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ВЛИЯНИЕ НА РАЗЛИЧНИТЕ ТЕМПЕРАТУРНИ РЕЖИМИ ВЪРХУ ЯКОСТНИТЕ ХАРАКТЕРИСТИКИ НА БЕТОНИ С ЧЕРУПКИ НА ПАЛМОВИ ЯДКИ

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STRENGTH AND ELEVATED TEMPERATURE CHARACTERISTICS OF PALM KERNEL SHELL CONCRETE

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Abstract:
This research work gives an account of the study conducted on the substitution of Palm Kernel Shell (PKS) for natural coarse aggregate in concrete. Nine Different types of palm kernel shell were collected from different regions of Nigeria and tested for their physical properties. Tests conducted on Palm Kernel Shell Concrete (PKSC) include workability, density, compressive strength and elevated temperature test at a water-cement ratio of 0.55 and concrete mixes of 1:2:4, 1:1.5:3 and 1:1:2.
The results of the physical properties show a wide range of values for the different types of palm kernel shell. This means that not all palm kernel shells are the same in strength and physical structure. In all mix proportions, workability and density of PKSC reduced as the percentage of PKS increased. This reduction in density is attributed to the light weight nature of the PKS aggregate having a bulk density of 694kg/m^3, which is approximately 51% lighter compared to the conventional crushed stone aggregate. A maximum compressive strength of 26.46 N/mm^2 was recorded for PKSC at 10% PKS content and concrete mix of 1:1:2. This value reduced as the percentage of PKS increased. This may be attributed to the lower aggregate impact value of PKS aggregate compared to natural aggregate and the smoothness of one side of the PKS aggregate which affects the bond between the PKS aggregate and the cement paste, thereby reducing concrete strength. Palm Kernel Shell Concrete was tested at elevated temperatures of 100^{0}C, 200^{0}C, 300^{0}C and 400^{0}C. There was no colour change in all the mix ratios of the PKS concrete at 100^{0}C. At 200°C, for PKS content of 10%, 20% and 30%, there was no colour change, but for 40% and 50% PKS content, the colour changed to light ash. When PKS concrete of 20% PKS is subjected to 100 ºC and 200^{0}C temperatures, its residual strengths are 21.23 N/mm^2 and 18.82 N/mm^2, respectively. These values satisfy the criteria of structural LWC strength as per ASTM C 330, which requires minimum 28-day compressive strength greater than 17 N/mm^2. PKS concrete of 20% PKS content can therefore offer 2 hours fire resistance.

Keywords:
Compressive Strength, Concrete, Density, Elevated Temperature, Palm Kernel Shell, Workability.

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1. INTRODUCTION

Palm Kernel Shell (PKS) is derived from the oil palm tree (elaeis guineensis), an economically valuable tree, and native to Western Africa and widespread throughout the tropics. PKS are used mostly as a source of fuel for domestic cooking in most areas where they occur. The shells are mostly dumped as waste products of the oil palm industry.

A number of studies over the last two decades showed that PKS can be employed as LWA in order to produce structural LWAC, with a reduction in density of 20-25% compared to normal weight concrete;, Shafigh et al. (2010), Ndoke(2011), Alengaram et al. (2013). These types of LWA will not only provide significant savings in the overall construction costs, but also address concomitant environmental problems by reducing solid waste. A cost analysis done by Olanipekun et al. (2006) revealed that a cost reduction of 42% is possible for concrete made from PKS.

Specific gravity of PKS varies but has never crossed the value of 2.0 as reported by various researchers, the range of specific gravity for PKS is around 1.17-1.62. The highest value of specific gravity of PKS is reported to be 1.62 by Ndoke (2011) who tried to use the PKS for soil stabilization. According to Alengaram et al. (2013), the specific gravity of the palm kernel shells does not place it in the category of common rock groups, whose gravities range from 2.62-3.00. However, it showed same porosity as granite, quartzite, far above limestone.

Loose and compacted bulk densities of PKS aggregate varies in the range of 500-600 kg/m^3 and 600-740kg/m^3, respectively, Jumaat et al. (2009), Shafigh et al. (2010), Olanipekun et al. (2006). Due to lower density of PKS, the density of concrete made of PKS usually falls in the range of 1600-1900 kg/m^3, Adebayo (2012). As PKS is an organic aggregate, it contains many pores and hence the water absorption is high. The average moisture content of samples of palm kernel shells tested was 23.3%, (Owolabi, 2012).

Mannan et al. (2007) found the slump of Palm Kernel Shell Concrete (PKSC) to be very low (0–4 mm), indicating very low workability. Alengaram et al. (2013) showed that by incorporating a small percentage of superplasticizer, a slump value of 105 mm (high workability) could be achieved. High range water reducing admixtures (Superplasticizer or SP) are capable of dispersing cement grains which are directed towards high slump value resulting in high workability.

Alengaram et al. (2010) reported a strength of 37 MPa which is 85% higher than the minimum strength of 20 MPa. They used silica fume and class F fly ash to enhance the early and later day strength and sulfonated naphthalene formaldehyde condensate as superplasticizer to disperse the cement grains effectively. Generally, based on the experimental results, the mechanical properties of PKSC increased with decreasing w/c ratio. Shafigh et al. (2010) investigated the probability of making high strength lightweight concrete (HSLWC) with crushed PKS and steel fiber. They achieved 28-day compressive strength in the range of 41–45 MPa with steel fibers; however, they achieved 28-day compressive strength of up to 48 MPa with crushed PKS and lime stone powder as a filler.

In conclusion, extensive research has been done on the physical and mechanical properties of Palm Kernel Shell (PKS) and Palm Kernel Shell Concrete (PKSC) but researchers have reported a wide variance in the values of properties of PKS and consequently PKSC, this is because PKS consists of different types. This research work therefore seeks to identify and test the properties of the different types of PKS locally available in Nigeria, and to also investigate the strength characteristics of Palm Kernel Shell concrete at elevated temperature.

2. MATERIALS AND METHOD

All concrete mixes used are made of Ordinary Portland Cement, natural coarse aggregate (crushed granite), Palm Kernel Shell (PKS), natural fine aggregate (river sand) and water. Ordinary Portland Cement (OPC) was determined to have a bulk specific gravity of 3.05 and free of lumps and balls**.** Maximum size of coarse and fine aggregates was 19mm and 2mm respectively. The Palm Kernel shells were locally sourced from various regions in Nigeria. Nine different types of PKS were collected, ranging from local breeds and hybrids. The PKS was prepared first by sieving it, washing it with detergent and rinsed severally in order to remove dust, oil and mud particles that adhered to the surface of PKS. After washing, the particles were again dried and then stocked piled due to high water absorption of PKS. The physical properties of all the nine different PKS types collected were tested. The PKS-type (Dura from Ekiti) with almost the most suitable values in properties as aggregate in concrete was then selected for further tests (workability, density, compressive strength, splitting tensile strength and elevated temperature test). The percentage of natural aggregate by weight of the total coarse aggregates was varied in steps of 25% from 0% (corresponding to normal concrete) up to a maximum of 100%. The water-cement ratio adopted was 0.55**.**

3. RESULTS AND DISCUSSION

3.1. Types of Palm Kernel Shell

For the purpose of this research, nine different samples of palm kernel were gotten from various regions in Nigeria. Five of them were local breeds (naturally occurring) while four were hybrids (crossed between two local breeds and/or genetically altered). Since there are only two local breeds that bear fruit, it was decided that they be gotten from different regions to investigate any variations in their properties due to environment and climate. Two of the hybrids were macrocarya and pisifeni, while the other two are only known by their native names “atipa” and “okuso”. Table 1 below gives the results of the physical properties of the different types of PKS.

Generally, the nine types of PKS have similar shape, which is oval, but some are round with angular edges. They all have a smooth surface texture. Also, all the nine types of PKS have a dark brown colour with less visible strips but the mesocarya and hybrids-1(atipa) have whitish edges with very visible brown strips. The average maximum aggregate size for the local breeds was 12.2mm, while that for the hybrids was 4mm. The average shell thickness for the local breeds was 3.1mm while that for the hybrids was 1.6mm.

The specific gravity and the bulk density of the local PKS is higher than the hybrids by an average percentage of 12% and 19% respectively. The implication of this is that when concrete is batched by weight, more PKS will be contained in the batch when the hybrids are used than when the local breeds are used. This will lower the workability, density and most probably the strength of the concrete, because more PKS aggregate mean larger surface area in the fresh concrete matrix, thereby reducing the adequacy of the cement paste. The specific gravity of a material is a reflection of the porosity of the material, lower specific gravity is an indication of higher porosity. Aggregate porosity is an important factor that determines the durability of concrete.

The average moisture content, water absorption and porosity of the local breeds are 6.2, 21.6 and 24 while that of the hybrids are 6.7, 25.0 and 25.5 respectively. Typically, the higher the values of these properties of the aggregate, the less durable the concrete can be. The average Abrasion, Aggregate Impact Value, Aggregate Crushing Value of the local breeds are 3.6, 7.3, 6.9 while that of the hybrids are 5.2, 5.1 and 4.6 respectively. Typically higher strength coarse aggregate yield higher strength concrete, aggregate quality adds greater stiffness to the concrete. Aggregate work to arrest cracks when concrete is subjected to flexural loads, increasing aggregate strength increases the compressive and flexural strength of concrete.

Finally, it is important to note from the results above that all palm kernel shells are not the same, they vary in all their physical properties as have been clearly stated above and in Table 6. The shells from locally bred oil palms have proven in their physical properties to be better aggregates in concrete than the shells from the hybrids of oil palms. The shells from the hybrids of oil palm can still be useful as a civil engineering structural material as they can be burned for use as a pozzolan. The shells from hybrids of oil palm will require less energy to be burned unlike the local breeds.

Table 1. Physical Properties of Different Types of PKS (Local and Hybrids)

Properties	Local						Hybrids				
	Dura (Ebonyi)	**Dura (Ekiti)**	**Dura (Ondo)**	**Dura (Benin)**	**Tenera (Ekiti)**	**Ave-rage**	**Macroca-rya form**	**Hybrid -1 (Atipa)**	**Hybrid -2 (Okuso)**	**Pisifeni form**	**Ave-rage**
Shape	Oval/ round	Oval	Oval/ round	Oval	Oval/ round		Round with angular edges	Oval/ round with angular edges	Oval/ round with angular edges	Oval	
Maximum aggregate size (mm)	14.0	12.5	12.5	12.0	10.0	12.2	8.0	6.0	4.0	3.0	4.0
Shell thickness (mm)	3.5	3.0	3.0	3.5	2.5	3.1	2.0	1.5	2.0	1.0	1.6
Specific gravity	1.38	1.27	1.29	1.25	1.22	1.28	1.19	1.17	1.09	1.11	1.14
Bulk density (kg/m^3)	740	694	712	659	628	687	607	584	555	562	577
Moisture Content (%)	6.2	6.1	6.0	6.4	6.2	6.2	6.4	6.8	6.6	7.0	6.7
Water Absorption (24hrs) (%)	22.0	19.0	21.0	22.0	24.0	21.6	24.0	26.0	24.0	26.0	25.0
Porosity (%)	22.0	22.0	20.0	20.0	24.0	21.6	24.0	24.0	28.0	26.0	25.5
Abrasion (%)	3.2	3.5	3.4	3.7	4.0	3.6	4.4	4.7	4.8	6.8	5.2
Aggregate Impact Value (%)	7.8	7.9	6.9	7.2	6.5	7.3	6.4	5.6	4.7	3.8	5.1
Aggregate Crushing Value (%)	7.4	7.2	6.9	6.8	6.4	6.9	5.2	5.2	5.4	2.4	4.6

3.2. Workability of Normal and Palm Kernel Shell Concretes

Figure 2 below gives the results of the workability of palm kernel shell concrete of different mix proportions. From the results, it can be seen that as the percentage of PKS aggregate increases in the concrete, the workability reduces, in all the mix proportions.

Generally, workability of palm kernel shell concrete is good enough, even at 100% PKS aggregate content, it depends on the water-cement ratio and the mix proportion. The reason for this may be the rough surface of the shell on one side, improving the adhesion and the size of palm kernel shell used in this study. Also, the pre-soaking of the PKS before use in the concrete opened the pores of the PKS, thereby reducing the water-absorption of the aggregate in concrete, consequently enhancing its workability in concrete.

3.3. Density of Palm Kernel Shell Concrete

Density of Palm kernel shell concrete of different mix proportions are presented in Figure 3, maximum density recorded was 2672kg/m^3 from the control concrete of mix proportion 1:1:2, the lowest density was 1287 kg/m^3 from 100% PKS content with mix proportion of 1:2:4. For all the mix proportions, density reduces as the PKS aggregate content increases. This is due to the generally light weight nature of PKS aggregates having a unit weight of less than 2000 kg/m^3, which is approximately 60% lighter compared to the conventional crushed stone aggregate.

The density of PKS concrete increases as the cement content in the mix increases, the 1:1:2 mix gave the highest density recorded while the lowest density (1912 kg/m^3 at 50% PKS) recorded was for 1:2:4 mix.

Majorly, all the mix proportions produced a normal weight concrete, except at 50% PKS of 1:2:4 which gave a density of 1912 kg/m^3 at 90 days. For all the mixes, density increases with age of concrete. The development of the density with age is similar with that of the normal concrete as the difference in density at 7 days and 90 days is less than an average of 8% for all the mixes. The development of density with age was not affected by mix proportion.

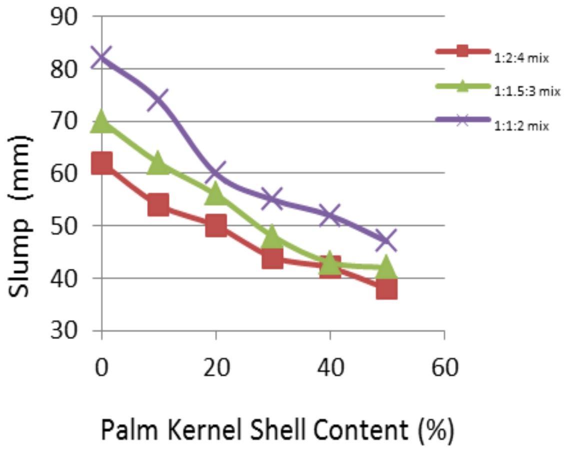

Figure 2. Slump test results of palm kernel shell concrete

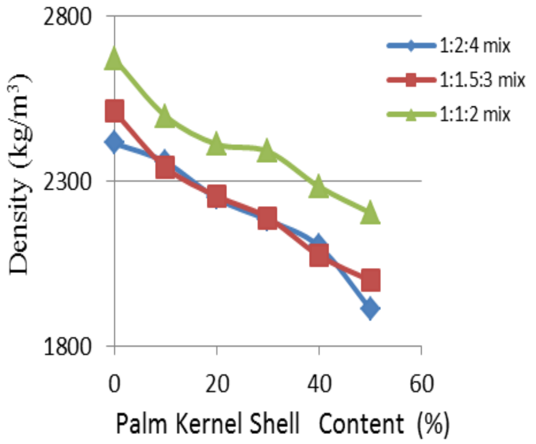

Figure 3. Density of Normal and PKS concrete for different mix proportions

3.4. Compressive Strength of Palm Kernel Shell Concrete

Table 3 shows the results of the compressive strength of normal concrete and PKSC of different mix proportions and ages. The maximum compressive strength recorded was 28.72N/mm^2, produced from a normal concrete with mix proportion 1:1:2. The maximum compressive strength recorded for PKSC was 26.46N/mm^2 at 10% replacement level with mix proportion of 1:1:2. At 50% PKSC, with mix proportion of 1:2:4 batched by volume, the lowest compressive strength of 12.32N/mm^2 was recorded. All values at 90days age of concrete.

The strength of the concrete decreases as the percentage of PKS increases for all the mix proportions. Taking 90 days as the reference curing age, all the mix proportions in the mix ratio of 1:1:2, met the minimum strength requirement of BS 12 for normal strength concrete which is 20N/mm^2, while 10% and 20% PKS content of the 1:1.5:3 mix ratio and only 10% PKS content of the 1:2:4 mix ratio had compressive strength values above 20 N/mm^2. These could be explained from the fact that PKS is an organic material which is lightweight with lower Aggregate Impact Value compared to granite. Furthermore, the reduction in strength of concrete strength as a result of increment in the added percentage of PKS aggregate could be attributed to the smoothness of one side of the PKS aggregate which would have affected the bond between the PKS aggregates and the cement paste, thereby reducing the concrete strength.

It was observed that most of the compressive strength development takes place in the early stages but continues to increase at a gradual rate at later ages of 28-90 days. The continual increase in strength with age of palm kernel shell concrete indicates that the palm kernel shell concrete does not deteriorate once palm kernel shell aggregates are encapsulated into the concrete matrix. The PKS was intact, no biological decay was observed even after crushing at 90 days.

Table 2. Compressive Strength of Palm Kernel Shell Concrete

Mix	Age	Compressive Strength (N/mm^2)					
% PKS		0%	10%	20%	30%	40%	50%
1:2:4	7	13.17	11.34	10.01	9.81	8.45	6.18
	14	16.02	14.86	12.57	12.81	9.76	9.12
	28	20.14	19.12	16.88	15.52	12.96	11.02
	90	22.75	21.10	19.34	16.66	14.42	13.32
1:1.5:3	7	17.78	14.76	12.95	12.01	10.63	9.45
	14	20.15	18.04	15.57	14.75	13.54	11.67
	28	23.58	22.55	20.48	17.84	16.11	15.64
	90	24.64	24.15	22.52	18.15	17.10	16.75
1:1:2	7	16.48	16.35	15.73	14.37	13.32	11.44
	14	24.49	22.88	22.57	18.36	17.47	14.73
	28	26.58	26.34	24.65	20.98	20.71	18.74
	90	28.72	28.46	27.13	22.19	21.12	20.38

In general, the strength development of concrete is controlled by the inter-particle bond, porosity of the paste, strength of the paste and also strength of the aggregates. However, for palm kernel shell concrete, the inter-particle bond has a less vital role in the strength development due to the relatively smooth surface of a side of palm kernel shell aggregate (Figure 4). Consequently, in palm kernel shell concrete, the strength, stiffness and density of the palm kernel shell aggregate, all of which are low, are the governing factors for its strength development.

During the compression test, it was observed that for the control concrete, the failure was explosive, in which full disintegration of the specimen occurred. For palm kernel shell concrete, failure was gradual and the specimens were capable of retaining the shape after failure without full disintegration. The gradual failure in palm kernel shell concrete is mainly attributed to its fibrous nature and the good energy absorbing quality of the palm kernel shell aggregate as indicated by the low AIV (6.92%) and ACV (5.2%) compared to those of granite (11.4%) and (6.4%) respectively. This shows that the palm kernel shell aggregate was absorbing the compressive load at the upper part and not distributing it to the lower part of the specimen. This type of behaviour is beneficial for structures that require good impact resistance properties.

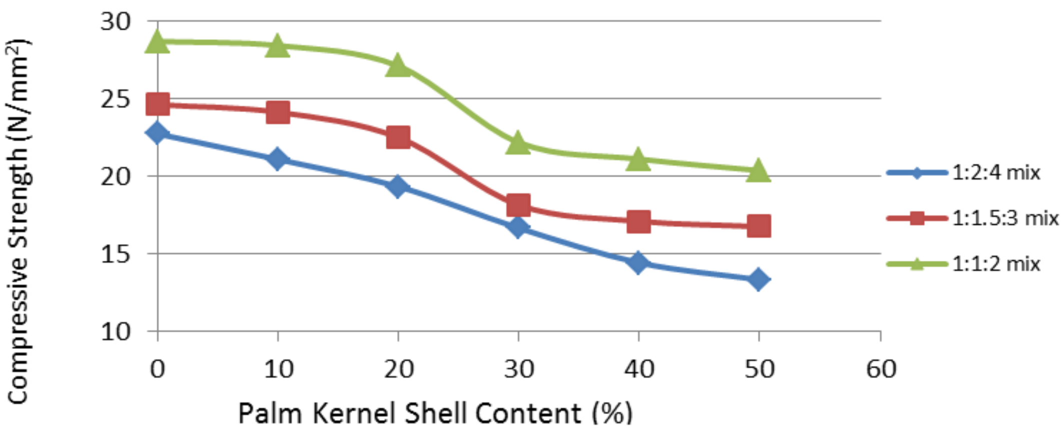

Figure 4. Compressive Strength of Palm Kernel Shell Concrete at 90days

3.5. Effect of Elevated Temperature on Palm Kernel Shell Concrete

Table 4. Results of Temperature tests on Palm Kernel Shell Concrete.

Tempe-rature	% PKS	Residual Density (kg/m^3)	Residual Strength (N/mm^2)	Loss in Density (%)	Loss in Strength (%)
100^0C	0	2635	26.52	1.40	7.70
	10	2482	24.08	0.60	8.99
	20	2392	21.23	0.83	12.02
	30	2364	18.86	1.09	15.01
	40	2248	17.74	1.53	16.00
	50	2168	16.71	1.63	18.01
200^0C	0	2601	25.12	2.66	12.53
	10	2419	22.49	3.16	15.00
	20	2303	18.82	4.52	22.01
	30	2256	16.86	5.61	24.02
	40	2108	15.42	7.67	26.99
	50	2086	14.06	5.35	31.01
300^0C	0	2577	23.14	3.56	19.43
	10	2388	20.11	4.40	24.00
	20	2250	17.13	6.72	29.01
	30	2186	14.42	8.54	35.02
	40	2030	13.31	11.08	36.98
	50	1892	11.82	14.16	42.05
400^0C	0	2544	21.17	4.79	26.29
	10	2340	18.26	6.33	31.00
	20	2188	14.72	9.29	39.00
	30	2126	12.43	11.05	43.98
	40	1995	11.40	12.61	46.02
	50	1860	10.39	15.61	49.01

The results of the temperature tests on palm kernel shell concrete cubes are reported as an average of three specimens and they are presented in Table 5. The formation of surface cracks and the colour changes due to the variation of temperature on palm kernel shell concrete are shown in Fig 8a,b,c,d,e,f,g. When concrete gets heated up to higher and higher temperatures, due to physiological and chemical changes, the colour keeps changing. The changes in colour and cracks formation were observed on the specimens.

3.5.1. Colour changes on Palm Kernel Shell Concrete

In case of normal concrete, there was no change of colour up to 300^0C, and the residual strengths are 26.52N/mm^2, 25.12 N/mm^2,23.14 N/mm^2, 21.17 N/mm^2 at 100^0C, 200^0C, 300^0C, and 400^0C respectively. At 400^0C, the normal concrete appeared in very light brown colour. There was no colour change in all the mix ratios of the PKS concrete at 100^0C. At 200°C, for PKS content of 10%, 20% and 30%, there was no colour change, but for 40% and 50% PKS content, the colour changed to light ash. At 300^0C, all the palm kernel concretes changed to whitish grey except the 10% PKS content which was light ash. At 400^0C, the 40% and 50% PKS concrete turned very brown while the 10%, 20% and 30% PKS content were light brown.

3.5.2. Residual strength on Palm Kernel Shell Concrete

Figure 5 and 6 gives the results of the residual compressive strength and density of PKS concrete at different temperatures. At 100^0C, the 50% PKS concrete retained 82.6% of the concrete compressive strength and at 400^0C, it retained 51.6% of the strength. When PKS concrete of 20% PKS is subjected to 100^0C and 200^0C temperatures, its residual strengths are 21.23 N/mm^2 and 18.82 N/mm^2, respectively. These values satisfy the criteria of structural LWC strength as per ASTM C 330, which requires minimum 28-day compressive strength greater than 17 N/mm^2. PKS concrete of 20% PKS content can therefore offer 2 hours fire resistance.

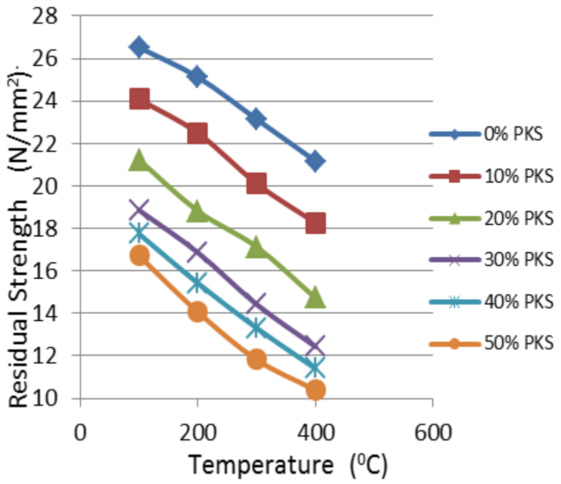

Figure 5. Residual Strengths of Palm Kernel Shell Concrete at Elevated Temperatures

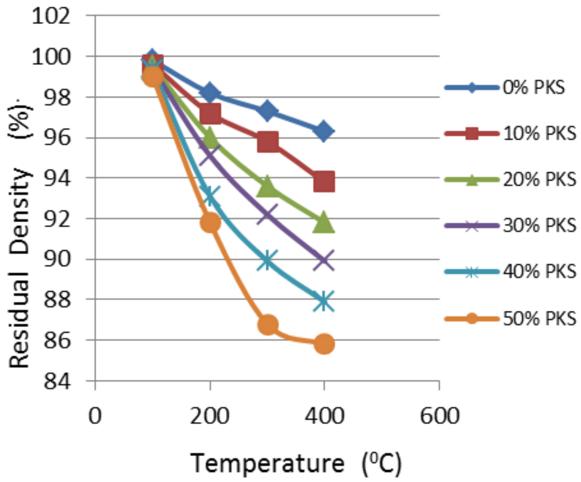

Figure 6. Density of Normal and PKS concrete Shell Concrete at Elevated Temperatures


a)

b)

c)

Figure 7. Normal concrete at (a) 100^0C (b) 200^0C (c) 300^0C

Figure 8d. Normal concrete (lower row) and 10% PKS (upper row) at 400^0C

Figure 8e. 20% (lower row) and 30% (upper row) PKS at 400^0C

Figure 8f. 40% PKS at 400^0C

Figure 8g. 50% PKS at 300^0C

4. CONCLUSIONS AND RECOMMENDATION

From the results of the various tests conducted, the following conclusions can be drawn:

1. it is important to note from the results above that all palm kernel shells are not the same, they vary in all their physical properties. The shells from natural breeds have proven in their physical properties to be better aggregates in concrete than the shells from the hybrids of oil palms.
2. generally, workability of palm kernel shell concrete is good enough, even at 100% PKS aggregate content, it depends on the water-cement ratio and the mix proportion.
3. the density of PKS concrete increases as the cement content in the mix increases. All the mix proportions produced a normal weight concrete, except at 50% PKS of 1:2:4 which gave a density of 1912 kg/m^3 at 90days.
4. the strength of concrete decreases as the percentage of PKS increases for all the mix proportions. The mix ratio of 1:1:2 and up to 50% PKS content, met the minimum strength requirement of BS 12 for normal strength concrete which is 20 N/mm^2, while 10% and 20% PKS content of the 1:1.5:3 mix ratio and only 10% PKS content of the 1:2:4 mix ratio had compressive strength values above 20 N/mm^2.

5. when PKS concrete of 20% PKS is subjected to 100^0C and 200^0C temperatures, its residual strengths are 21.23 N/mm^2 and 18.82 N/mm^2, respectively. These values satisfy the criteria of structural LWC strength as per ASTM C 330, which requires minimum 28-day compressive strength greater than 17 N/mm^2.

It is worthy of note that if PKS should be used as aggregate in concrete, especially in load bearing structural elements, they should be carefully selected to be sure they are only from oil palms that are not hybrids or crossbreeds.

REFERENCES

[1] Alengaram U.J,, Mahmud H, Jumaat MZ. Development of lightweight concrete using industrial waste material, palm kernel shell as lightweight aggregate and its properties. In: 2nd International conference on chemical, biological and environmental engineering (ICBEE 2010); 2010. p. 277–81.

[2] Alengaram, U.J., Shafigh, P., Mahmud, H.B., Jumaat, M.Z., 2013. Engineering properties of oil palm shell lightweight concrete containing fly ash. Mater. Des. 49, 613-621.

[3] Jumaat MZ, Alengaram UJ, and Mahmud H, 2009, “Shear strength of oil palm shell foamed concrete beams”, Material and Design, 30, pp. 2227-2236.

[4] Mannan, M.A., Kurian, V.J., Ganapathy, C., Teo, D.C.L., 2007. Lightweight Concrete made from oil palm shell (OPS): structural bond and durability properties. Build. Environ. 42 (7), 2614-2621.

[5] Ndoke P.N (2011) Performance of Palm Kernel Shell as a Partial Replacement for Coarse Aggregate in Asphalt Concrete. A journal of the Department of Civil Engineering, Federal University of Technology, Minna.

[6] Olanipekun E. A., Olusola K. O., and Ata O., “A comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates,” Building and Environment, vol. 41, no. 3, pp. 297–301, 2006.

[7] Owolabi Adebayo, “Assessment of Palm Kernel Shells as Aggregate in Concrete and Laterite Blocks.” Journal of Engineering Studies and Research Volume 18 (2012) No. 2 88.

[8] Shafigh P, Jumaat M. Z., and Mahmud H., “Mix design and mechanical properties of oil palm shell lightweight aggregate concrete: a review,” International Journal of Physical Sciences, vol. 5, no. 14, pp. 2127–2134, 2010.