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Palm Kernel Shells as a partial replacement for Sand in Sandcrate block production

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Abstract
The study explores and compares the properties of masonry blocks produced with palm kernel shell (PKS) as partial replacement to the traditional sandcrete blocks in an attempt to establish the percentage replacement of PKS that yields properties and characteristics that meets acceptable standards. After a review of relevant literatures, samples of materials required were collected and batched by weight to a mix proportion of (1:6). The PKS replacement varies from 0%, 10%, 20%, 30%, 40% and 50% with water cement ratio of 0.5. Total of 24 blocks were moulded, cured for 28days, subjected to various tests including water absorption, weight, density, and compressive strength. The water absorption test result indicates that up to 40% PKS replacement, the water absorption capacity of the block produced exceeds the minimum standard recommended by ASTM. The weight and density of the PKS block increases up to 10% PKS replacement, and furthermore reduces when the PKS exceeds 10%. With regard to strength test, it was revealed that, the compressive strength of the PKS blocks exceeds the minimum requirement of 2.8N/mm2 when the PKS replacement do not exceeds 40%. For blocks with PKS as partial replacement to meet standard specification, the PKS content should not exceed 40%. Further studies must focus on the factors that can effective the durability of blocks with KPS, and the socio-economic dimensions that impart on its acceptability as an alternative material to the conventional blocks.

1. Introduction

The construction industry in general and the building sector in particular contribute to the degradation of the environment through the deforestation of the natural resources, energy consumption, atmospheric pollution and wastes generation (Adedeji and Ajayi, 2008). According to Babafemi and Olawuyi, (2012), one of the major challenges facing the construction industry is the growing concern over resource depletion. This is because the industry relies heavily on conventional materials such as cement, granite and sand for the production of concrete. The high and increasing cost of these materials has greatly hindered the development of shelter and other infrastructural facilities in developing countries (Olutoge, 2010). That has made the search for alternative materials that meet the performance standards of the conventional materials imperative.

The prospect of using PKS as an alternative to the convention sand sounds promising. However, its use as a building material is not common in most of part of the world including Ghana (Emiero and Oyedepo, 2012). Effort to produce affordable houses which will impose less environmental stresses and make construction sustainable has necessitated research to the use of alternative materials. Such materials according to Osei and Jackson (2012) should be locally available and can replace conventional ones used in construction. Furthermore, the materials should be cheap, readily available and contribute to stress reduction on the environment.

To overcome or minimize these cankers, there have been efforts by Governments at various levels carrying out the policy of direct intervention into the provision of shelter by building low cost housing units. Alengaram, Mahmud and Jumaat (2010), stated that in many developing and underdeveloped countries in Asia and Africa, the research on the use of industrial waste materials such as oil palm kernel shell (OPKS) from palm oil production is envisaged. Consequently, the quest for alternative cheaper materials and utilization of industrial waste and by-product materials in infrastructure development is proven economically viable when environmental factors are considered and these materials meet appropriate performance specifications and standards. Olutoge (2010) concluded that there arises the need for engineering consideration of the use of cheaper and locally available materials to meet desired need enhance self-efficiency, and lead to an overall reduction in construction cost for sustainable development.

Ramli (2003) indicated that the requirement for vegetable oil is constantly increasing; hence more cultivation of oil palm is forecast in the future. Consequently, the production of palm oil result on waste by products such as Palm Kernel Shell (PKS), Palm Kernel Fiber (PKF), Palm Oil Mill Effluent (POME) and Empty Fruits Bunches (EFB). Stockpiling these wastes have created storage problem to the factories as large quantities of them are produced every day. Similarly, these wastes are mostly stockpile in open fields and have negative impact on the environment.

Efforts have been made to use the oil palm shell as aggregate in concrete (Okafor, 1988; Okpala, 1990; Basri et al., 1999; Mannan and Ganapathy, 2004, Olanipekun et al., 2006; Teo et al., 2007; Shafigh et al., 2011). The findings from the research have brought immense change in the development of building structures using lightweight concrete (LWC). Recent study by Muntohor and Rahman, (2011), concentrated on the use of oil palm shell for the production of masonry blocks (shellcrete). These previous study focused on only the compressive strength and durability of the "shellcrete", other properties such as weight, density and water absorption capacity which greatly affect the strength and stability of structures constructed with such materials have not been reported on.

This study was aimed to compare the properties of masonry blocks produced with palm kernel shell as partial replacement to that of the conventional sandcrete blocks. Specifically, the study sought:

1. To identify the properties of the PKS blocks with respect to weights, densities, water absorption and compressive strengths.
2. To compare the properties of the PKS blocks in terms of weights, densities, water absorption and compressive strengths to that of the conventional sandcrete blocks.
3. To determine the percentage replacement of PKS with sand blocks that can yield properties comparable to the properties of conventional sandcrate block.

This research focused on partial replacement of the PKS in percentages of 0%, 10%, 20%, 30%, 40% and 50% for the fine aggregates in the sandcrete blocks production. The physical properties in terms of weights, densities, water absorption and compressive strength we examined.

The article is structured as follows: First, a review of extant literature relevant to the need for use of PKS as partial replacement for sand was undertaken. This is followed by a description the experimental procedures used in the study. The results of the various laboratory tests were then discussed. Finally, implications, limitations and directions for future research are offered.

2. Review of Extant Literature

2.1 PKS as a Sustainable Building Material in Ghana

As a quest for implementing affordable housing system for both the rural and urban population of Ghana and other developing countries, various proposals focusing on cutting down conventional building material costs have been put forward. One of the suggestions in the forefront has been the sourcing, development and use of alternative, non-conventional local construction materials including the possibility of using some agricultural and industrial wastes and residues (e.g. palm kernel shells) as construction materials (Tukiman and Mohd, 2009). The quality and cost effectiveness of construction materials employed in housing developments are among the major factors that determines the optimal delivery of housing projects (Akutu, 1983). Therefore, materials to be used for building construction must provide objective evidence of quality and cost effectiveness in terms of functional requirements and low income economy respectively. In view of this, the search for low-cost material that is socially acceptable and economically available, at an acceptable quantity within the reach of an ordinary man becomes a subject of continuous interest. The belief that the African region is full of raw materials suitable for local uses encourages this, yet the construction sector is not making optimal use of them (Ramachandran, 1983).

2.2 The need for seeking alternative for Sand

The Ghanaian Construction Industry is likely to face a shortage of sand in near future due to over exploitation of sand from rivers, pits and sea shore. A study by Aromolaran (2012) indicates that there is increase in demand for sand for construction and other purpose as communities grow to construction at present requires less wood and more concrete, which sprout a demand for low-cost sand or other alternatives. The possible ecological impact of these indiscriminate sand mining and threats to the livelihoods of local communities includes the depletion of groundwater; lesser availability of water for industrial, agricultural and drinking purposes; destruction of agricultural land; loss of employment to farm workers, and damage to farm roads and bridges. More so, there are considerable pressures to reduce the consumption of primary aggregate for the environment reasons. Extracting large quantities of material from quarries or pits can cause loss of valuable or scenic land, dust and noise emissions and extra-traffic on unsuitable rural roads. Near-shore dredging can as well disturb wave and current flow, causing unwanted seabed movement (Domone and Illston, 2010).

It is reported that over 90% of physical infrastructure in Ghana, Nigeria and other African countries are being constructed using sandcrete blocks (Oyebade and Anosike, 2012). Sarndcrete blocks according to Joshua and Lawal (2011), are constructional masonry units that have been generally accepted to the extent that when an average individual thinks of building, the default mindset is the use of sandcrete blocks.

2.3 Properties of PKS
In a study to determine the structural behavior of reinforced palm kernel shell formed concrete beams by Alengaram, Jumaat and Mahmud (2010), the natural moisture content and 24 hour water absorption of PKS were determined. The thicknesses and the size of PKS were also measured. The particle size distribution and the specific gravity were determined. The loose and compacted densities were also found. Table 2.1 indicates the result.

Table 2.1: Physical properties of palm kernel shells and Normal Weight Aggregate (NWA)

Properties	Values	
	NWA	PKS
Thickness (mm)	15	1.0-3.0
Bulk density (compacted) (kg/m^3)	1510	620
Specific gravity (SSD)	2.67	1.27
Fineness modulus	6.57	6.24
Water absorption (1hourr) (%)	<1	10-12
Water absorption (1hourr) (%)	<1	25
Aggregate impact value (AIV) (%)	16.78	3.91

Source: Alengaram, Jumaat and Mahmud (2010)

Further study reports that the PKS are of different shapes, such as angular, polygonal etc., depending on the breaking pattern of the nut whereas their colour ranges from dark grey to black. The surfaces of the shells are fairly smooth for both concave and convex faces. However, the broken edge is rough and spiky. The thickness varies and depends on the species of palm tree from which the palm nut is obtained and ranges from 0.15 - 8 mm (Basri et al., 1999, Okpala, 1990).The shell has a 24hour water absorption capacity range of 21 - 33%. This value implies that the OPS have high water absorption compared to conventional gravel aggregates that usually have water absorption of less than 2% (Neville, 2008). This high water absorption according to Alengaram et al., (2010) could be due to the high pore content. It was also reported that the porosity of the shell is 37% (Okpala, 1990). Because of the higher porosity of OPS than conventional aggregates, loose and compacted bulk densities and the specific gravity range from about 500-550, 590 - 620 kg/m3 and 1.14 - 1.37, respectively. The shell is noted to be hard and does not easily suffer deterioration. The Los Angeles abrasion value of the OPS and crushed stone was reported as 4.8 and 24% respectively. This shows that it is much lower than conventional coarse aggregates and has a good resistance to wear (Basri et al., 1999).

3 Methodology

In coming out with the properties of the masonry block produced with PKS as partial replacement for the fine aggregates, an experimental investigation was conducted to study the following properties: density, weight, water absorption and compression strength. The materials, mix proportions, measurements and test methods used in this study are further described. The arrangement of the experimental program is summarized in the flow chart shown in Figure 3.1.

3.1 Selection of Materials
3.1.1 Cement
The ordinary Portland cement produced by Ghana Cement Limited (GHACEM) being Ghana's largest cement producer and as such readily available in almost every part of Ghana was used for all the mixes required for this study. This cement also conforms to the requirements of the British Standard Code (BS 12 of 1996).To prevent the cement from being exposed to moisture and hardened before usage, it was kept in air tight packages and stored inside the laboratory.

3.1.2 Fine Aggregates (Sand)
The sand used was clean, sharp river sand from a River that is free from clay, loam, dirt and organic or chemical matter of any description. It was obtained by sieving in order to fulfill the requirement of 100% passing through the 4.75mm sieve and 100% retained on the 75µm sieve.

3.1.3 Water
Water used for the entire experiment was potable water, noted to be fresh, colourless, odourless and tasteless water that was free from organic matter of any type. This was supplied by Ghana Water Company Limited (GWCL) and its quality satisfies the BS 12 (1996) requirements.

3.1.4 Palm Kernel Shells
The PKS used for this study were the industrial waste stockpiled by the local palm kernel oil producing firms in the country. Such palm kernel oil production sites served as the source from which the PKS used were obtained. The shells were put in a basket in batches and thoroughly flushed with water to remove impurities that could contaminant or affect the blocks properties and later spread in open space for it to dry thoroughly.

3.2 Grading of Aggregates
The grading of aggregates defines the properties of different sizes in the aggregates. The grading is noted to have a considerable effect and economy in the use of cement (Okpala, 1990). According to Handoo, et al, (1997), it is important to note that of a given consistency and cement content, a well graded aggregate produces a stronger mix than a poorly graded one. Dry sieve analysis which is in accordance with BS standard was adopted to conduct a grading test on both the fine aggregates and the PKS.

3.3 Mix Proportions
The total amount of materials needed for each mix was determined by the assumption of light weight block of density 1500kg/m^3. For the purpose of this study, a block of 150 x 150 x 150mm was produced under laboratory condition. The mix ratio used was 1:6 (one part cement to six parts of sand) at constant water cement ratio of 0.5. The sand content was replaced with the PKS from 0% to 50%. The 0% PKS replacement served as the control sample for the study. To prevent shortage as a result of waste, compaction and bulking of aggregates, 15% was allowed on the materials. Table 3.1 indicates the estimated quantity of materials required per mix.

3.4 Sample Details
Four (4) blocks each was produced from per mix design. This comprises of three (3) number 150 x 150 x 150mm cube that were crushed later for the strength test and one (1) number of 150 x 150 x 150mm cube for the water absorption test. In all a total of 24block samples was mould for the study. The total quantities of materials required for the 24blocks indicated in Table 3.2 was obtained from Table 3.1 by multiplying each quantity by three (3).

3.5 Mixing Process
Hand mixing was adopted to produce the samples. According to cement and concrete institute, it is possible to make blocks on a small scale without a concrete mixer. Hand mixing was as well noted to have the advantage of reducing the amount of capital required and providing employment, though it may limit output and not always be thorough. However measures were put in place to control these deficiencies. Prior to mixing, all the components were weighted according to the mix proportions indicated in Table 3.2. The actual procedure followed is indicated below:

1. The mixing was done on an impermeable surface made free from all harmful materials which could alter the properties of the mix, by sweeping and brushing or scraping.
2. The measured aggregates samples was spread using a shovel to a reasonably large surface area.
3. In the case of both sand and PKS as the core aggregates, the two materials were first mixed thoroughly until a uniform mix is obtained.
4. Cement was then spread evenly on the aggregates and the composite materials once again thoroughly mixed with the shovel.

5. The dry mixture was further spread again to receive water which was added gradually while mixing, until the measured water was exhausted.

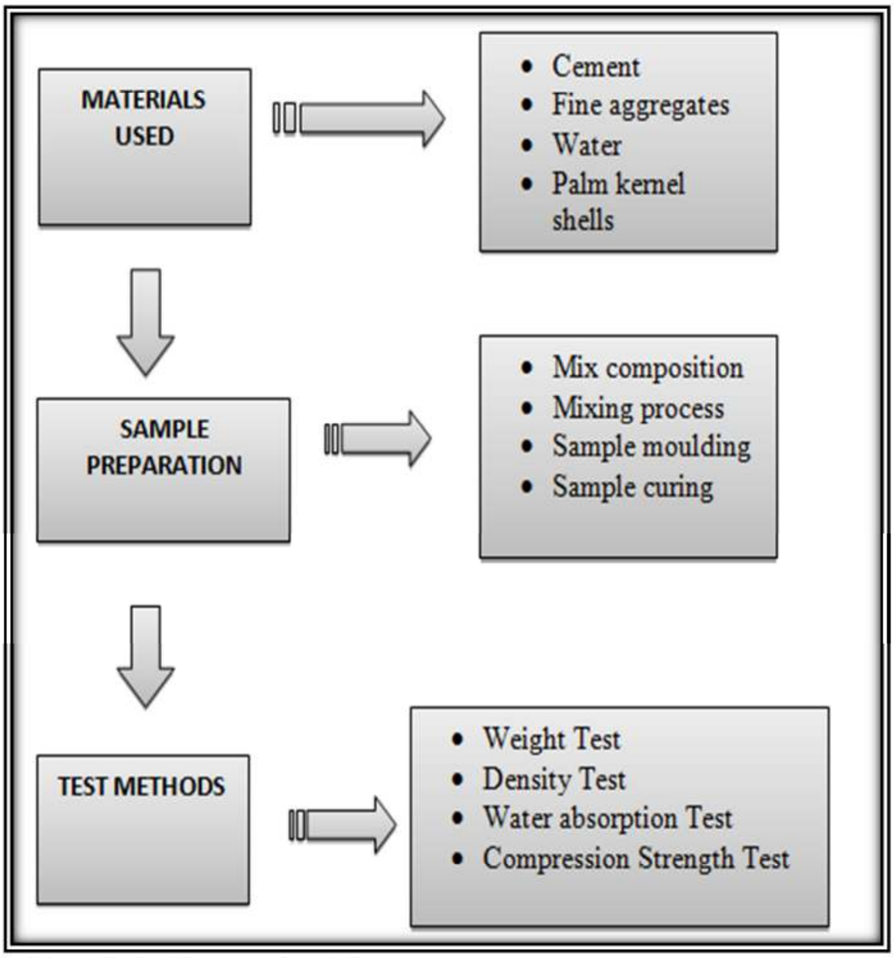

Figure 3.1: Flow chart of the experimental program

Table 3.2: Quantities of materials water cement ratio per mix

Mix	W/C ratio	Water (kg)	Cement (kg)	Sand (kg)	PKS (kg)	Design Ratio
Control Mix (0% PKS)	0.5	0.45	0.9	5.1	0.0	1:6:0
10% PKS	0.5	0.45	0.9	4.6	0.5	1:5.4:0.6
20% PKS	0.5	0.45	0.9	4.1	1.0	1:4.8:1.2
30% PKS	0.5	0.45	0.9	3.6	1.5	1:4.2:1.8
40% PKS	0.5	0.45	0.9	3.1	2.1	1:3.6:2.4
50% PKS	0.5	0.45	0.9	2.6	2.6	1:3:3

Table 3.2: Total quantities of materials for the study

Mix	W/C ratio	Water (kg)	Cement (kg)	Sand (kg)	PKS (kg)	Design Ratio
Control Mix (0% PKS)	0.5	1.3	2.6	15.4	0.0	1:6:0
10% PKS	0.5	1.3	2.6	13.9	1.5	1:5.4:0.6
20% PKS	0.5	1.3	2.6	12.3	3.1	1:4.8:1.2
30% PKS	0.5	1.3	2.6	10.8	4.6	1:4.2:1.8
40% PKS	0.5	1.3	2.6	9.3	6.2	1:3.6:2.4
50% PKS	0.5	1.3	2.6	7.7	7.7	1:3:3
Total (kg)		7.8	15.6	69.4	23.1	

3.6 Moulding

For casting purposes, the typical steel mould (size: 150 x 150 x 150mm) were used for all the samples. The interior of the mould was first lubricated with mould oil to prevent the blocks from sticking to the sides so as to give the block a smooth surface and enable easy removal of the mould from the block after casting.

3.7 Curing

According to Obande (1990), adequate curing of blocks is essential to ensure sufficient hydration of the cement and also gain of strength; hence the blocks samples after casting were left under open shed for curing up to a period of 28days before they were taken to the laboratory for testing. During this period, water was sprinkle on the green blocks at least twice a day for seven (7) days to ensure proper curing.

3.8 Testing

After the 28days curing and drying period, the samples were taken to the laboratory for tests on weights, densities, water absorption and strength

3.8.1 Weight

An electronic weighing scale will be used to weigh the block samples and the result will be recorded on a data sheet. Each sample will be weighed twice; first dry weight and second wet weight (bulk weight) after each sample is immersed in water for 24hours.

3.8.2 Density

Two densities would be determined thus: dry density and wet (bulk) density. The dry density will indicate the density of the blocks after the 28days curing and drying period whiles the bulk density will refers to the density of the blocks after soaking in water for 24hours.

To determine the densities, the volume of block will be calculated. The masses of the blocks obtained from weight test will be used to calculate the densities (p) from based on the formula:

$p = \frac{M}{V} g/cm^3$ Where:

M = mass (g) and V = volume (cm^3) of block sample

3.8.3 Water absorption

Water absorption test will be conducted on the samples after the 28days curing period based on the adopted procedure by Muntohar and Rahman (2011) indicated in chapter two of this study. The weight result recorded was used to determine the amount of water absorbed from the formula:

$w_{24} = \left(\frac{m_s - m_d}{m_d}\right) \times 100\%$ Where:

w24 = the absorbed water after 24 hours of immersion (%); *ms* = mass of specimen after immersion (*g*); and *md* = mass of specimen before immersion (*g*).

3.8.4 Compressive strength

The compressive strength test was carried out at 28-day curing age using ELE 2000kN compressive testing machine. All the three specimens for each mix proportion were crushed. The crushing was done on the edge face with a 3mmthick flat steel plate placed at top and bottom of sample for even distribution of load. The compressive strength was then calculated for each block sample using the equation:

$$Compressive\ Strength = \frac{\text{Load}}{Area} N/mm^2$$

4 Results, Findings and Discussion

In this research, six (6) types of blocks with different proportional substitution of PKS aggregates were prepared. The first type of block is the control sample, which consisted of 100% normal fine aggregated (sand) whereas the second to sixth are blocks made with PKS aggregates substitution percentages of 10%, 20%, 30%, 40% and 50% respectively. The results of the aggregates grading for both the sand and PKS are discussed in this section. The section also included results and discussions on the strength performance of the different types of blocks produced with the varying PKS aggregates replacement for the sand. Furthermore, all the results were obtained from tests conducted according to methods outlined in section 3.

4.1 Grading of Aggregates

Calculating for C_u and C_z of the PKS aggregate, 4.05 was obtained for C_u whereas C_z equals 1.30 respectively. Comparing the result to the unified soil classification systems grading criteria presented in Table 4.1, the curvature (C_z) criterion is not met. However, the C_u value is less than the minimum required value of six (6) for sands; hence the PKS can be classified as poorly graded. The calculations on the river sand reveal that C_u is equals 3.32 whiles C_z is 1.13. Comparing the values to Table 4.1, the uniformity criterion was met, that is greater than one but less than three (3). The result of curvature criterion is however less than the minimum value of six (6) for sand. Hence the river sand is also poorly graded.

Table 4.1: Unified Soil Classification Grading Criteria

	Material	
Criterion	**Gravel**	**Sand**
Uniformity	$C_u > 4$	$C_u > 6$
Curvature	$1 \leq C_z \leq 3$	$1 \leq C_z \leq 3$

Source: Spin.mohawkc.on.ca

Table 4.2 and 4.3 as well as Figure 4.1 and 4.2 shows the particle size distribution of the river sand and the PKS aggregate used for the study. The result from grading tests on both the river sand and the PKS indicated that both materials were all poorly graded. However, both aggregates were put together and combined graded which achieved good results.

Table 4.2: Particle Size Distribution of Sand

Sieve sizes/particles grades	Weight retained (g)	Weight retained (%)	Cumulative weight retained (%)	Weight passing (g)	Weight passing (%)
10.00	0	0%	0%	1500	100.0%
4.750	12	0.8%	0.8%	1488	99.2%
2.000	53	3.5%	4.3%	1435	95.7%
1.180	159	10.6%	14.9%	1276	85.1%
0.150	1265	84.3%	99.3%	11	0.7%
0.075	8	0.5%	99.8%	3	0.2%
Pan	3	0.2%	100.0%	0	0.0%
Total	**1500**	**100%**	**319.1**		

$$Finesness\ Modulus = \frac{319.1}{100} = 3.191$$

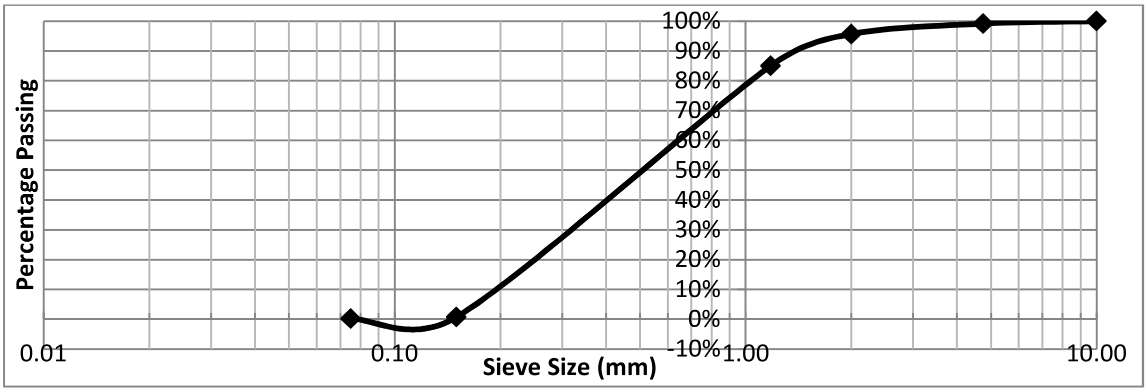

Figure 4.2: Graph of particle distribution of sand

Table 4.3: Particle Size Distribution of PKS Aggregate

Sieve sizes/particles grades (mm)	Weight retained (g)	Weight retained (%)	Cumulative weight retained (%)	Weight passing (g)	Weight passing (%)
20.00	0	0.0%	0%	900	100.0%
10.00	13	1.4%	1.4%	887	59.1%
9.50	7	0.8%	2.2%	880	58.7%
6.30	386	42.9%	45.1%	494	32.9%
5.00	112	12.4%	57.6%	382	25.5%
4.75	41	4.6%	62.1%	341	22.7%
2.00	236	26.2%	88.3%	105	7.0%
Pan	105	11.7%	100.0%	0	0.0%
Total	**900**	**100%**	**356.8%**		

$$Finesness\ Modulus = \frac{356.8}{100} = 3.568$$

Figure 4.3: Particle distribution of PKS aggregate

4.2 Water Absorption

The relationship between the PKS aggregates content and the resulting densities of water absorption of the block produced are presented in Figure 4.3. It could be deduced form the figure that, the amount of water absorbed by the block reduces as the percentage replacement of the PKS increases. However from 10% to 40% PKS aggregate replacement, the resulting water absorptions densities are more than the 130kg/m³ being the minimum standard water absorption density of block made of lightweight aggregates (ASTM Standard C55, 2011). Water absorption is defined as the transport of liquids in porous solids caused by surface tension acting to the capillaries. The resulting decrease in water absorption of the samples as the PKS content increases can therefore be as a result of the coarse nature of the PKS aggregates which tend to make the block porous the more its contents increases.

In terms of water absorption capacity, the study has reveal that sandcrete blocks produced with more than 40% PKS aggregate replacement for sand content tend to be more porous since its water absorption decreases below the 130kg/m^3 recommended by the ASTM Standard C55 (2011). Nevertheless, the 10% to 40% PKS aggregates blocks could be used in most areas where the traditional sandcrete block is recommended to be used. Also, it was found from the study that, the amount of water absorption reduces as the percentage replacement of the PKS aggregates increases as the figure 4.4 indicates.

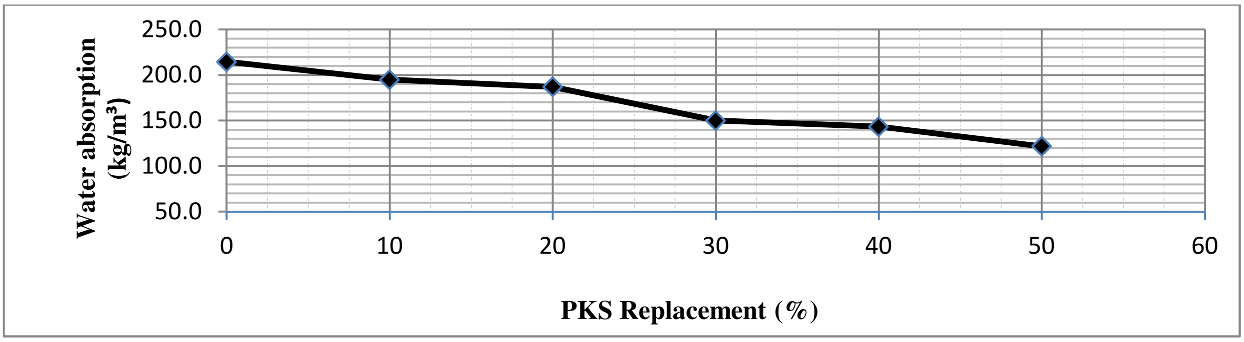

Figure 4.4: Relationship between percentage PKS replacement and water absorption capacity

4.3 Weight and Density

Figure 4.6 and 4.7 shows the properties with respect to weights and densities of the block samples produced. It could be observed from both Figures that, the relationships are the same. This means the higher the weight of a block, the higher the density. Referring to the values on the Figure 4.6 and 4.7, a block of 10% PKS aggregate replacement is found to be heavier and denser (5.999kg and 1.77kg/m³) as compared to the control sample of 0% PKS aggregate replacement (5.834kg and 1.728kg/m³). It could also be noticed that, from 20% upward PKS replacement, the values for both the weights and densities decreases. This indicates that for a better partial replacement of PKS percentage for sand in block production, 10% substitution is the ultimate if the emphasis is solely on the weight or density.

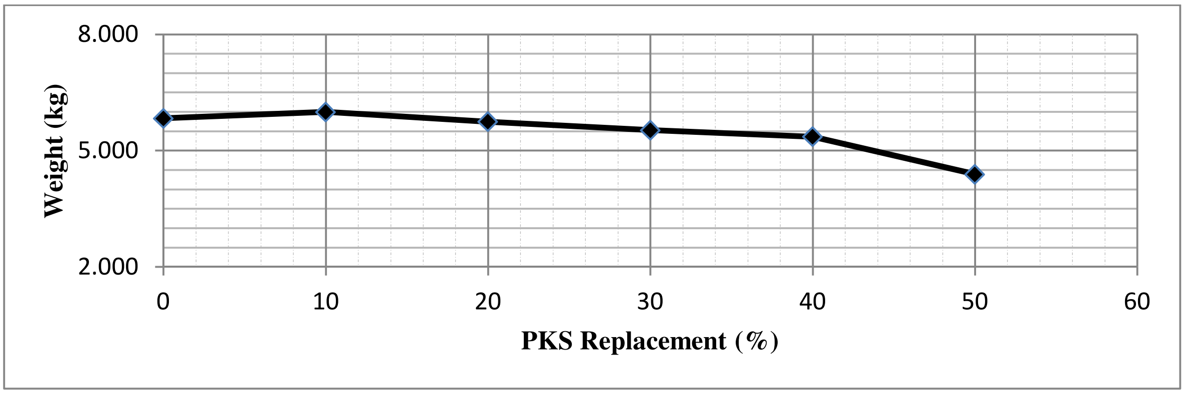

Figure 4.5: Relationship between percentage PKS replacement and block weight

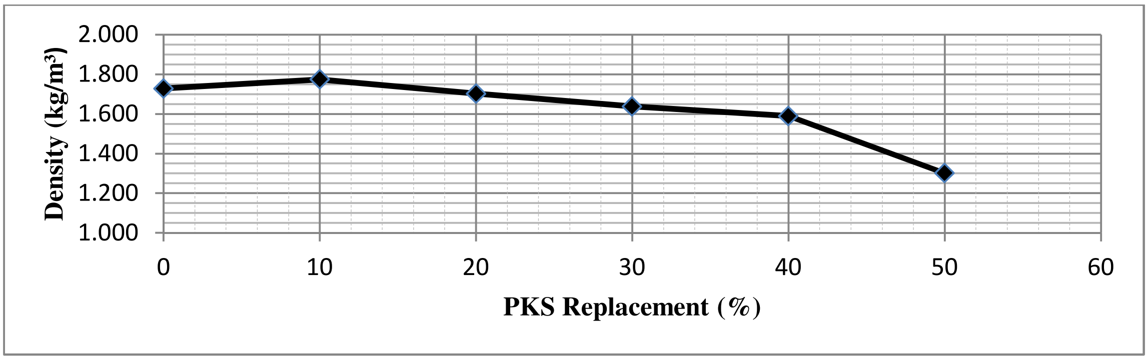

Figure 4.6: Relationship between percentage PKS replacement and block density

Compressive Strength

The relationship between the compressive strength and the PKS aggregates content is shown in Figure 4.8. It can be observed that aside the 50% PKS aggregates replacements which has its compressive strength (1.605N/mm^2), lower than the compressive strength (3.6N/mm^2) of the control sample (0% PKS aggregates replacement), the compressive strength of the 10% to 40% PKS aggregates replacements were higher than that of the control sample. Furthermore, the compressive strength result of the 10% to 40% of the PKS aggregates replacements exceeds the minimum compressive strength (2.8N/mm^2) requirement by the BS 6073. Figure 4.8, indicates that the compressive strength increases from 0% to 10% PKS aggregates replacement, and decreases from 10% upwards of replacement of PKS aggregates. Comparing the results of the compressive strength test to the density test results, the relationship seems the same; hence from 0% to 10% PKS aggregate replacement in block production, the particles are more closely packed. This confirms the statement by Baiden and Asante (2004), that the more closely packed the particles in a material, the higher the density. Further, examination of the results indicates that, between 0% to 10% PKS aggregate replacement, not only are the particles closely packed; rather aggregates mix design becomes composed of well graded aggregates (sand and PKS). Hence the resultant effect of both higher densities and higher compressive strength.

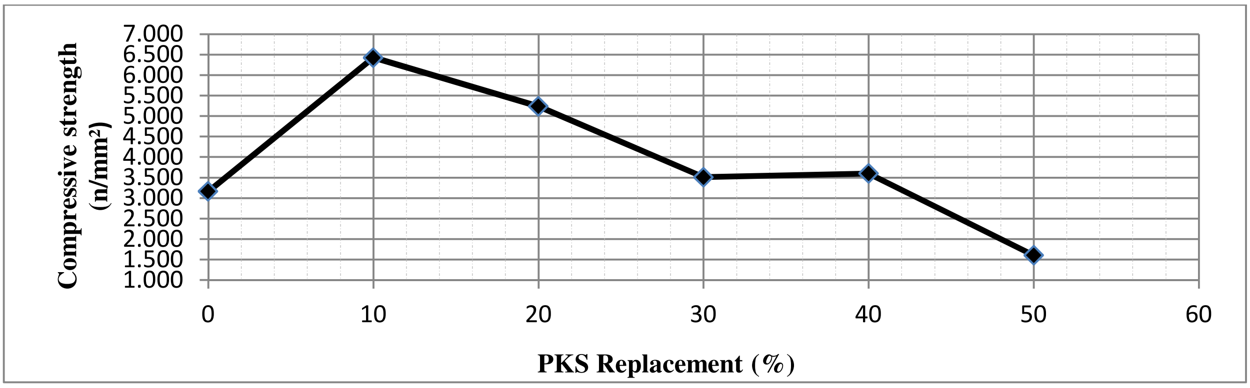

Figure 4.7: Relationship between percentage PKS replacement and compressive strength of block

5 Conclusions and Practical Implications

5.1 Summary of Findings

The study has reveal that both river sand and the PKS from the local palm oil producers are poorly graded since result from grading test on both material sampled did not satisfy grading test requirement . In term of water absorption, it was observed from the study that from 10% to 40% PKS aggregate replacement, the resulting water absorption capacity exceeds the minimum standard recommend by ASTM C55, (2011). It also appeared from the study that the weights and densities of the blocks produced increases up to 10% PKS aggregate replacement. On the contrary, above 10% replacement, the weights and densities of the PKS blocks decreases. Also the study has reveal that the compression strength of the PKS blocks exceeds the minimum compression strength of 2.8N/mm^2 required by the BS 6073-1, (1981) when the PKS aggregate replacement for the sand do not exceeds 40%

5.2 Conclusion

PKS blocks were found to be more porous than the traditional sandcrete block, however, up to 40% PKS aggregates replacement, the resulting porosity do not exceed the minimum acceptable standard.

Blocks produced from PKS aggregates are heavier, denser and stronger than the traditional sandcrete blocks when the PKS aggregates content do not exceeds 10%.

At such percentage replacement, the blocks could be classified into medium weight concrete blocks, whereas above 10% to 40% PKS replacement, the blocks produced could be classified as light weight concrete blocks.

5.3 Recommendation

Based on the result obtained, the following recommendations were made:

1. The researcher is optimistic that when both the river sand and PKS aggregates are put together and combined graded, the results will to some extend satisfy the grading requirement recommended in the review. This will therefore eliminate the issue of the aggregates not being economical to use.

2. In terms of water absorption, it is recommended that the use of PKS aggregate in place of sand should not be more than 40% for block production. Furthermore, the PKS blocks are strongly recommended not to be used in areas where high moisture penetration is anticipated.

3. The blocks with percentage PKS aggregate replacement not exceeding 10% (medium weight blocks) is recommended for load bearing walls such as gravity retaining walls, whereas those produced from 10% to 40% PKS is recommended for areas where light weight concrete blocks are suitable.

4. Blocks produced with PKS content above 40% was found to be very light, porous and of low compressive strength, hence recommended for non-load bearing partition walls.

5.4 Future Research

Future research must focus on:

1. Ground PKS as fine aggregate replacement in block manufacture to determine whether the high percentage substitution of PKS aggregates in block production can be achieved and also examine their properties with respect to water absorption, weight, density and compressive strength results to establish possible variations from those obtained in this study.
2. Factors that affect durability such as chemical attacks should be investigated to determine their rate of influence on the durability of the blocks.
3. The socio-economic dimensions of building with such blocks must be investigated.

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