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[1.] E. E.IKPONMWOSA, [2.] C. A. FAPOHUNDA, [3.] O. E.OSANYINLOKUN

EFFECTS OF PALM KERNEL SHELL ASH ON SOME STRUCTURAL PROPERTIES OF CONCRETE WITH RECYCLED COARSE AGGREGATES

[1,3.] Department of Civil and Environmental Engineering, University of Lagos, NIGERIA
[2.] Department of Building, Caleb University, Imota, Lagos, NIGERIA

Abstract: This paper presents the results of an investigation conducted to determine some structural properties of concrete made with recycled coarse aggregates but containing (PKSA) as partial replacement of cement by weight. Cement was replaced with palm kernel shell ash (PKSA) up to 50% by weight at interval of 5% to produce the concrete used in the investigation. The properties investigated were: setting times, workability, compressive strength, and tensile strength. The results showed that: (i) higher setting times and reduced workability resulted with PKSA, (ii) reduction in compressive strength beyond 20% cement replacement with PKSA, (iii) the tensile strengths of the concrete specimens increase with curing age but reduce with increase in PKSA content in the mix, with the ratios of tensile splitting strength to compressive strength of PKSA blended cement concrete of 13 and 20 % for all the specimens.
Keywords: Compressive Strength, Consistency, Setting times, Tensile Strength, Workability

1. INTRODUCTION

The demand for concrete continues to be on the increase due to myriads of construction activities that are not only essential to sustain the present civilization, but also aimed at providing housing needs for the low income earners, which constitute the largest group of the populace. Although concrete consists in cement, sand, gravel and water, the most expensive of these is cement. In Nigeria for example, with an estimated deficit of 16 to 18 million housing unit, about 112 million tones of cement is required (Oluwakiyesi, 2011). Falade et al. (2013a) put the cost of meeting the cement needs at about 15% of the nation annual budget. In addition to its prohibitive cost, its production is endangering the environment because of the consumption of non-renewable materials (Mehta, 1999) and high consumption of energy which most developing nations cannot afford. Subsequently, research efforts have been directed at finding alternative and suitable materials as partial replacement of cement, especially from both industrial and agricultural wastes. Some of the industrial waste that have been found suitable include: fly ash (Wilson and Ding, 2007), silica fume (Yilmak, 2010) and blast furnace slag (Fernandez, 2007). The agricultural wastes found suitable are: sawdust ash, rice husk ash (Givi et al., 2010), periwinkle shell ash, sugar cane straw ash, bamboo leaf ash, Bambara groundnut shell ash, groundnut ash, pitchstone fines, cassava peel ash (Salau and Olonade, 2011), pulverized bone (Falade et al., 2013a, 2013b), palm kernel shell ash (Abdullah, et al., 2006, Hussein et al., 2009, Olutoge et al. 2012). With respect to palm oil fuel ash however, it has been used by named researchers in concrete which coarse aggregates are either granite chippings or gravel. In the present usage however, the coarse aggregates in the study was recycled aggregates from crushed concrete. Results of investigations carried out by RMC, (2007), CCAA, (2008), Kumar and Dhinakaran, (2011) had shown that construction wastes such as recycled aggregate (RA) obtained from crushed concrete rubble and demolished structures can be used for concrete production. This paper presents the results of investigation into the palm kernel shell ash (PKSA) as a partial replacement of cement in the production of concrete with recycled aggregates as the coarse aggregates. The parameters investigated were: setting times of cement-PKSA pastes, workability, compressive strength and tensile strength of concrete with recycled aggregates as coarse aggregates in which the cement fraction was partially substituted with PKSA.

2. MATERIALS AND METHODS

2.1 Materials

The materials used for this investigation are: cement, fine aggregates, and, coarse aggregates, water, and palm kernel shell ash (PKSA). Ordinary Portland cement was used as the main binder. It was manufactured in accordance with BS 12 (1996) and classified as CEM I and /or CEM II (NIS 444, 2003) was used as cement. For fine aggregates, river sand that was obtained from River Ogun, and treated to conform to the requirements of BS 882 (1982) was used. The coarse aggregates were recycled aggregates, obtained from concrete waste that was mechanically crushed. It was treated by mechanical sieve analysis to remove all particles passing through

5.6mm sieve, so that those the fraction retained on 19mm sieve was used for this investigation. Palm kernel shell was collected from palm kernel shells dump site at different palm oil processing centre in Emure–Ekiti, Ekiti State, Nigeria. They were washed and sun dried to remove the moisture and burnt to ash in open air condition. The ash was sieved through 600μm sieve size to produce ash. The water used was a potable water conforming to the requirements of BS 3148 (1980). For this study, a mix proportion of 1:2:4 (Cement/PKSA: Sand: Recycled Aggregate) by weight, with water cement ratio of 0.65 was used. The ordinary Portland cement in the mix was partially replaced by weight with palm kernel shell ash (PKSA). The proportion of palm kernel shell ash in the mix was between 0% and 50% at interval of 5%. The water cement ratio was kept constant for each mix at all proportions of palm kernel shell ash to the cement. A total of one hundred and twenty (120) 150 x 150 x 150 mm cube specimens and eighty (80) 300 x 150 mm cylinder specimens cast and tested. Table 1 is the summary of the mix proportion for the study.

Table 1: Summarized Concrete Design for all Mixes

Mix No	Mix Id.		Water (kg)	Cement (kg)	PKSA (kg)	RCA (kg)	FA (kg)	W/B
1	A	Per m^3	25.38	39.05	0	156.20	78.10	0.65
2	B	Per m^3	25.38	37.10	1.95	156.20	78.10	0.65
3	C	Per m^3	25.38	35.14	3.91	156.20	78.10	0.65
4	D	Per m^3	25.38	33.19	5.86	156.20	78.10	0.65
5	E	Per m^3	25.38	31.24	7.81	156.20	78.10	0.65
6	F	Per m^3	25.38	27.33	11.72	156.20	78.10	0.65
7	G	Per m^3	25.38	23.43	15.62	156.20	78.10	0.65
8	H	Per m^3	25.38	19.52	19.53	156.20	78.10	0.65

PKSA = palm kernel fuel ash, RCA = recycled concrete aggregates, FA = fine aggregates, w/b = water/binder ratio

2.2. Investigations

Preliminary Investigations

Some preliminary investigations were carried out on both the fine and coarse aggregates to determine their physical properties. These are: specific gravity, mechanical sieve analysis, aggregates crushing values, densities. Also, the chemical composition of the PKSA was carried out at the Department of Chemistry, University of Lagos. All these were carried out in accordance with relevant standards.

Consistency and Setting Times

Water requirements for standard consistency and setting behaviors of cement-PKSA paste were evaluated in accordance with BS 12 (1996), using the Vicat probe and the Vicat needle apparatus. In the paste used for study, cement was partially replaced by PKSA by weight up to 50% at interval of 5%. The sample without the PKSA served as the control.

Workability

The workability of the fresh concrete was determined using slump test and compaction factor test. The specimens were made in accordance with BS 12350: Part 2 (2000).

Density and Compressive Strength

The density and compressive strength tests were carried out respectively in accordance with BS 12350: Part 6 (2000) and BS EN 12390-3 (2009). Compressive strengths on cube specimens were measured at 7, 14, 28, 56 and 90 days of moist-curing. The specimens were allowed to dry for about 2 hours before testing. The strength characteristics of each cube were determined on 600kN Avery Denison Universal Testing Machine at a loading rate of 120kN/min. Three specimens for each of the curing ages were tested to failure by crushing, and the average failure load was recorded. The average failure load of the three specimens was then divided by the area of the specimens to obtain the compressive strength. The weight of each of the cube specimens at the point of testing for compressive strength was taken, and later used for the computation of the density.

Tensile Strength

The splitting tensile strength was carried out on 300 x 150 mm cylinder specimens in accordance with the provision of BS 12390: Part 6 (2009). Tensile strength was performed on the cylinder specimens after 7, 14, 28, 60, and 90 days of moist-curing. The splitting strengths were determined on 600KN Avery Denison Universal Testing machine at a loading rate of 120KN/min until failure. The splitting tensile strength (T_s) is then calculated as in equation as follows:

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

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).

3. RESULTS AND DISCUSSIONS

Physical Properties and Sieve Analysis of Materials

Some physical properties of the materials are presented in Table 2.From Table 2, both cement and the PKSA were of the same fineness, however, all the weight indicators showed that PKSA is lighter than cement.

Lightness of PKSA means than more volume of PKSA per unit weight replaced with cement will be required. Table 2 also showed values of the coefficient of uniformity ($C_u = \frac{D_{60}}{D_{10}}$) and coefficient of curvature ($C_c = \frac{D_{30}\ x\ D_{30}}{D_{60}D_{10}}$) computed from the results of the sieve analysis conducted for the sand and coarse aggregates. For the sand, these values are were respectively 6.00 and 1.01.

Table 2: Some Physical Properties of Materials Used

Physical Property	Fine Aggregate	Recycled Coarse Aggregate	Cement	PKSA
Fines Content (% Passing Through 600µm Sieve)	-	-	100	100
Fineness Modulus	3.14	4.34	-	-
Coefficient Of Uniformity (C_u)	6.00	2.29	-	-
Coefficient Of Curvature (C_c)	1.01	1.08	-	-
Specify Gravity	2.62	2.65	3.15	2.47
Dry Density (Kg/M^3)	1605.60	1742.89	-	698.44
Bulk Density ((Kg/M^3)	1667.74	1749.52	1297.79	839.25
Moisture Content (%)	0.30	0.21	-	0.007
Aggregate Crushing Value	-	30.38	-	-
Aggregate Impact Value	-	17.26	-	-

For the recycle aggregates used as coarse aggregates, the values were respectively 2.29 and 1.08. Also the fineness modulus were 3.14 for fine aggregates and 4.34 for the recycle aggregates. As these values fall within the range considered for good quality concrete production (Mindess et al. 2003), it can be thus be concluded that both the sand and coarse aggregates were well graded and suitable for concrete production.

Chemical Composition of Palm Kernel Shell Ash and Cement

Table 3 shows the chemical composition of ordinary Portland cement and palm kernel shell ash produced from open air burning. From Table 2, it can be observed that the composition of major oxides (SiO_2, CaO, and Al_2O_3) for PKSA is 50.6%. This qualifies the PKSA used to be classified as class C pozzolans (ASTM C 618 – 03). Further, the alkalis K_2O and Na_2O with combined percentages of 0.47% and 1.80% for both cement and PKSA are low, thus reducing the risk of possible destructive alkali-aggregate reactions (Neville, 2003). Also the loss on ignition, a measure of the extent of carbonation and hydration of free magnesia due to atmospheric exposure for cement and PKSA are less than 3% as set by BS 12 (1992). Both materials are however free of cyanide which causes corrosion of reinforcement.

Table 3: Chemical Composition of OPC and PKSA

Chemical composition (%)	OPC	PKSA
Silicon Dioxide (SiO_2)	17.28	42.60
Aluminum Oxide (Al_2O_3)	4.17	2.40
Ferric Oxide (Fe_2O_3)	2.24	5.60
Calcium Oxide (CaO)	61.67	4.30
Magnesium Oxide (MgO)	1.05	2.20
Sodium Oxide (Na_2O)	0.05	1.30
Potassium Oxide (K_2O)	0.42	0.50
Sulphur Trioxide (SO_3)	1.68	0.02
Manganese Oxide (MnO)	-	0.003
Phosphorus Oxide (P_2O_2)	-	0.005
Moisture content	-	0.007
Loss on ignition	0.03	0.78

Water Demand for Consistency and Setting Times of Cement Paste

The results of the standard consistency test, initial and final setting times for the PKSA blended cement pastes are shown in Figures 1 and 2. From figure 1, it can be seen that as the PKSA content increases more water was required to produce paste of the same consistency. This could be due to increase in the volume of PKSA per unit weight replaced with cement. Increase in volume will result in large surface area, and subsequently more water demand, as the quantity of PKSA is increased.

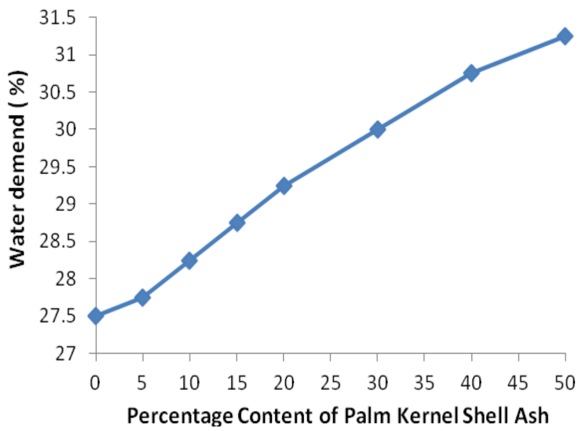

Figure 1: Effect on PKSA on the consistence of cement-PKSA paste

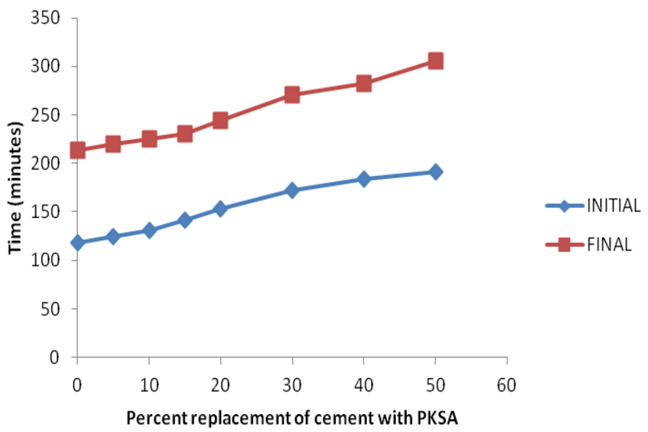

Figure 2: Effect of PKSA on the initial and final Setting Times of Cement-PKSA paste

Also from figure 2, it can be seen that the setting times – initial and final, increased relative to the control, as the level of replacement of cement with PKSA increased. This is an indication that the presence of PKSA in the matrix inhibits chemical activities of hydration. That is, PKSA has a retarding influence on the cement-PKSA paste. This is obvious considering Table 3, in which the combined major oxides (SiO_2, CaO, and Al_2O_3) for PKSA was 50.6% and that of cement 83.12%. In reactivity terms, the oxides figures make cement more faster in reactivity than PKSA.

Workability

The results of the slump tests to assess the effect of PKSA on concrete are presented in Table 4. From the table, it can be observed that the recorded slump decreased as the percent replacement of cement with PKSA is increased. This is an indication that harsher or lean mix progressively resulted with increase in the level of PKSA in the mix. The reason is obvious from the properties exhibited by PKSA (Table 2, Figures 1). From table 2, it was seen that PKSA is lighter than cement, and which means a larger volume is required for a unit weight replacement. And figure 2 showed that more water is needed as PKSA content is increased. Subsequently, when used in concrete with constant water/cement ratio, the water becomes less sufficient as the PKSA content is increased. The increase in specific surface area resulting from more volume was not accompanied by corresponding increase in water. The effect is harsher mix as the PKSA level increased. This is the reason for reduction in slump as the content of PKSA in the mix increased. The compacting factor test also confirms this trend as can be seen from Table 4. In addition all the specimens displayed true slump.

Table 4: Slump Flow and Compaction Factor

% PKSA	Slump value (mm)	Compaction factor	Slump Type
0	119	0.95	TS
5	114	0.94	TS
10	102	0.92	TS
15	97	0.90	TS
20	94	0.88	TS
30	82	0.86	TS
40	73	0.84	TS
50	61	0.82	TS

Compressive and Tensile Strengths of Cement – PKSA blended Cement Concrete

The results of the compressive strength were presented in Figures 3 and 4. From figure 3, it can be observed that the compressive strengths of the cube specimens increased with curing age at all the replacement level of cement with PKSA considered.

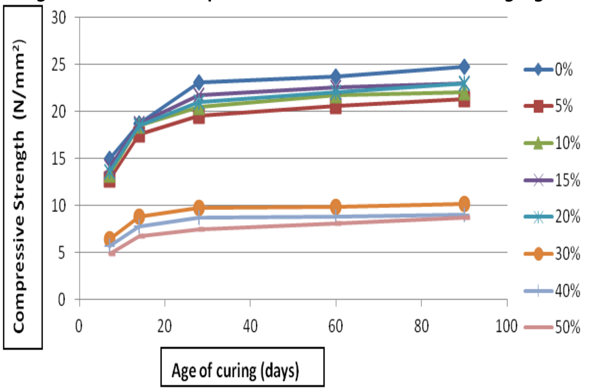

Figure 3: Variation of Compressive Strength with Curing Age (days)

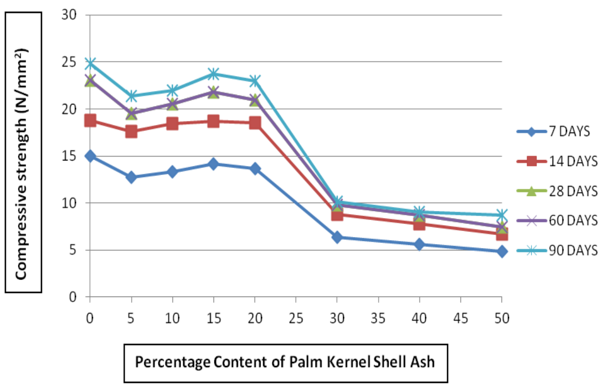

Figure 4: Effect of PKSA on Compressive Strength of the Specimens

This is an indication that the formation and the quantity of the strength-forming C-S-H gel increased with curing age.Figure 4 however showed that the compressive strengths of the specimens decreased as the level of cement replacement with PKSA increased at all the curing ages. That is, the progressive inclusion of PKSA in the mix progressively weakens the ability of the matrix to produce the strength-forming C-S-H gel.

This trend can be explained from the results of chemical investigations presented in Table 3. It was obvious from the table 3 that the combined percentage of major oxide composition (SiO_2, CaO, and Al_2O_3), which is a strong strength indicator, is high for cement when compared with the values recorded for PKSA. Thus PKSA does not contain the major oxides composition in sufficient quantity compared to the cement it replaced, thus accounting for progressive lower compressive strength as the level of cement replacement with PKSA increased. The results of the critical values calculated from the statistical analysis are shown in Table 5, with the intent to determine whether the difference/reduction in strengths were significant or not. Using a 5% confidence interval, the critical value is 4.303.

Table 5: Statistical Critical Values at all levels of Cement replacement with RSW

	0%	5%	10%	15%	20%	30%	40%	50%
28-day	0.17	1.13	2.45	3.12	4.13	18.75	21.45	59.27
60-day	0.16	1.01	1.87	2.12	3.35	28.41	68.96	65.70
90-day	0.17	0.92	1.45	2.01	2.45	30.34	59.34	69.79

Table 6: Compressive Strength - Strength Activity Index

% PKSA	7-day		14-day		28-day		60-day		90-day	
	CS	SAI (%)	CS	SAI (%)	CS	SAI (%)	CS	SAI (%)	CS	SAI (%)
0	14.98	100.00	18.65	100.00	23.05	100.00	23.72	100.00	24.80	100.00
5	13.42	89.97	17.61	84.87	19.57	84.90	20.63	86.97	21.35	86.09
10	13.33	88.59	18.45	88.92	20.50	88.94	21.76	91.74	22.00	88.71
15	14.15	94.46	18.68	94.91	21.77	94.45	22.55	95.05	23.71	95.60
20	13.54	91.05	18.52	90.99	20.98	91.02	22.02	92.83	22.97	92.62
30	6.36	42.46	8.80	42.41	9.78	42.43	9.88	41.65	10.11	40.77
40	5.64	37.65	7.80	37.59	8.67	37.61	8.76	36.93	9.04	36.45
50	4.86	32.44	6.73	32.43	7.48	32.45	8.06	33.98	8.72	35.16

From table 5, at 28, 60 and 60 days of curing, the computed critical values were less than 4.303 for cement replacement with PKSA up to 20%. This indicates that for up to 20% cement replacement with PKSA, there is no significance difference in strength compared with the control sample. This conclusion seems to be corroborated also from the computed Strength Activity Index (SAI) shown in Table 6 to evaluate to what extent can the PKSA used in this study be considered as pozzolanic. The strength activity index (SAI) is measured as the strength relative to the control, in percent. For SCM to be classified as pozzolan the strength of the blended cement at 7-day and/or 28-day must not be less than 75% of the strength of normal concrete (ASTM C 618-08). From Table 6, up to 20% cement replacement with PKSA is pozzolanic at all the curing ages.

= **Tensile Strength of Concrete with PKSA**

The results of the tensile strength measured through the splitting tensile strength are shown in Figures 5 and 6. From figure 5, it can be observed that the tensile strength increased with the curing age.

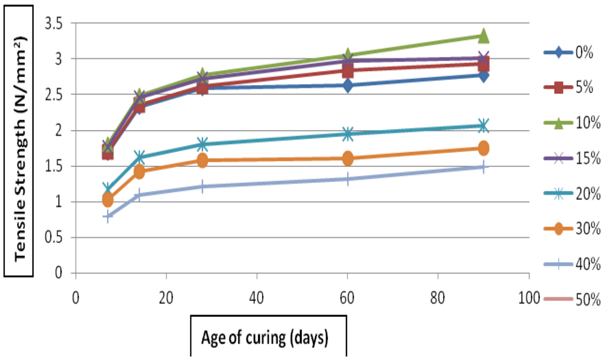

Figure 5: Variation of Tensile Strength with the Curing Age

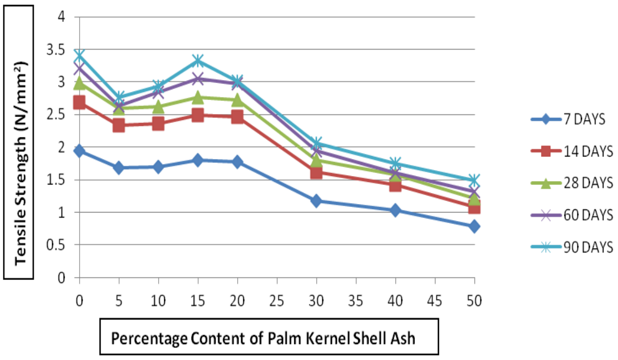

Figure 6: Effect of PKSA on Tensile Strength of Concrete Specimens

Figure 6 howevershowsreduction in splittingtensilestrength as thepercent of cement replacementwith PKSA wasincreased at allthecuringages. The reasons may not be unconnected with the observation by Neville (2003) that all the factors that affects the compressive strength of concrete also affect its tensile strength. Sincereducedcompressivestrengthswereobservedwiththeaddition of PKSA, it isreasonablethentoexpectreduction in thetensilestrength.

= **Relationship Between the Compressive Strength and Tensile Strength**

In practice, it is much easier to assess the compressive strength of concrete than the tensile strength. Obtaining a ratio between the two strengths is very useful for the purpose of quality control, as the tensile strength can be obtained easily (from this ratio) once the compressive strength has been determined. In this study, the ratios (β) of the tensile strength (f_t) and compressive strength (f_c), for all the replacement level of cement with PKSA, at all the curing ages are shown in Table 6. From table 6, it can be observed that the ratio is between 13% and 20%. For concrete with compressive strength of less than 25N/mm^2 (as obtained in this study, Table 6) the ratio of tensile strength to compressive strength has been found to be between 8% and 11% of the compressive strength (Shetty, 2006). Thus the values obtained in this study showed improved tensile strength characteristics at all the replacement levels, measured in terms of the splitting tensile strength.

Table 6: The Ratio (β) of Tensile strength (f_t) to the Compressive Strength (f_c)

% PKSA	7-day			14-day			28-day			60-day			90-day		
	f_c	f_t	β	f_c	f_t	β	f_c	f_t	β	f_c	f_t	β	f_c	f_t	β
0	14.98	1.94	0.13	18.75	2.68	0.13	23.05	2.98	0.13	23.72	3.21	0.14	24.8	3.4	0.14
5	12.72	1.68	0.13	17.61	2.33	0.13	19.57	2.59	0.13	20.63	2.63	0.13	21.35	2.77	0.13
10	13.33	1.70	0.13	18.45	2.36	0.13	20.50	2.62	0.13	21.76	2.84	0.13	22.00	2.93	0.13
15	14.15	1.80	0.13	18.68	2.49	0.13	21.77	2.77	0.13	22.55	3.05	0.14	23.71	3.33	0.14
20	13.64	1.77	0.13	18.52	2.46	0.13	20.98	2.73	0.13	22.02	2.97	0.14	22.97	3.01	0.13
30	6.36	1.17	0.18	8.80	1.62	0.18	9.78	1.80	0.18	9.88	1.95	0.20	10.11	2.06	0.20
40	5.64	1.03	0.21	7.80	1.42	0.18	8.67	1.58	0.18	8.76	1.61	0.18	9.04	1.75	0.19
50	4.86	0.79	0.16	6.73	1.09	0.16	7.48	1.21	0.16	8.06	1.32	0.17	8.72	1.49	0.17

4.CONCLUSIONS

From the results of this investigation, the following conclusions are made:

i. Palm kernel shell ash (PKSA) used in this investigation meets the minimum requirement for classification as Class C pozzolan as per ASTM Standard C 618-03.
ii. The standard consistency, initial and final setting times of normal cement paste increased as PKSA increased. Results show that PKSA could cause delay in setting times of cement paste. This is an advantage in pre – mix and hot weather concreting.
iii. The slump/workability of palm kernel shell ash concrete reduces as the percentage of PKSA increased.
iv. The compressive strengths of concrete specimens up to 20% cement replacement level are the same as that of the control, but beyond that, there is decrease in compressive strength with increase in PKSA for all the curing ages.

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v. The tensile strengths of the concrete specimens increase with curing age but reduce with increase in PKSA content in the mix,

vi. The ratios of tensile splitting strength to compressive strength of PKSA blended cement concrete lies between 0.13 and 0.20 (13 – 20 %) for all the specimens.

The results presented above are from beam and cylinder specimens, investigations still need to be conducted using slab specimens for confirmation of results obtained using beam specimens. This is because the design of both in practice is similar in principle.

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ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering