_2, Al_2O_3 and Fe_2O_3 than OPC. And the sum of the silica, alumina and iron oxide contents of the PKSA investigated indicates that it satisfies the requirement for a class N pozzolan as stated by ASTM C618-12. And the benefit of its high silica and alumina content which in finely divided form can react with excess lime release during the hydration of OPC to form more calcium silicates hydrates responsible for further strength gain in concrete. Also, the high silica and alumina contents show a strong correlation with long term pozzolanic activity.

From the results obtained for consistency, initial and final setting times and soundness as displayed in Table 1 and the oxide composition in Table 2, the cement used in this research work conforms to Type 1 Portland cement in accordance to ASTM C150-15 which specifies physical properties; consistency of 26% to 33%, an initial setting times of greater than or equal to 45 minutes, a final setting time of less than or equal to 600 minutes and a soundness of less than 10 mm expansion.

Table 1: Physical properties of Dangote cement and PKSA used in study

S.No.	Properties	Experimental values	
		Cement	PKSA
1	Specific gravity	3.14	2.15
2	Bulk density kg/m^3	1286	760
3	Fineness (%)	98	85
4	Consistency (%)	30.5	-
5	Initial setting time (minutes)	118	-
6	Final setting time (minutes)	195	-
7	Soundness	0	-

Table 2: Chemical/Oxide composition of PKSA and cement used in this study

Oxides	PKSA (%)	Cement (%)
SiO_2	58.85	21.45
Al_2O_3	17.78	4.60

Fe_2O_3	5.49	2.82
CaO	2.95	63.76
MgO	2.68	1.98
Na_2O	0.76	0.20
K_2O	4.12	0.36
SO_3	0.53	-
P_2O_5	0.13	-
LOI	6.30	-
$SiO_2 + Al_2O_3 + Fe_2O_3$	82.12	-

Aggregates

Specific gravity and bulk density of aggregates

The results obtained from the specific gravity tests conducted shows a specific gravity of 2.53 for fine aggregate and a specific gravity of 2.60 for coarse aggregate. This is satisfactory as both fell within the range as stated by ACI 207.1R-07. This indicated therefore that the aggregates used in the experimental work are normal weight aggregates and suitable to produce concrete for general purpose. The results obtained for bulk densities are 2878.5kg/m3 and 2920.2kg/m3 for coarse aggregates and 2122.9kg/m3 and 2257.0kg/m3 for fine aggregate. The high values of density of the coarse aggregates indicates that the aggregates have a wide range of heavy particles while the fine aggregate are saturated with water indicative by its high-water absorption value and thus the high bulk densities. The aggregates can therefore be used in Portland cement concrete.

Table 3: Physical properties of fine and coarse aggregates used in study

S.No.	Properties	Experimental values	
		Fine aggregate	Coarse aggregate
1	Specific gravity	2.53	2.60
2	Bulk density(dry) kg/m^3	2122.9	2878.5
3	Bulk density (SSD) kg/m^3	2257.0	2920.2
4	Aggregate impact value AIV (%)	-	30
5	Aggregate crushing value ACV (%)	-	28
6	Water absorption (%)	6.3	1.5
7	Finess modulus	2.43	6.7

Fineness Modulus (FM) of Aggregates

The coarser the aggregates, the higher the FM. The FM for fine aggregate generally ranges from 2.0 to 3.3 as specified in ASTM C33-15. The fine aggregate sample having a FM 2.43 used in this experimental work falls within the range as specified by ASTM C33-15.

While the FM is typically computed for fine aggregates, it is necessary to calculate the FM of coarse aggregate for certain proportioning methods. The calculation follows the same procedure, with attention given to exclude sieves that are not specified in the definition (25.0- and 12.5-mm sieves) and to include all of the specified finer sieves. The FM obtained for the coarse aggregate sample used in the experimental work was 6.7 which fell within the range of 6.5 to 8.0 as specified in ASTM C33-15.

Water Absorption

Absorption in aggregates is important as it can affect the amount of water to achieve a given water/cement ratio used in a concrete mix. The amount of water an aggregate can absorb tends to be an excellent indicator as to the strength or weakness of the aggregate. Therefore, the aggregate moisture content will affect the water content (and thus the water-cement ratio also) and the water content affects aggregate proportioning because it contributes to aggregate weight. The water absorption obtained in this research work was 1.5% and 6.3% for coarse and fine aggregates respectively. The coarse aggregate value was within the range as stated in ASTM C127-15 limits but the fine aggregate was above the specified limit of ASTM C128-15 this is as a result of the amount of water contained in its pores.

Aggregate impact value

The aggregate impact values obtained in this experimental research work ranged from 28% to 32% with a mean of 30%. Comparing these results to the maximum permissible AIV (i.e. 30% for concrete used for wearing surfaces) indicates that the aggregate is strong enough and has good abrading properties. They can therefore be applied for ordinary concrete work. Aggregate impact values (AIV) below 10 percent are regarded as exceptionally strong, 20 to 30 percent as good and AIV above 35 percent would normally be regarded as weak. Aggregate impact value test gives an indication of aggregate's toughness property (i.e. property of a material to resist impact). Aggregate impact values are used to classify the stone aggregates with respect to toughness property and therefore gives an indirect indication of the strength characteristics.

Aggregate crushing value

The aggregate crushing value offers a relative measure of the resistance of an aggregate to crushing under a gradually applied compressive load. The laboratory test results obtained for the crushing value test ranges from 27% to 30% with an average of 28%. A value less than 10 signifies an exceptionally strong aggregate while above 35% would normally be regarded as weak aggregates. Comparing these with the permissible ACV 30% for concrete used on wearing surfaces) shows that the aggregate used in the experimental work are good enough in resisting applied loading and can give optimum performance when used in Portland cement concrete construction.

Particle size distribution

The particle size distribution curve for fine aggregate (FA) is presented in Figure 1. The curve of fine aggregate sample fits between the upper and lower limit zones as indicated in the graph. The shape of the curve shows that the fine aggregate sample used is a well graded sand and belonging to zone 2. It can be used with a low water-cement ratio for rich and workable mixes.

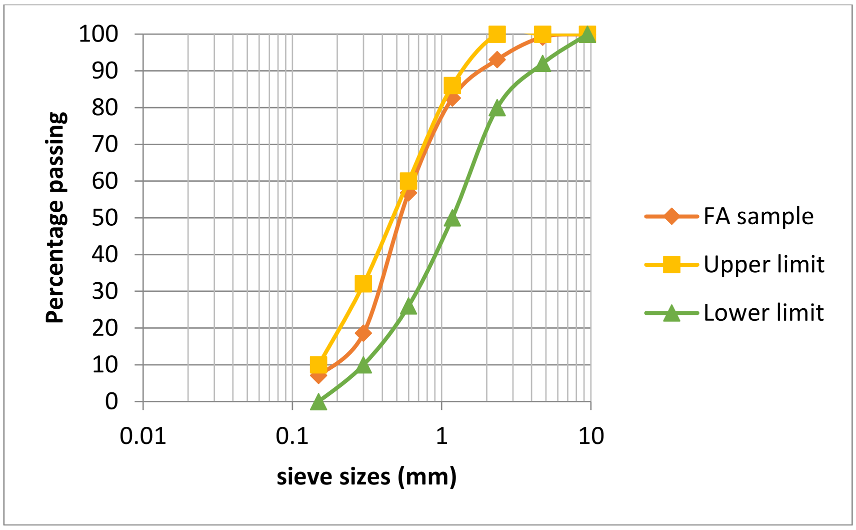

Figure 1: Grading chart for fine aggregate (FA) showing ASTM C33-15upper and lower limits for FA

The particle size distribution curve of the coarse aggregate (CA) is presented in Figure 2. The shape of the curve indicates that there is a good distribution of aggregate sizes ranging from the smallest to the largest and therefore the sample is uniformly graded and can therefore be used for Portland cement concrete mixes. The coarse aggregate grading curve is fitted on the upper limit curve with the two larger mesh sizes having samples slightly coarser than the upper grading limit of ASTM C33-15 for coarse aggregate.

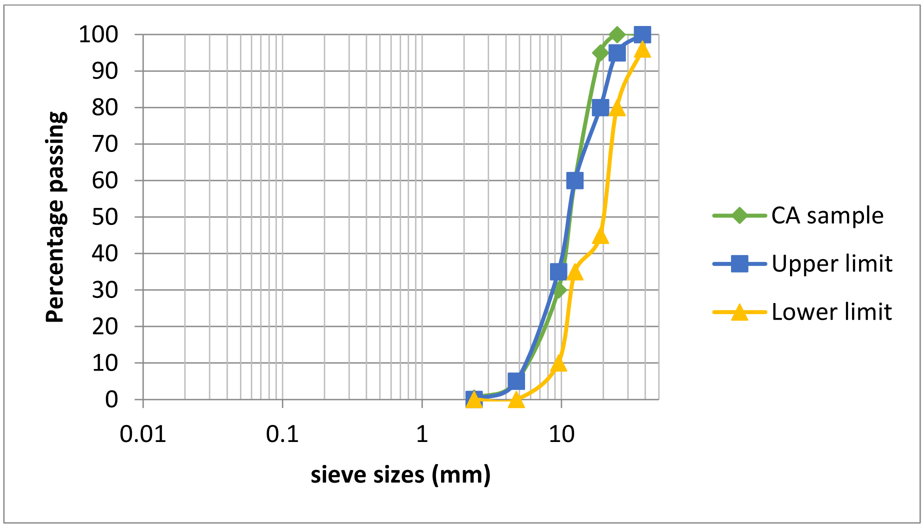

Figure 2: Grading chart for coarse aggregate (CA) showing ASTM C33-15 upper and lower limits for CA

Concrete

All raw results are displayed in Tables A1 to A4 in Appendices

Measurement of workability of concrete

The result for slump shows that for control and 5% to 25% replacement, the concrete mix had high workability while 30% replacement had medium workability.

From figure 3 it can be seen that there was decreasing trend in the slump values as the percentage of PKSA dosage increases in the mix; this is as a result of the mix becoming stiff as the PKSA content increases. Although there was a reduction in the slump values with an increase in PKSA percentage for all mixes the slump values for 30% replacement is also satisfactory as the slump values falls within the maximum and minimum values recommended by ACI 211.1-91 for use in mass concrete works. The slump type was 'true slump' for all the concrete mixes.

The trend of the graphs shows that palm kernel shell ash has potential to absorb more water than ordinary Portland cement in the mix. Nevertheless, water-binder (w/b) ratio of 0.65 was adequate to produce workable mix with true slump for all the percentages of PKSA used for the mixes.

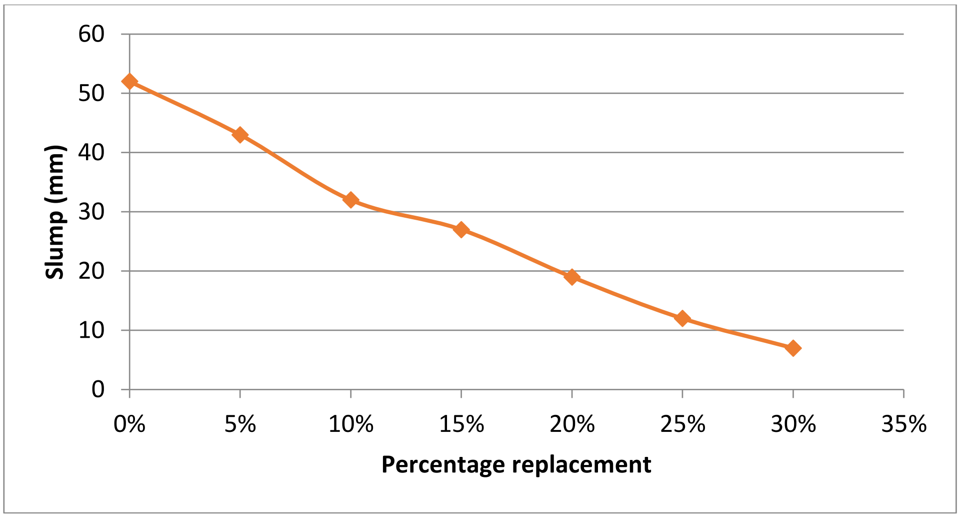

Figure 3: Slump for different mix ratios at different percentage replacement levels

While for the compacting factor (CF) the test results indicate that the values of all concrete mixes containing 5% to 20% PKSA replacement in addition to the control concrete possessed medium workability while the 25% and 30% replacement level had a low workability. Similar to the slump trend, the compacting values decreased with an increase in PKSA content and the mix became stiff after 20% replacement level.

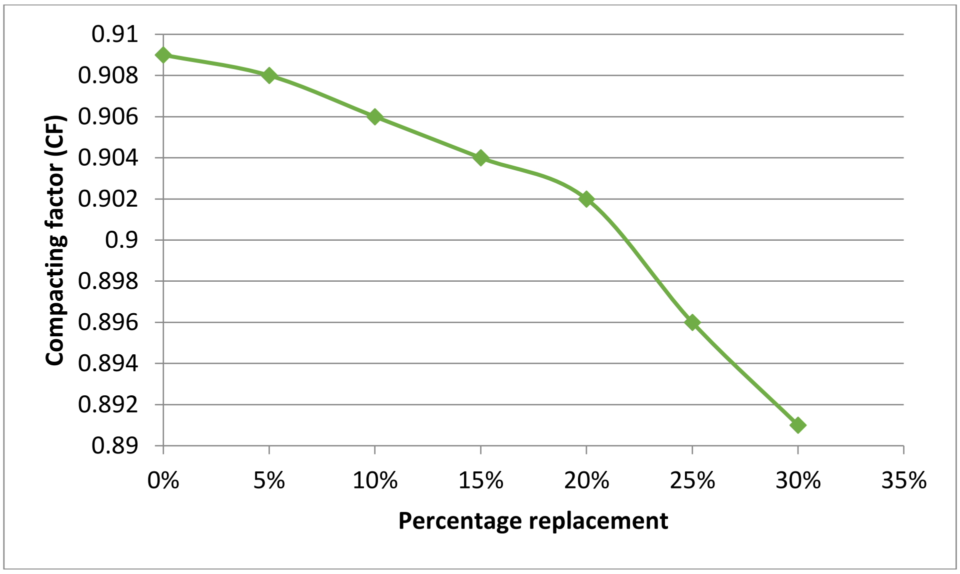

Figure 4: Compacting factor for different mix ratios at different percentage replacement level

The trend of the CF in Figure 4 indicated a reduction in the workability of the concrete mix with an increase in pozzolan content. The compacting factor values for 0.65 - ratio which was used for the mix design is considered as satisfactory as it falls within low to medium workability for control to 30% dosage of PKSA. Precisely, the compacting Factor assesses the impact of a standard amount of work (height of fall) on compaction, and necessitates sufficient water content to attain relatively complete compaction. This is true in the case of water-binder ratio of 0.65 used for all the mixes.

Compressive strength test

The strength development rate is primarily dependent on the hydration rate of cement influenced by both the initial hydration of palm kernel shell ash and subsequent rehydration due to pozzolanic reactivity of PKSA in the concrete blend of PKSA/OPC. At the early ages of 3, 7, 14 and 28 days, the trend was a reduction in compressive strength as the volume of PKSA increased from 5% to 30% replacement in comparison to the control concrete. This phenomenon could be ascribed to the dilution effect and delayed initiation of the pozzolanic reaction of $Ca(OH)_2$ in the PKSA. At the later ages of 60- and 90-days hydration the strengths tended to be constant from control to 10% except at 15% replacement which gave strengths slightly higher than the control concrete. Indeed, this aligns with the observation that the strength of pozzolanic materials rises as the hydration of the cementitious materials increases, driven by the reaction between free lime released during cement hydration and the silica content of supplementary cementitious materials (SCM). Therefore, at this later stage, the amorphous aluminous and siliceous minerals could still be actively reacting with $Ca(OH)_2$, generating additional C-S-H and hydrated calcium aluminates. This process enhances interfacial bonding between the aggregates and pastes leading to an improvement in the compressive strength of concrete.

While as the age of curing increased from 3 days to 90 days despite the increase in PKSA content a gradual increase in compressive strength development was observed. This suggests that PKSA has the potential to contribute to late-stage strength development. The lower compressive strength of the concrete at early ages could be attributed to the fact that, in the initial stages of hydration the PKSA pozzolan may have acted as a filler, occupying voids between paste and sand. As time progresses it transforms into a pozzolan, influencing its pozzolanic action on the concrete by converting excess $Ca(OH)_2$ into useful C-S-H which is crucial for strength gain. This behavior indicates that PKSA exhibits pozzolanic characteristics.

The trend in the strength values for the concrete are represented graphically in Figures 5 and 6 for compressive and splitting tensile strength respectively.

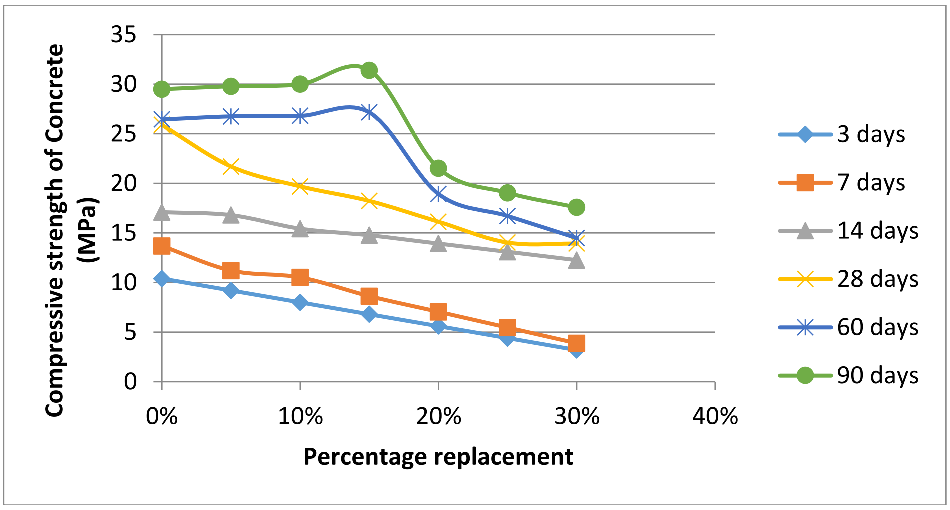

Figure 5: Graph of compressive strength of concrete at all ages for all replacement levels

Splitting tensile strength test

The overall trend in the tensile strength of PKSA/OPC concrete showed a decrease as the quantity of PKSA increased. However, there was an increase in tensile strength with the progression of hydration age. While the strength development rate was slow in the early stages, there is evidence of an upward inclination in strength gain at later ages as displayed in Fig 7. The tensile strength was constant at 5 and 10% replacement in comparison to the control after 28 days and increased more than the control for 15% replacement level at 60 and 90 days

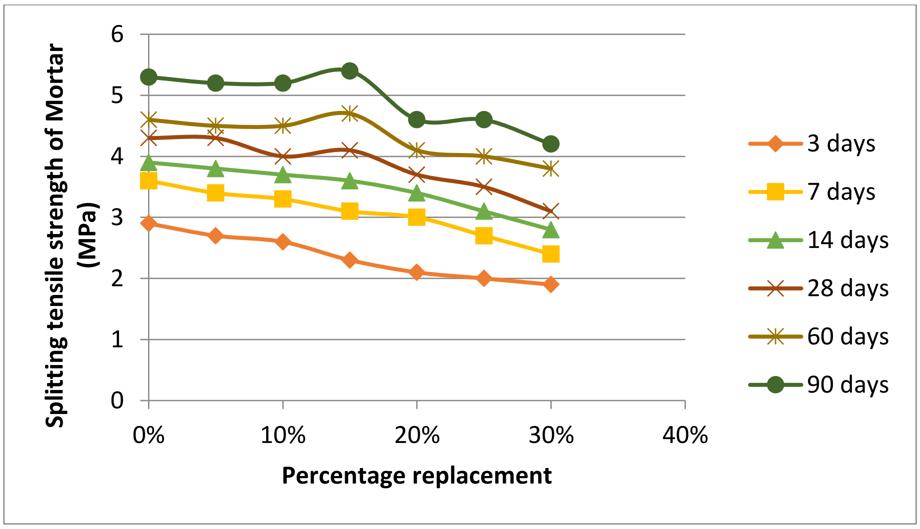

Figure 6: Graph of splitting tensile strength of concrete at all ages for all replacement levels

Flexural strength test

It was observed from the experimental results that there is a general increase in the flexural strength as the curing days increased from 3 to 90 days, although as the dosage of PKSA was increased from 5 to 30% the flexural strength decreased in contrast to the control. The addition of PKSA causes a positive effect on the flexural strength of concrete after 28 days; however, the gain in flexural strength is higher at 60 and 90 days at 15% replacement in comparison to concrete without PKSA (control) and tended to be constant for 5 and 10% replacements levels as can be observed from the trend in Fig 7. The flexural strength values of the concrete made with PKSA blended cements of 2 to 4 MPa shows the potential of such concrete mixture for use in PCC applications according to ASTM C78-15. The use of PKSA resulted in significant improvement in flexural strength; its addition to concrete exhibited an increase in the flexural strength as hydration days increased. The higher strength at 15% replacement of OPC with PKSA was due to the increased pozzolanic reaction and the packing ability of the PKSA particles as the dosage of PKSA was increased.

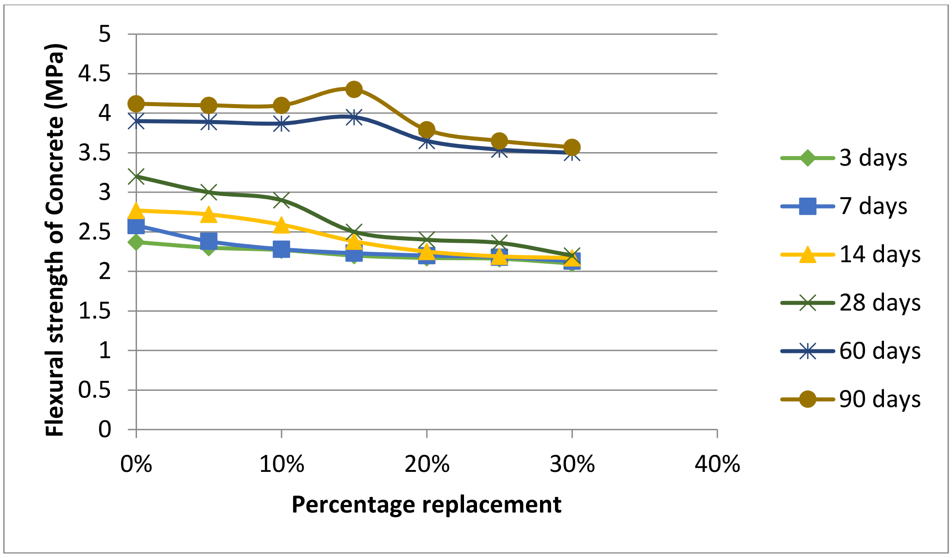

Figure 7: Graph of flexural strength of concrete at all ages for all replacement levels

CONCLUSIONS

Compressive, flexural and splitting tensile strength characteristics of cement-palm kernel shell ash blended concrete were studied. The study concludes as follows:

i. From the results obtained for physical properties and oxide composition, the cement used was Type 1 and PKSA exhibited pozzolanic properties and can be termed a Class N pozzolan.
ii. Based on the physical properties reported, the fine aggregate sample used is a well graded sand and belonging to zone II. It can be used with a low water-cement ratio and for rich and workable mixes. The coarse aggregate sample is uniformly graded, with good abrading properties and also good enough in resisting applied loading and can give optimum performance when used in Portland cement concrete (PCC) construction.
iii. Although there was a reduction in the slump values with an increase in PKSA percentage for all w/c ratio mixes the slump values for control concrete to 10% for 0.5 and 0.55 and 15% replacement for 0.65 is satisfactory as the slump values falls within the maximum and minimum values.
iv. The compacting factor values for 0.65 w/c ratio which was used for the mix design is considered as satisfactory as it falls within low to medium workability for control to 20% dosage of PKSA.
v. Although as the age of curing increased from 3 days to 90 days despite the increase in PKSA content there was a gradual increase in strength development in compressive strength.
vi. The low compressive strength of the mortar/concrete could be attributed to the reason that in the early ages of hydration the PKSA pozzolan could have contributed as fillers, filling the voids between the pastes and the sand and at later ages it turns into a pozzolan thereby impacting its pozzolanic action on the mortar and concrete by using the excess $Ca(OH)_2$ into useful C-S-H which is responsible for the gain in strength in the concrete.
vii. These results generally show that before after 28 days of curing time, the concretes with 15% replacement gave the best value of compressive strength.
viii. The general inclination of tensile strength of the PKSA/OPC mortar was decreasing as the dosage of the PKSA increased and the tensile strength increased with increasing hydration age. Although the rate of development of strength at early ages was very slow, an upward tendency of strength gain at later ages has been demonstrated.
ix. The flexural strength of concrete containing 15% PKSA at curing age later than 28 days gave strengths higher than normal (control) concrete.

REFERENCES

ACI 207.1R-07 “Guide to Mass Concrete” ACI Manual of Concrete Practice, American Concrete Institute, Detroit, Michigan 2007.

ASTM C127-15 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate ASTM International, West Conshohocken, PA, 2013, www.astm.org

ASTM C128-15 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate ASTM International, West Conshohocken, PA, 2013, www.astm.org

ASTM C136-14 Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates ASTM International, West Conshohocken, PA, 2014, www.astm.org

ASTM C143-00, Standard Test Method for Slump of Hydraulic-Cement Concrete, ASTM International, West Conshohocken, PA, 2000, www.astm.org

ASTM C150-15 Standard Specification for Portland Cement, ASTM International, West Conshohocken, PA, 2007, www.astm.org

ASTM C1602-12, Standard Specification for Mixing Water used in the Production Hydraulic Cement Concrete, ASTM International, West Conshohocken, PA, 2012, www.astm.org

ASTM C29-09, Standard Test Method for Bulk Density (Unit Weight) and Voids in Aggregate, ASTM International, West Conshohocken, PA, 2009, www.astm.org

ASTM C33-15, Standard Specification for Concrete Aggregates, ASTM International, West Conshohocken, PA, 2015, www.astm.org

ASTM C496-11 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, ASTM International, West Conshohocken, PA, 2007, www.astm.org

ASTM C618-12 Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, ASTM International, West Conshohocken, PA, 2007, www.astm.org

BS 812-110:1990: Testing Aggregates. Methods for determination of aggregate crushing value (ACV). BSI 389 Chiswick High Road London W4 4AL.

BS 812-112:1990, testing Aggregates. Methods for determination of the aggregate impact value (AIV) BSI 389 Chiswick High Road London W4 4AL.

BS EN 12350-4:2009 Testing fresh concrete: Part 4 Degree of compactability. BSI 389 Chiswick High Road London W4 4AL.

BS EN 12390-3:2009 Testing hardened concrete. Compressive strength test of specimens. BSI 389 Chiswick High Road London W4 4AL. http://www.bsi-global.com/

BS EN 12390-3:2009 Testing Hardened Concrete - Part 5: Flexural Strength of Test Specimens. BSI 389 Chiswick High Road London W4 4AL.

Chen, C., Habert, G., Bouzidi, Y., Jullien, A. (2010). Environmental impact of cement production: details of the different processes and cement plant variability evaluation. Journal of Cleaner Production 18, 478 – 485.

Fadele O. A. and Ata O.; (2016) "Compressive Strength of Concrete Containing Palm Kernel Shell Ash" American Journal of Engineering Research (AJER) 5(12), 32-36.

King, B. (2000), A Brief Introduction to Pozzolans. in: Alternative Construction - Contemporary Natural Building Methods, John Wiley & Sons, London

Olutoge, F.A., Quadri, H.A and Olafusi, O.S. (2012), Investigation of the strength properties of Palm Kernel Shell Ash concrete. ETASR 2(6), 315-319.

Sooraj, V. M. (2013). Effect of palm oil fuel ash (POFA) on strength properties of concrete. International Journal of Scientific & Technology Research, 3(6), 1–7.

Sulaiman T.A and Aliyu, I. (2020) "Combined effect of rice husk ash and cement kiln dust as cement replacement materials in concrete" FUDMA Journal of Science (FJS), Vol 4 No 1 pp 446-452

APPENDIX

Table A1: Slump and Compacting factor result for all percentage replacement

	Slump (mm)	**Compacting factor**
Percentage replacement of OPC with PKSA	**w/c = 0.65**	
0%	50	0.909
5%	44	0.908
10%	33	0.906
15%	25	0.904
20%	20	0.902
25%	10	0.896
30%	10	0.891

Table A2: Compressive strength of concrete (MPa) at different percentages and curing periods

Percentage replacement of OPC with PKSA	**3 days**	**7 days**	**14 days**	**28 days**	**60 days**	**90 days**
0%	10.4	13.69	17.1	25.9	26.45	29.50
5%	9.2	11.21	16.8	21.7	26.76	29.80
10%	8	10.52	15.43	19.7	26.81	30.0
15%	6.8	8.63	14.77	18.23	27.16	31.41
20%	5.6	7.05	13.93	16.13	18.93	21.53
25%	4.4	5.46	13.1	14.03	16.71	19.05
30%	3.19	3.88	12.26	13.93	14.49	17.58

Table A3: Tensile strength of concrete (MPa) at different percentages and curing periods

Percentage replacement of OPC with PKSA	**3 days**	**7 days**	**14 days**	**28 days**	**60 days**	**90 days**
0%	2.9	3.6	3.9	4.3	4.6	5.3
5%	2.7	3.4	3.8	4.3	4.5	5.2
10%	2.6	3.3	3.7	4	4.5	5.2
15%	2.3	3.1	3.6	4.1	4.7	5.4
20%	2.1	3	3.4	3.7	4.1	4.6
25%	2.0	2.7	3.1	3.5	4.0	4.6
30%	1.9	2.4	2.8	3.1	3.8	4.2

Table A4: Flexural strength of concrete at different percentages and curing periods

Percentage replacement of OPC with PKSA	3 days	7 days	14 days	28 days	60 days	90 days
0%	2.37	2.58	2.77	3.2	3.9	4.12
5%	2.3	2.38	2.72	3.0	3.89	4.1
10%	2.27	2.28	2.59	2.9	3.87	4.1
15%	2.2	2.23	2.38	2.5	3.95	4.3
20%	2.17	2.2	2.25	2.4	3.65	3.79
25%	2.16	2.18	2.19	2.36	3.54	3.65
30%	2.1	2.13	2.17	2.2	3.5	3.57