Effects of Palm Kernel Shell and Rice Husk Ash as Partial Replacements of Normal Weight Aggregate and Ordinary Portland Cement in Concrete

Ezekiel S. Philips[1]*, Raphael N. Mutuku[2], and John N. Mwero[3]

[1] Civil Engineering (Structural), Pan African University, Institute of Basic Sciences, Technology and Innovation (PAUSTI), Nairobi, Kenya. E-mail: ezekielphilips@gmail.com
[2] Faculty of Engineering and Technology, Technical University of Mombasa, Mombasa, Kenya
[3] Department of Civil and Construction Engineering, University of Nairobi, Nairobi, Kenya

***Corresponding Author**

Abstract

Palm Kernel Shell (PKS) or oil palm shell, is a by-product of palm oil and palm kernel oil production. It is obtained in crushed fractions varying from fine to coarse aggregate in size. Also, Rice Husk Ash (RHA) is a by-product of rice production resulting from the combustion of rice husk. The aim of this research was to determine the suitability of using PKS and RHA as partial replacements of Normal Weight Aggregate (NWA) and Ordinary Portland Cement (OPC) respectively in concrete production. From the material characterization, both PKS and RHA were determined to be lightweight materials and hence batching in this research was by volume as it was discovered from the literature review that batching by volume gives better results than by weight for lightweight aggregates. Effects of PKS and RHA on normal weight concrete were determined in terms of concrete workability, density, compressive strength, splitting tensile strength, and water absorption. The mix ratio was 1:2:3 for cement, fine aggregate, and coarse aggregate respectively with a constant free water to cement (w/c) ratio of 0.58. PKS was varied at 0%, 25% and 50% while RHA was varied at 0, 10, 15, and 20%. Tests were conducted at 7 and 28 days of curing and results compared with a control cured and tested at the period. It was shown that 25% PKS and 15% RHA substitutions produced the highest strength than the other combinations at 28 days of curing and can be used to produce concrete for low cost construction.

Keywords: Palm kernel shell, rice husk ash, normal weight aggregate, normal weight concrete

1. Introduction

Concrete is the most common construction material used in almost every construction and also the second most consumed substance on Earth after water according to Smith and Maillard (2007). Its application includes buildings, roads, bridges, dams, retaining structures, stadiums, airports, among others, thereby increasing its demand on the daily basis and also an increase in its price. According to Ismail (2009), its usage is around 10 billion tons per year, which is equivalent to 1 ton per every living person. This high consumption of concrete is the result of the increased in population which brings about increase need for shelter, infrastructure, and work places.

With aggregates making about 60 to 80 percent of the volume of concrete, mining activities for aggregates which include stripping, drilling and blasting, and impact crushing have continued to increase leading to environmental instability, pollution, high cost of construction, and an eventual depletion of the natural resource. Also, cement contributes significantly to the high cost of construction as it is the most expensive constituent material in concrete. The United States Geological Survey (USGS, 2015), reported that the world cement production for the year 2011 was 3.6 billion tons and that by 2012, the production was increased to 3.7 billion tons. Production of cement requires a high amount of energy and there is also a high emission of carbon dioxide (CO_2) in the atmosphere. According to the Trend in Global CO_2 Emission (TGCE, 2015), cement production accounts for roughly 8% of the global CO_2 emissions.

Again, not only has increased in population led to the increased need for shelters, infrastructures and work places, but also an increase need for food. With rice being the primary food for many countries, rice farming has continued to increase all across the globe. Similarly, oil palm farming has also grown across the globe in recent years. According to the Global Palm Oil Conference (2015) report, world production of palm oil and palm kernel oil has grown rapidly in recent decades from about 2 million metric tonnes in 1961 to over 56 million tonnes in 2012. The negative effect of these high agricultural activities is the high pollution across the globe as for instance, PKS, the by-product of the oil production process is openly burn as a mean of disposal emitting a significant amount of CO_2 in the atmosphere. Similarly with rice production, approximately 20kg of rice husks are obtained for 100kg of rice produced (Mehta, 1992)) which is also openly burn as a mean of disposal.

Hence to mitigate some of these challenges, this research hopes to establish the suitability of using PKS and RHA in concrete production by partially replacing NWA and OPC respectively for low cost construction. The aim is to reduce the high construction cost for shelters, infrastructures and work places, boost resource preservation, and finally reduce environmental pollution.

2. Material and Method

Materials used for this research included PKS, Normal Weight Aggregate (NWA), RHA, OPC, Fine Aggregate (river sand), and tape water. Basic characteristics of these materials were determined before their inclusion in concrete production. Equipment included 150mm cube molds, 100mm diameter and 200mm height cylinder molds, mixing tray, shovels, trowel, vibrator, and batch box, Universal Testing Machine, oven and curing tanks. Others included pyknometer, weighing scale, Aggregate Impact value machine, test sieves, among others.

The mix ratio use in this study was 1:2:3 for cement, sand, and coarse aggregate respectively by volume with a constant free water to cement ratio of 0.58 in accordance with BS 1881-125 (1983). Mixing was done manually with a control mechanism to prevent the loss of water quantified for the mixing purpose. Cubes of dimensions 150mm X 150mmX 150mm and cylinders with a diameter of 100mm and 200mm long were casted, cured and demoldedat 7 and 28 days prior to testing. Method of curing used was by immersing specimens in curing tanks. The particle size distribution (PSD) was performed for PKS, NWA, and fine aggregate in order to determine the grading of each in accordance with BS 812-103 (1990).

The workability of the concrete was determined through slump test. Slump test was conducted in accordance with provision of BS 1881-102 (1983). The water absorption test was conducted on hardened concrete for all mixes. Three cube specimens of each concrete mix were cured for 28 days before testing. After the 28 days curing, the specimens were placed in a drying oven of temperature 100^{o}C for a period of 72hrs conforming to specification of BS 1881-122 (1983).

For the determination of the compressive strength, 3 cube specimens for each mix were tested at 7 and 28 days of curing using a Universal Testing Machine (UTM) as specified in BS 1881-115 (1983). Also, the UTM was used to determine the splitting tensile strength on concrete cylinders at 7 and 28 days of curing in accordance with BS 1881-117 (1983).

3. Results and Discussion

3.1. Material Characteristics

Characterization of PKS and NWA were in terms of PSD, water absorption, specific gravity, ACV, AIV, and bulk density. RHA was characterized in terms of specific gravity, particle size distribution (hydrometer analysis), and chemical composition. Fine aggregate was characterized in terms of PSD, water absorption, specific gravity, and fineness modulus.

3.1.1 Characteristics of PKS, NWA, and fine aggregate

The result for the particle size distribution (PSD) of PKS and NWA is shown in Figure 1 while that of the fine aggregate is presented in Figure 2. It can be seen that the combined particle sizes of PKS and NWA were between 5mm – 15mm and that PKS was finer as compared to the NWA which might demand more cement paste for a stronger bonding of the aggregate. Hence, with all factors being constant, PKS substitution might result in reduce workability and strength of the concrete and might also increase concrete water absorption due to its increased surface area as it is finer than the NWA. Also, the NWA used was single size as about 80% was retained on sieve no. 10mm which might lead to the production of concrete with many voids, or the use of a larger portion of fine aggregate to fill those voids between the aggregates.

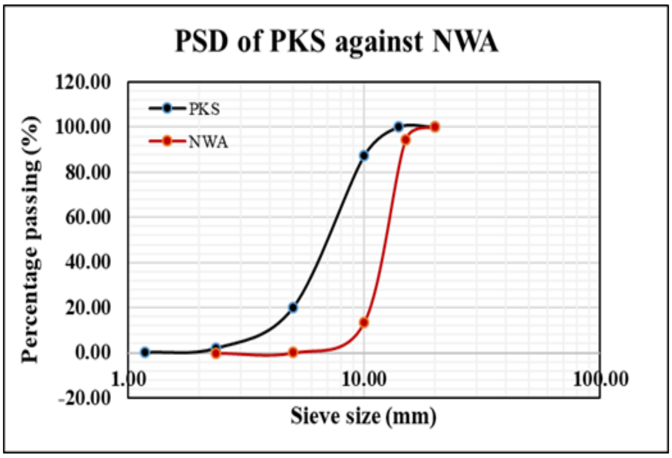

Figure 1: Particle size distribution of PKS and NWA

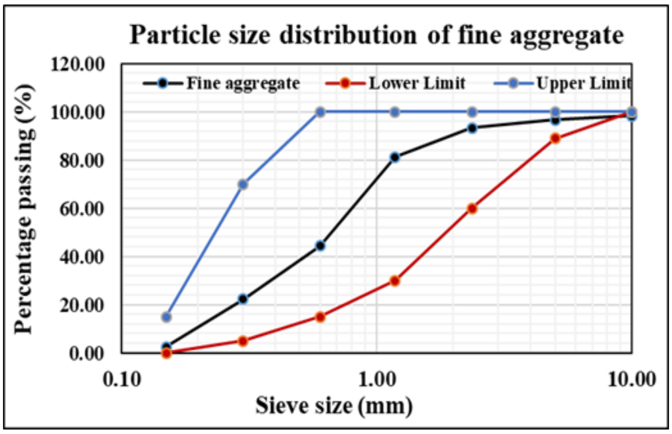

Figure 2: Particle size distribution of fine aggregate

The fine aggregate used has particles in the range of 0.15mm – 5mm in conformation to the requirements of BS 882 (1992), hence indicating uniformity in the concrete. Also, the particle size distribution satisfied ASTM C33 (1999) requirement for graded aggregate which required that the fine aggregate be less than 45% retained on any one sieve. ASTM C33 also suggested that the fineness modulus be kept between 2.3 and 3.1. This due to the fact that a 'very fine' fine aggregate will increase water demand of the mix, while a 'very coarse' fine aggregate could compromise workability. The fine aggregate used had a fineness modulus of 2.68.

PKS had a 24hrs water absorption of 30.4% while the 24hrs water absorption of NWA and fine aggregate were 2.9% and 6.5% respectively. Hence, it can be seen that PKS has a high water absorption as compared to NWA and fine aggregate used in this research. This therefore might result in reduce concrete workability as the quantified water could be absorbed by the PKS. Reduction in workability leads to poor compaction of concrete, thereby producing concrete with so many pores that can compromise on concrete strength and durability. Also, the absorptive nature of PKS might be advantageous in concrete as it may serve as internal reservoir thereby enhancing the development of concrete strength gradually.

PKS had a specific gravity of 1.4 while that of NWA and fine aggregate were 2.58 and 2.44 respectively. According to Popovics (1992), aggregates with specific gravity less than 2.4 are classified as light weight aggregate (LWA), and therefore, PKS was treated as a LWA in this research. This low specific gravity of PKS might lead to the production of concrete with low density which can bring about reduction in construction cost as smaller sections can be used in the construction. However, reduction in concrete density can also cause reduction in concrete compressive strength.

The aggregate crushing value (ACV) of PKS was 2.15% while that of NWA was 17.5%. According to BS 812 (1990), the maximum recommended ACV for aggregates for the production of concrete is 30%, implying that the higher the ACV, the poorer is the material in resisting compressive load. Therefore, PKS used in this research had a better resistance to compressive load than the NWA. Similarly, the aggregate impact value (AIV) for PKS was 4.6% while that of NWA was 7.6%. Again, BS 882 (1992) recommended the maximum limit for aggregates adequate for concrete with good impact resistance to 25%. This also imply that aggregates with a high AIV have a weak impact resistance than those with a low AIV. Therefore, the PKS used was tougher than the NWA and should perform better in preventing crushing, degradation, and disintegration when stockpiled, fed through, or compacted with rollers without causing construction and performance problems. Table 1 shows the characteristic summary of PKS, NWA, and fine aggregate used in the research.

Table 1: Characteristics summary of PKS, NWA, and fine aggregate

Characteristic	PKS (LWA)	NWA	Fine aggregate
Maximum aggregate size (mm)	10	14	10
Specific Gravity	1.40	2.58	2.44
24hrs water absorption (%)	30.44	2.92	6.53
Bulk density (kg/m^3)	582.982	1,366.23	1,665.00
Loose Density (kg/m^3)	514.389	1,255.40	1,523.58
Aggregate Crushing Value, ACV (%)	2.15	17.42	-
Aggregate Impact Value, AIV (%)	4.63	7.635	-
Fineness modulus	-	-	2.68

3.1.2Characteristics of RHA and OPC

3.1.2.1 Physical properties of RHA and OPC

As shown in Table 2, the specific gravity of RHA and OPC used were 1.77 and 3.11 respectively, and hence it can be said RHA used in this research was treated as a lightweight material since the specific gravity was below 2.4. However, though lightweight, the material will not float in water since the specific gravity is greater than 1 and therefore mixing of the concrete can easily be achieved. Again, the low specific gravity of RHA can contribute significantly in the reduction of concrete density thereby bring a significant reduction in construction cost. On the other hand, if batching is done by weight and all other factors are held constant, for the same masses of RHA and OPC, the volume of RHA will be twice that of OPC as the specific gravity of OPC is almost twice that of RHA.

Also, it can be seen that the bulk density of RHA is just about 25% that of OPC. Hence it can be said that the OPC is about 4 times denser than the RHA, and therefore RHA can be said to contain more pores than the OPC. The most likely implication could be reduction of concrete workability as the quantified water for a particular workability will be absorbed into those pores.

Figure 3 shows the particle size distribution of RHA using hydrometer analysis. It can be seen that about 50% of the particles were between 0.25mm (250µm) to 0.1mm (100µm), about 15% between 0.01mm (10µm) to 0.1mm (100µm), and about 15% below 0.01mm (10µm). The inclusion of particle sizes up 0.25mm was due to the fact that natural rice husk ash was considered for this research and hence no further grinding was done.

Table 2: Physical properties of RHA and OPC

Property	RHA	OPC
Specific Gravity	1.77	3.11
Bulk Density (kg/m^3)	355.79	1396.67
Loose Density (kg/m^3)	267.59	1165.36
Mean particle size (mm)	0.15	
Color	Grey	Grey

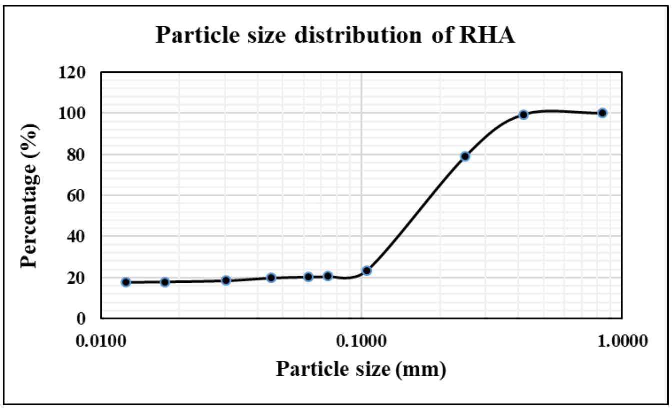

Figure 3: Particle size distribution of RHA

3.1.2.2 Chemical properties of RHA and OPC

Table 3 shows the results of the chemical composition of RHA and OPC used in the research. From the table it can be seen that the combined percentage of silica (SiO2), Iron Oxide (Fe2O3), and Alumina (Al2O3) for RHA was 80.5 thereby meeting the 70% minimum requirement of ASTM C618 for a good pozzolana. Also, the free lime content (CaO) of the OPC used was 59%. Therefore, the presence of silica, iron oxide, and alumina above the minimum requirement for a good pozzolana shows the ability of the RHA to form cementitious compound when mixed with the free lime of the OPC in the presence of moisture.

Table 3: Chemical properties of RHA and OPC

Chemical composition	**Content (%)**	
	RHA	**OPC**
Silica (SiO_2)	80.00	22.00
Aluminum (Al_2O_3)	0.20	4.80
Calcium Oxide (CaO)	0.80	59.00
Magnesium Oxide (MgO)	0.14	0.75
Sodium Oxide (Na_2O)	0.12	0.28
Potassium Oxide (K_2O)	1.40	0.60
Iron Oxide (Fe_2O_3)	0.33	2.44
Manganese Oxide (MnO)	0.12	0.04
Titanium Oxide (TiO_2)	0.05	0.20
Loss of Ignition (LOI)	9.50	6.30

The Loss on Ignition (LOI) for the RHA recorded was 9.5 while it was 6.3 for the OPC. Though relatively high when compared to other pozzolanas but still below the 12% maximum standard as per ASTM C618 (2005). This high LOI could be due to the fact that the pyro processing was incomplete, and hence igniting the sample resulted in the evaporation of variety of components in the sample. For instance, carbonates could have been lost by the time the ignition was between 800 – 1000^{o}C. Hence, possible implication could be pre-hydration which could result in reduced workability, compressive strength, and might also increase setting time of the concrete.

The calcium oxide (CaO) content of 0.8 for the RHA is also a good indicator for the production of durable concrete according to Shehata et al. (1999), who stated that low CaO content is good as it helps in the reduction of pore solution alkalinity.

3.2 Workability of PKS and RHA concrete

Workability of PKS and RHA concrete is shown on Figure 4. As shown, the workability of the concrete reduces with increase in PKS and RHA content in the mix as compared to the control concrete. This can be attributed to the finer particle sizes of PKS (Figure 4-3) as compared to the NWA and hence demanding more water for a higher workability. Also, the absorptive characteristic of RHA according to Kartini (2011) might have contributed to the reduction in workability. That could be the reason why there was a reduction in slump for all of PKS and RHA combinations than the control concrete. Again the high loss on ignition for RHA might have contributed significantly to the reduction in the workability of the concrete. High loss of ignition might have been due to the incomplete combustion process thereby containing some unburn elements that might have absorbed the water quantified for the mix and thus reducing the concrete slump.

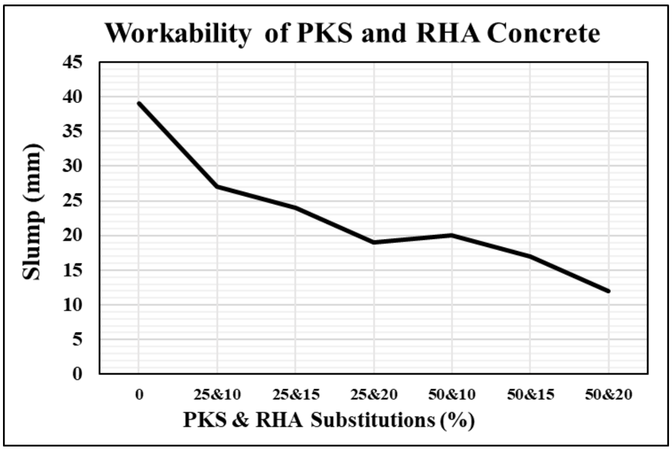

Figure 4: Workability of PKS and RHA concrete

From the graph, it appears like the RHA contributed more to the reduction in the slump than the PKS. It can be seen from the slump curve that when 25% PKS and 10% RHA were combined, the resulting slump was higher than for all other combinations. Hence, holding PKS at 25% while increasing the content of RHA to 20%, there was a further reduction of about 30%. When RHA was maintained at 10% and PKS increased to 50%, the reduction in slump was about 26%. This shows that RHA was more water demanding than the PKS which could be true since the water absorption of PKS was accounted for in the mix.

Hence, reduction in concrete workability might result in the production of porous concrete due to compaction difficulties. Porous concrete due to poor compaction lead to the reduction in concrete strength, reduced concrete density, and also increased water absorption that could compromise on the durability of the concrete.

3.3 Density of PKS and RHA concrete

The density of PKS and RHA concrete reduces with increase in PKS and RHA content but increases with curing age. As shown in Figure 5, the least density recorded was 2095.7 kg/m^3 when both PKS and RHA were at their highest percentages (50%PKS & 20%RHA). At their lowest percentages (25%PKS & 10%RHA), the highest density of 2276.3 kg/m^3(about 92% of the control concrete) was recorded. Thus, the reduction in the density can be attributed to the low specific gravity of PKS (Table 1) as compared to NWA and also the low specific gravity of RHA (Table 2) as compared to OPC. Also, the reduction in the concrete slump (Figure 4) might have caused poor compaction and thereby producing porous concrete with a reduced density. On the other hand, the increase in the density of the concrete with curing age might have been due to the absorption of the curing water in the pores of the concrete.

Again, it can be seen that though both PKS and RHA contributed in the reduction of the concrete density, bulk of the reduction was governed by the PKS content. The curve can be seen to have dropped significantly when PKS content was increased from 25% to 50% which was not the case for the increase in the content of RHA. This could be due to the fact that the specific gravity of PKSwas lower than that of RHA and also PKS had a larger volume and a higher percentage in the mix than the RHA.

However, the lowest density from all of the combinations was above the 2000kg/m^3 minimum requirement for NWC according to BS 5328-1 (1997). Hence, PKS and RHA partial replacement for NWA and OPC respectively by volume produces NWC with a significant reduction in density that can result in significant savings in construction cost as smaller sections can be selected rather than larger ones as those for high density concrete. Nevertheless, reduction in concrete density might also lead to the reduction in the concrete strength.

Statistically, a factorial analysis was carried out to check the effect of PKS, RHA, and the interaction between PKS and RHA on the density of the concrete. It was determined that PKS ($p = 0.000$) had a significant effect on the density of the concrete, RHA ($p = 0.000$) also had a significant effect on the density of the concrete, but the interaction between PKS and RHA ($p = 0.135 > 0.05$) had no significant effect on the concrete density. From the post hoc test, it was shown that there was a significant difference in the density of the concrete between all of PKS substitutions. For RHA, though it had a significant effect on the concrete density, it was found that there was no significant difference in the density of the concrete between 10% and 15% substitutions, and also between 15% and 20% substitutions at 0.05 level of significance.

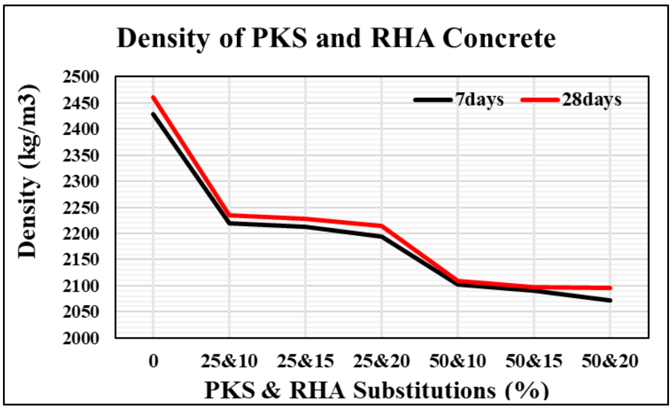

Figure 5: Density of PKS and RHA concrete

3.4 Compressive strength of PKS and RHA concrete

As shown in Figure 6, the compressive strength of PKS and RHA concrete reduces with increase in PKS and RHA content but increases with curing age. This can be attributed to the increased surface area of PKS as it was finer (Figure 1) than the NWA thereby resulting into weak bonding as more cement paste might have been demanded. It can also be attributed to poor compaction which might have resulted due to the reduction in the slump (Figure 4) creating voids that might have led in the reduction of the compressive strength. Also, the reduction in the concrete density with increase in PKS and RHA content (Figure 5) might have also contributed to the reduction in the compressive strength. Again, since lime – pozzolana reactions required time, it could be that the 28 days curing period was not sufficient for the full development of the strength and thus resulting in the reduction of the compressive strength.

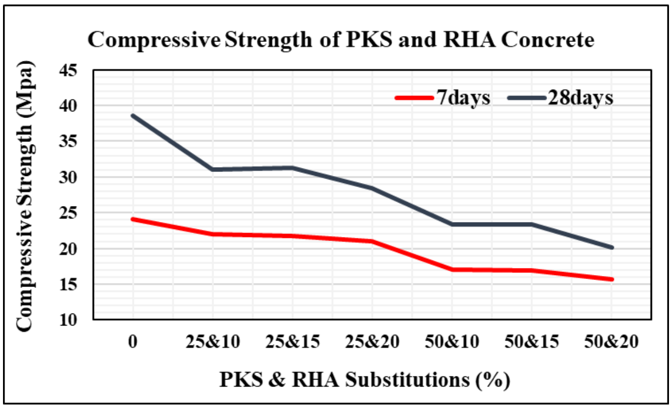

Figure 6: Compressive strength of PKS and RHA concrete

From the graph, the 25%PKS and 15%RHA combination is seen to have the highest compressive strength than any other combination at 28 days of curing. The reason for this might be that beyond the 7 days of curing, the lime – pozzolana reactions might have started and that the 15% RHA had the maximum amount of silica content needed to have reacted with the free lime and thus resulting in a faster strength development rate than the other substitutions. However, though compressive strengths for all of the combinations were lower than that of the control concrete, the least compressive strength obtained was yet still above the minimum compressive strength requirement of 2,500psi (17MPa) for structural concrete according to ACI 116R (2000). Hence, PKS and RHA can be used as partial replacement of NWA and OPC respectively to produce structural concrete for the low cost construction of residential buildings.

A factorial analysis was carried out to check the effect of PKS, RHA, and the interaction between PKS and RHA on the compressive strength of the concrete. It was determined that PKS ($p = 0.000$) had a significant effect on the compressive strength of the concrete, RHA ($p = 0.000$) had a significant effect on the compressive strength of the concrete, but the interaction between PKS and RHA ($p = 0.999 > 0.05$) had no significant effect on the concrete compressive strength. From the post hoc test, it was shown that there was a significant difference in the concrete compressive strength between all PKS levels of substitution. However, though RHA had a significant effect on the concrete compressive strength, it found that there was no significant difference in compressive strength between 10% and 15% substitutions at 0.05 level of significance.

3.5 Splitting tensile strength of PKS and RHA concrete

Figure 7 depicts the splitting tensile strength of PKS and RHA concrete. Similar trends as the compressive strength were observed with the splitting tensile strength. Increase in the percentage of PKS and RHA contents resulted in the reduction of the splitting tensile strength while there was an increase in the splitting tensile strength with curing age. Reduction in the splitting tensile strength with increase in PKS and RHA contents can also be attribute to the increase surface area of PKS which might have resulted in poor bonding. Reduction in the concrete slump (Figure 4) might have also caused poor compaction hence leading to porous concrete and the subsequent reduction in concrete strength. Also, the reduction in the concrete density (Figure 5) might have also contributed to the splitting tensile strength reduction of the concrete. Again, 28 days of curing might not have been sufficient for the full development of strength and hence resulting to a lower strength.

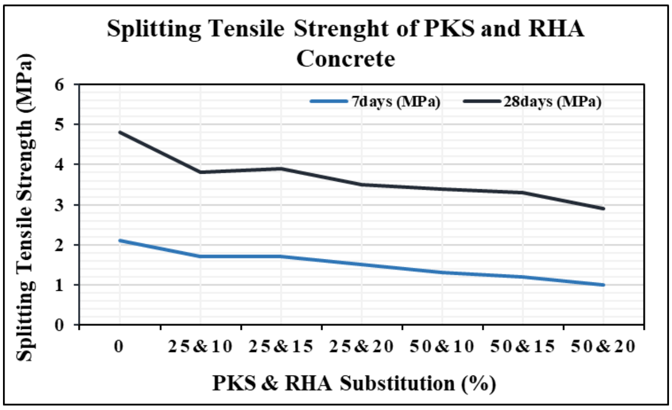

Figure 7: Splitting tensile strength of PKS and RHA concrete

A factorial analysis was also carried out to determine the effect of PKS, RHA, and the interaction between PKS and RHA on the splitting tensile strength of the concrete. It was determined that PKS ($p = 0.000$) had a significant effect on the splitting tensile strength of the concrete, RHA ($p = 0.012$) had a significant effect on the splitting tensile strength of the concrete, but the interaction between PKS and RHA ($p = 0.986 > 0.05$) had no significant effect on the splitting tensile strength of the concrete. From the post hoc test, it was shown that though PKS had a significant effect on the splitting tensile strength of the concrete, there was no significant difference in the splitting tensile strength of the concrete between 25% and 50% substitutions. Similarly, it was found that there was no significant difference in the splitting tensile strengths between 0% and 10%, 0% and 15%, and also between 10% and 15% RHA substitutions at 0.05 level of significance.

3.6 Water absorption of PKS and RHA concrete

The water absorption of PKS and RHA concrete increases with increase in PKS and RHA content as can be seen in Figure 8. This can be attributed to the high water absorption characteristic of PKS (Table 1) as compared to NWA. Also, the absorptive characteristic of RHA according to Kartini (2011) might have also contributed to the increase in water absorption with increase in RHA content. Again, the reduction in the concrete slump (Figure 4) might have caused poor compaction that may have produced porous concrete and hence increasing the water absorption of the concrete.

The water absorption of the concrete with 25% PKS and all the percentages of RHA were lower than when PKS was increased to 50% with the same RHA percentages. Hence, it can be said that water absorption was chiefly governed by the PKS percentage in the mix. This can be attributed to the high absorption characteristic of PKS.

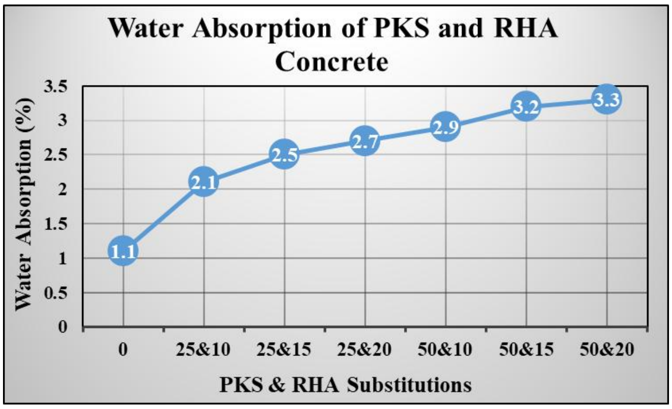

Figure 8: Water absorption of PKS and RHA concrete at 28 days

Though water absorption of PKS and RHA concrete is higher than the control concrete, but can be said to be low when compared to other lightweight aggregate concretes such as expanded polystyrene concrete and pumice aggregate concrete with water absorption in the range of 14 – 22% according to Guduz and Ugur (2005). High water absorption can lead to less durable concrete especially in aggressive environments. On the other hand, the absorptive characteristic of PKS and RHA can be advantageous as they may serve as inner reservoirs thus enhancing the gradual development of concrete strength.

A factorial analysis was conducted to determine the effect of PKS, RHA, and the interaction between PKS and RHA on the water absorption of the concrete. It was determined that PKS ($p = 0.000$) had a significant effect on the concrete water absorption, RHA ($p = 0.000$) had a significant effect on the concrete water absorption, but the interaction between PKS and RHA ($p = 0.485 > 0.05$) had no significant effect on the concrete water absorption. From the post hoc, it was shown that there was a significant difference in the water absorption between all PKS substitutions, and also there was a significant difference in water absorption between all RHA substitutions at 0.05 level of significance.

4. Conclusions and Recommendations

4.1 Conclusions

The following conclusions can be drawn from the investigation:

1. The specific gravity, AIV and ACV of PKS fall within acceptable range for lightweight aggregate, and also, RHA chemical compositions satisfied the requirement of pozzolana and can be used as partial replacement for OPC.
2. The workability of the concrete reduces with increase in the replacement percentages of PKS and RHA.
3. The partial replacements of PKS and RHA for NWA and OPC respectively reduces concrete density. However, 50% PKS and 20% RHA substitutions by volume still produce concrete density within the acceptable range for NWC.
4. The partial replacements of PKS and RHA for NWA and OPC respectively reduces concrete compressive with increase in PKS and RHA content. However, replacement levels up to 50% PKS and 20% RHA by volume produce compressive strength within the acceptable range for structural concrete.
5. The splitting tensile strength of the concrete reduces with increase in the substitution levels of PKS and RHA in the mix.
6. Increase in PKS and RHA contents in the mix increases the water absorption of the concrete.

4.2 Recommendations

1. The use of PKS and RHA in concrete production should be encourage. This will reduces the high demand for NWA and OPC, boost resource preservation, minimize environmental pollution, and also reduce construction cost.
2. Further studies on the durability performance of PKS and RHA concrete should be carried out especially for aggressive environments as PKS is a bio-degradable material.

References

ACI Committee 116 (ACI 116R-2000). Cement and Concrete Terminology. American Concrete Institute, armington Hills, Mich.,2000, 73 pp.

ASTM C33 (1999). Standard specification for concrete aggregates. USA: ASTM international.

ASTM C618 (2005). Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. USA: ASTM International. www.astm.org/standards/C618.htm: pp. 1 – 623.

BS 812 Part 103 (1990). Testing aggregates. Methods for determination of particle size distribution. British Standards Institution, London, UK.

BS 882 (1992). Specification for aggregates from natural sources for concrete. British Standards Institution, London, UK.

BS 1881 Part 102 (1983). Testing concrete. Method for determination of slump. British Standards Institution, London, UK.

BS 1881 Part 115 (1983). Testing concrete. Specification for compression testing machines for concrete. British Standards Institution, London, UK.

BS 1881 Part 117 (1983). Testing concrete. Method for determination of tensile splitting strength. British Standards Institution, London, UK.

BS 1881 Part 122 (1983). Testing concrete. Method for determination of water absorption. British Standards Institution, London, UK.

BS 1881 Part 125 (1983). Testing concrete. Method for mixing and sampling fresh concrete in the laboratory. British Standards Institution, London, UK.

BS 5328 Part 1 (1997). Guide to specifying concrete. British Standards Institution, London, UK.

Global palm oil conference (2015). Background Document: An overview of the palm oil sector: countries and companies. Bogota, Colombia 12-13 March, 2015. http://www.iuf.org/w/sites/default/files/Palm%20Oil%20Background%20document.pdf

Guduz, L. and Ugur, I. (2005). The effects of different fine and coarse pumice aggregate/cement ratios on the structural concrete properties without using any admixtures, Cement and Concrete Research, Vol. 35(9), pp.1859–1864.

Ismail Mohamed A. (2009). Study on the Properties of Palm Oil Fiber. Faculty of Civil Engineering Universti Teknologi Malaysia, 93.

Kartini, K. (2011). Rice Husk Ash-Pozzolanic Material for Sustainability. International Journal of Applied Science and Technology, 1(6), 169–178.

Mehta, P.K. (1992). Rice husk ash—a unique supplementary cementing material. Proceedings of the International Symposium on Advances in Concrete Technology, CANMET/ACI, Athens, Greece, pp. 407–430

Popovics, S. (1992). Concrete Materials Properties, Specifications and Testing, 2nd Edition, Noyes Publications, New Jersey, USA.

Shehata, M. H., Thomas, M. D. A., and Bleszynski, R. F. (1999). The effects of fly ash composition on the chemistry of pore solution in hydrated cement pastes. Cement and Concrete Research 29 (1999) 1915–1920.

Smith, T., and Maillard, P.-L. (2007). The Sustainable Benefits of Concrete Pavement.

United States Geological Survey (USGS, 2015). Mineral Commodity Summaries, January 2015. https://minerals.usgs.gov/minerals/pubs/mcs/2015/mcs2015.pdf

Trend in Global Carbon Dioxide Emission (TGCE, 2015). PBL Netherlands Environmental Assessment Agency. http://edgar.jrc.ec.europa.eu/news_docs/jrc-2015-trends-in-global-co2-emissions-2015-report-98184.pdf