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Palm Kernel Shell as Partial Replacement for Normal Weight Aggregate in Concrete

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Abstract
Palm Kernel Shells (PKS) are fractions of shells that result from the cracking of the nut to remove the seed for the production of palm kernel oil. They are of irregular shapes and vary in sizes from fine aggregate to coarse aggregate. The aim of this research was to determine the effect of PKS on Normal Weight Concrete (NWC) as partial replacement of normal weight aggregate (NWA). Effects of PKS on NWC considered were in terms of workability, density, compressive strength, splitting tensile strength, and the water absorption of the concrete. Batching was by volume since PKS was characterized as a light weight material, and substitutions were made at 0%, 25%, and 50%. The mix ratio adopted was 1:2:3 for cement, fine aggregate, and coarse aggregate with a constant free water to cement ratio (w/c) of 0.58. Curing method was by immersion and effect on the mechanical properties (compressive and tensile strengths) were determined at 7 and 28 days of curing. It was observed that the compressive, tensile strength, workability, and concrete density reduce as PKS content is increased in the mix. On the other hand, water absorption increases with increased in PKS content. However, results were in acceptable range for normal concrete.
Keywords: Palm kernel shells, normal weight concrete, normal weight aggregate

1. Introduction

Concrete is a composite material consisting of cement, aggregates and water all in definite proportions with water and cement being the only active constituents. Aggregates on the other hand serve as inert filler materials while at the same time improving concrete workability, volume stability and durability. According to Gambhir (2013), the reasons of using aggregate in the production of concrete are due to the economic reasons, volume stability and durability of concrete. Aggregates account for about 60 – 80 percent of the total volume of concrete depending on the mix design. Extraction and crushing of these natural aggregates usually involves stripping, drilling and blasting, and impact crushing causing pollution and environmental instability, and also leading to a total depletion of the natural resource. Ismail (2009) reported that concrete usage is around 10 billion tons per year, which is equivalent to 1 ton per every living person. This high production and consumption of concrete is due to the continuous increase in the population. Increase in population hence leads to an increase in the demand for basic needs of mankind such as shelter, workplace, and infrastructure hence leading to the high cost of the material and thus the high cost of construction. This increase in the cost of construction was reported by Global Construction Perspective (2015), as it was reported that global construction had reached 8.7 trillion United States Dollars (USD) in 2012 and is expected to rise to 15 trillion USD by 2025.

Also, increase in population brings about increase in agricultural activities in order to tackle the problem of food insecurity. This has also increase agricultural activities across the globe with palm farming being one of those main activities. According to the Global Palm Oil Conference (2015), 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. Hence, World Bank had estimated that world consumption of palm oil will double by 2020 (Global Palm Oil Conference, 2015). Hence, the negative effect of these agricultural activities is the high environmental pollution. For instance, PKS which result from the palm kernel oil production is openly burn as a mean of disposal releasing significant amount carbon dioxide (CO_2) in the atmosphere.

Therefore, as a mean of addressing some of these challenges, that is, the high cost of cpmcrete, depletion of the natural resource and environmental pollution, this research aim was to determine the suitability of using PKS in concrete production as a partial replacement of NWA for low cost construction. Hence, the use of PKS in concrete production will bring about a significant reduction in the construction cost, reduction in the mining activities for aggregate, and also a significant reduction in environmental pollution.

2. Materials and Methods

Materials used for this research included PKS, NWA, fine aggregate, ordinary Portland cement (OPC), and Water. PKS was obtained from Uganda, Buggala Island in Kalangala while NWA was locally obtained and prepared in accordance with BS 882 (1992). Aggregate crushing value in accordance with BS 812 (1990), aggregate impact value in accordance with BS 882 (1992), particle size distribution in accordance with BS 812-

103 (1990), as well as the specific gravity and the 24 hrs water absorption tests in accordance with BS 812-2 (1995), were determined for both PKS and NWA. The fine aggregate used was collected locally from Meru, a town in eastern Kenya and the headquarters of the Meru County. The sand was sieved on a 5.0mm test sieve to remove larger particles. Water absorption, particle size distribution and fineness modulus were determined before used. Portable water from Jomo Kenyatta University of Agriculture and Technology (JKUAT), free from impurities, was used throughout the research for both mixing and curing of concrete. The cement used for this research was Ordinary Portland Cement (OPC) class 42.5N locally obtained and was used in accordance with BS EN 197-1 (2000).

The mix ratio use in this study was 1:2:3 for cement, sand, and coarse aggregate respectively by volume with a constant w/c of 0.58 in accordance with BS 1881-125 (1983). Mixing was done manually using shovels and trowels. Cubes specimens (150x150x150mm) and cylinders (100mm in diameter and 200mm height) were casted and cured for 7 and 28 days.

The workability of the concrete was determined through slump test in accordance with provision of BS 1881-102 (1983), while the water absorption test was conducted in accordance with BS 1881-122 (1983). Compressive strength and splitting tensile strength were determined using a Universal Testing Machine (figure 1) in accordance with BS 1881-116 (1983) and BS 1881-117 (1983) respectively.

Figure 1: Universal testing machine (UTM)

3. Results and Discussion

3.1 Material Characteristics

3.1.1 Particle size distribution of PKS and NWA

Results for the particle size distribution (PSD) of PKS and NWA are presented in Figures 2. The maximum aggregate size for PKS was 10mm and 14mm for NWA. From the figure it can be seen that the combined particle sizes of PKS and NWA were between 5mm – 15mm which represented about 90% of the total aggregate. Again, the figure shows that the PKS used in this research was finer than the NWA and therefore its substitution for NWA will increase the surface area of the aggregate which might lead to a high demand of cement paste for proper bonding. Holding all factors constant, PKS substitution for NWA will produce less workable concrete due to the increase surface area of PKS. With poor workability, compaction might also be poor leading to a concrete with many voids that could reduce concrete strength, density, and durability as it may also result in increased level of water absorption.

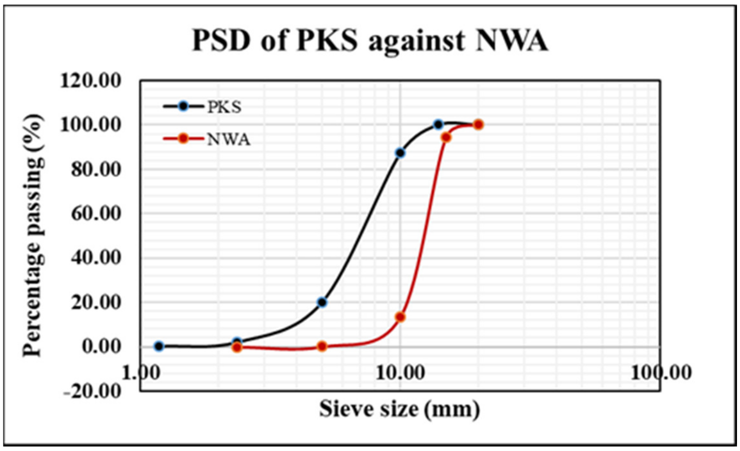

Figure 2: Particle size distribution of PKS and NWA

Also from the figure, it can be seen that the NWA used was single size aggregate as about 80% of the aggregate was retained on sieve no. 10mm. Hence, the likely implication could be the formation of voids in the mixed due to the lack of smaller sizes to fill the voids. However, to avoid this situation, a large portion of fine aggregate is required to fill up those voids in order to produce durable concrete with less voids.

3.1.2 Particle size distribution of fine aggregate

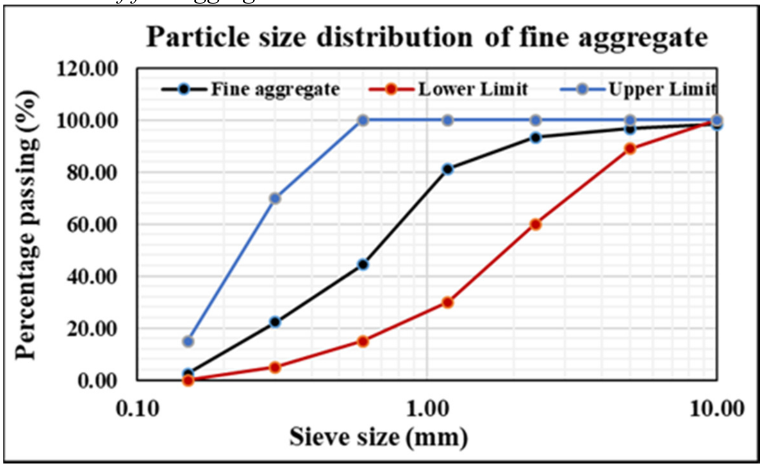

Figure 3: Particle size distribution of fine aggregate

The fine aggregate used was well graded as particles range from 0.15mm – 5mm in sizes. Hence, from Figures 3, it can be seen that the grading of the aggregates satisfied the requirements of BS 882 (1992), hence indicating uniformity in the concrete. Graded aggregate contributes to the quality of the concrete better than non-graded aggregate. Graded aggregate also increases the density of the concrete and reduces water permeability. It also leads to workable concrete with less voids and improves durability.

Also, the figure shows that the particle size distribution satisfied ASTM C33 (1999) requirement for graded aggregate, which requires that the fine aggregate be less the 45% retained on any one sieve. Too much material on one sieve means gap – grading, which will increase the cement – paste demand in the mix. ASTM C33 also suggested that the fineness modulus be kept between 2.3 and 3.1. This is 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. Hence, the fineness modulus obtained was 2.68 which shows that the material was not very fine and not very coarse either. Therefore suitable for the production of concrete with high workability and finish-ability.

3.1.3 Water absorption of PKS, NWA, and fine aggregate

The 24 hours water absorption for PKS, NWA, and fine aggregate obtained were 30.4%, 2.9%, and 6.5% respectively. Of the three aggregates, it can be seen that PKS had the highest percentage of water absorption. This high water absorption of PKS can be attributed to the presence of micro tiny pores on the convex surface of the material. Though seems pretty high but still lower in water absorption than other aggregates such as pumice aggregates which have a 24hrs water absorption of 37% according to Hossain and Khandaker (2004).

Hence, it can be said that the high water absorption of PKS could lead to poor concrete workability as the quantified water for a given concrete workability might be absorbed by the PKS. This situation leads to poor compaction of concrete by creating voids that could compromise concrete strength and durability. Also, due to absorptive nature of PKS, using PKS in concrete might serve as internal reservoirs as the absorbed water is stored in the concrete and hence enhance the gradual development of concrete strength as it is known that concrete strength continues to develop in the presence of moisture.

3.1.4 Specific gravity of PKS, NWA, and fine aggregate

The specific gravity for PKS, NWA, and fine aggregate recorded were 1.4, 2.58, and 2.44 respectively. From these results, PKS can be characterized as a light-weight aggregate (LWA) according to Popovics (1992), who stated that aggregates with specific gravity less than 2.4 are classified as LWA. Therefore, for this research, PKS was considered as a LWA.

Thus, due to the fact that PKS has been determined to be a lightweight aggregate, batching by weight will therefore mean that for the same masses of PKS and NWA, the volume of PKS will be about twice that of NWA in the mix. This increases the surface area of PKS in the mix and increasing the demand for more cement paste. Hence, if the w/c ratio is held constant, concrete produce with PKS will have poor workability and strength than the concrete produced with the NWA. It can therefore be said that batching by volume works better than by weight for PKS aggregate.

Also, the low specific gravity of PKS might lead to the production of concrete with density below 2000kg/m^3. This might also cause the reduction in compressive strength as concrete density contributes significantly to the compressive strength. On the other hand, the low density of PKS concrete could bring about significant savings in construction cost as smaller sections can be selected rather than larger sections like those for normal concrete.

3.1.5 Aggregate crushing value of PKS and NWA

The ACV for PKS and NWA were 2.15% and 17.42% respectively. BS 812 (1990) gave the maximum recommended ACV for aggregates for concrete production to 30%. This means that aggregate with higher ACV have poor resistance to compressive load while those with low ACV have good resistance to compressive load. Hence, from the results obtained, it can be seen that PKS has a lower ACV than the NWA and is therefore expected to perform better when being crushed under a gradually applied compressive load. In order words, it can be said that the material is more ductile than the NWA, and that the material can sustain stress without abrupt failure.

3.1.6 Aggregate impact value of PKS and NWA

The AIV for PKS and NWA were 4.6% and 7.6% respectively. BS 882 (1992) specified limit for AIV for aggregates which are adequate for concrete with good impact resistance is 25%. As with the ACV, this also means that aggregate with higher AIV have weak impact resistance while those with low AIV have good impact resistance. Therefore, from the results obtained, PKS showed better impact resistance than the NWA.

Hence, it can be said that PKS is tougher than the NWA and can prevent crushing, degradation, and disintegration when stockpiled, fed through, and 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
24 hr 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

3.2 Workability of PKS concrete

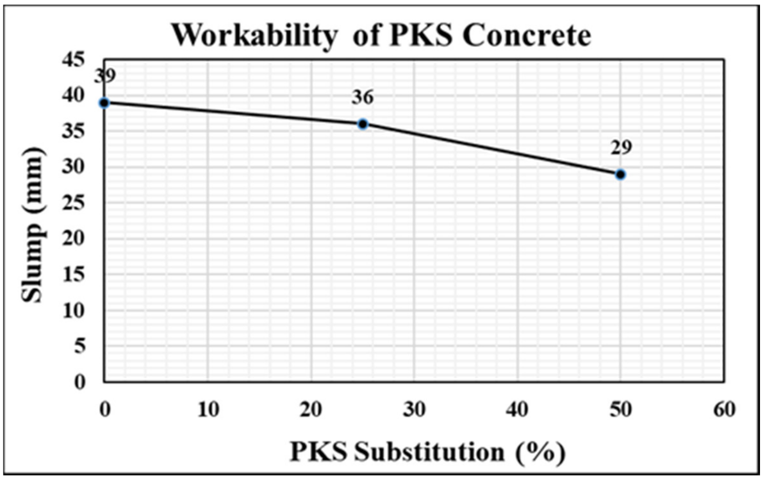

Figure 4: Workability of PKS concrete

The results obtained from the slump test for different percentages of PKS substitution for NWA are presented in Figure 4. With a constant w/c ratio, the concrete slump with 0% PKS was 39mm, 36mm at 25%PKS substitution, and 29mm at 50%PKS substitution. Though the water absorption of PKS was taken into account, there was still a reduction in slump with increase in PKS content. Similarly, Danashmand and Saadatian (2011), and Williams et al., (2011) reported reduction in workability with increase in PKS content. This might be due to the finer particle sizes of PKS (Figure 2) when compared to the NWA, and hence increasing the surface area thereby demanding more water.

Hence, decrease in workability as PKS increases can require more compacting efforts which can lead to poor compaction. Poor compaction thus lead to leaving voids in the concrete which can caused reduction in concrete strength, density, and durability. Also, poor compacted concrete can increase the water absorption of concrete which affects concrete durability.

3.3 Density of PKS concrete

The difference in the density of the concrete with various PKS percentages is shown in Figure 5. The result shows the densities of 2459.9, 2311.9 and 2135.6 at 0%, 25% and 50% PKS substitutions respectively at 28days of curing. The figure also shows that the density of the concrete increases with curing age but decreases with increase in PKS content. Similar trend for PKS concrete density has been reported by Itam et al. (2016), Ikponmwosa et al., (2014), and Osei and Jackson (2012). This can be attributed to the low specific gravity of PKS (Table 1) when compared with NWA thus resulting in the reduction of concrete density as PKS percentage is increased in the mix. Also, it can be said that because of the reduction in slump, there must have been poor compaction which could have resulted in leaving voids in the concrete and hence reducing the density. However, up to 50% PKS substitution, the concrete density was still above the 2000kg/m^3 requirement for NWC as specified by BS 5328 -1 (1998) which contradicts with Ikponmwosa et al. (2014) findings that 50% PKS substitution led to a LWC. This can be attributed to the fact that batching by volume replaces equal quantity of NWA by PKS, which if by weight could mean twice the quantity of PKS for NWA at equal masses.

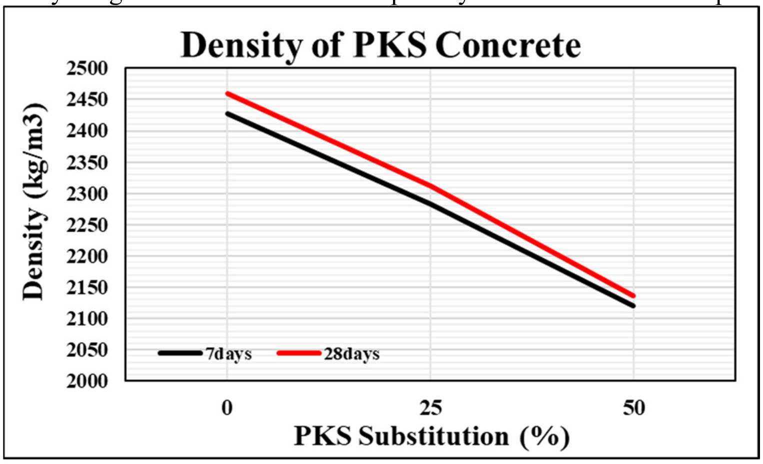

Figure 5: Density of PKS concrete

Hence, reduction in concrete density with increase in PKS content might result in the reduction of concrete strength as concrete density contributes to concrete compressive strength. Also, reduction in concrete density can lead to a significant reduction in construction cost as smaller sections can be selected instead of larger ones as those for NWC.

Statistically, effect of PKS on the density of NWC was determined using a one-way analysis of variance (ANOVA). Result from the analysis showed that there was a statistically significant effect on the density of PKS concrete by the different substitutions as was determined by a one-way ANOVA ($F(2, 6) = 181.766$, $p = 0.000$). Furthermore, to determine which substitutions were significantly different from each other, a "post hoc test" was used. From the post hoc test, it is shown that between all levels of PKS substitution, there was a significant difference in the densities of the concrete at the 0.05 significance level.

3.4 Compressive strength of PKS concrete

The highest values obtained for the compressive strength at 7 and 28days of curing were 24.1MPa and 38.6MPa respectively for the control as shown in Figure 6. The compressive strengths obtained for 25% and 50%PKS substitutions were 22.2MPa and 17.3MPa at 7days of curing and, 33.4MPa and 25.3MPa at 28days respectively.

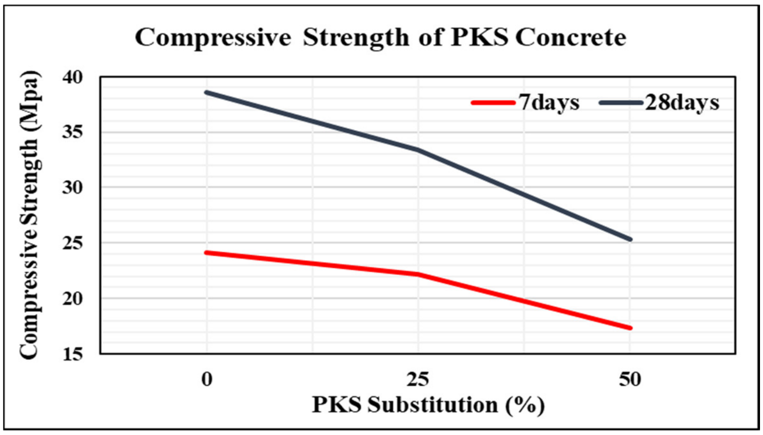

Figure 6: Compressive Strength of PKS concrete

Hence, it can be seen that the compressive strength of concrete increases with days of curing but decreases with an increase in the PKS percentage in the mix. Similar reports were made by Itam et al. (2016), Ikponmwosa et al., (2014), Daneshmand and Saadatian (2011), and Olutoge et al. (2012). Reduction in concrete compressive strength can be attributed to the poor workability of PKS concrete as was seen through the slump test (Figure 4). Reduction in workability might have resulted in poor compaction thereby compromising on concrete compressive strength. Also, the finer particle sizes of PKS (Figure 2) when compared to the NWA might have caused the reduction in the compressive strength as PKS surface area was increased thereby demanding more cement paste for proper bonding. Again, reduction in concrete density with increase in PKS content might have contributed to the reduction in compressive strength. However, the compressive strengths obtained for all of the substitutions were above the 17MPa minimum requirement for structural concrete as specified by ACI 116R (2000). The concrete can therefore be used for the low cost construction of residential buildings.

Statistically, the effect of PKS as partial replacement of NWA on the compressive strength of NWC for the different substitutions was determined by a one-way ANOVA. The analysis showed that there was a significant effect on the compressive strength of normal concrete by the different substitutions of PKS as was determined by a one-way ANOVA ($F(2, 6) = 106.960$, $p = 0.000$). Post hoc test conducted showed that there was a significant difference in the compressive strength of PKS concrete for all PKS substitutions at 0.05 significance level.

3.5 Splitting tensile strength of PKS concrete

The results for the splitting tensile strength at 7 and 28days of curing are shown in Figure 7. The trend of the splitting tensile strength curve is much similar to that of compression. As with the compressive strength, the tensile strength similarly decreases with an increase in PKS percentage but increases with curing age. Reduction in the splitting tensile strength can also be attributed to poor compaction, increased surface area of the PKS, and also reduction in concrete density with increase in PKS content. Hence failure was mainly due to bond failure between the aggregate and the cement paste.

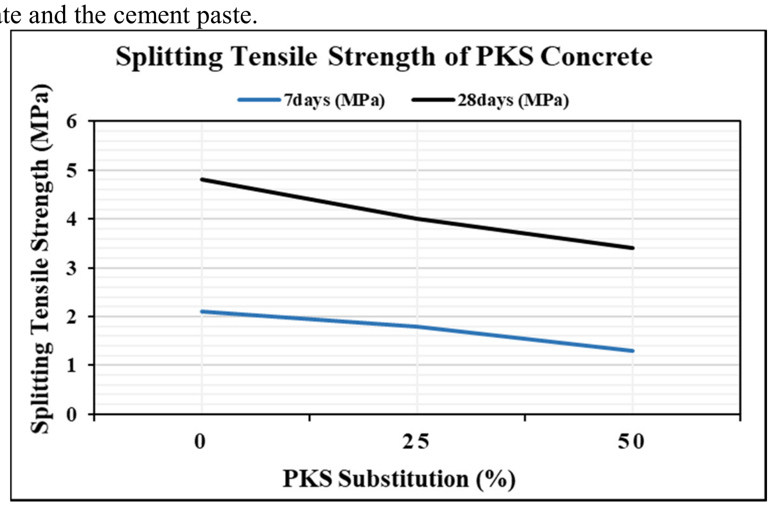

Figure 7: Splitting tensile strength of PKS concrete

From the figure, it can be seen that the splitting tensile strength reduces with increase in PKS content. Again, it was confirmed statistically that there was a significant effect on the splitting tensile strength of the concrete by the different PKS substitutions as was determined by a one-way ANOVA ($F(2, 6) = 37.625$, $p =$

0.000). However, from the post hoc test, it was shown that there was no significant difference between 25% and 50% substitutions, but there was a significant difference between 0% and 25%, and also between 0% and 50% PKS substitutions at the significance level of 0.05.

3.6 Water absorption of PKS concrete

The water absorption of PKS concrete at 28days is higher than that of the control concrete as shown in Figure 8. As oppose to the density, the water absorption of PKS concrete increases with an increase in PKS content in the mix. Similar findings have been reported by Itam et al. (2016) and Olanipekun et al. (2006). This increase in water absorption with increase in PKS content can be highly attributed to the high water absorption of PKS (Table 1). Since PKS is highly absorptive, increasing its content in the mix also increases the water absorption of the concrete. Also, increased in water absorption can partly be attributed to the reduction of concrete workability with increase in PKS content (Figure 4). Poor workability can result to poor compaction thus leaving voids in the concrete which might have increased the water absorption of the concrete.

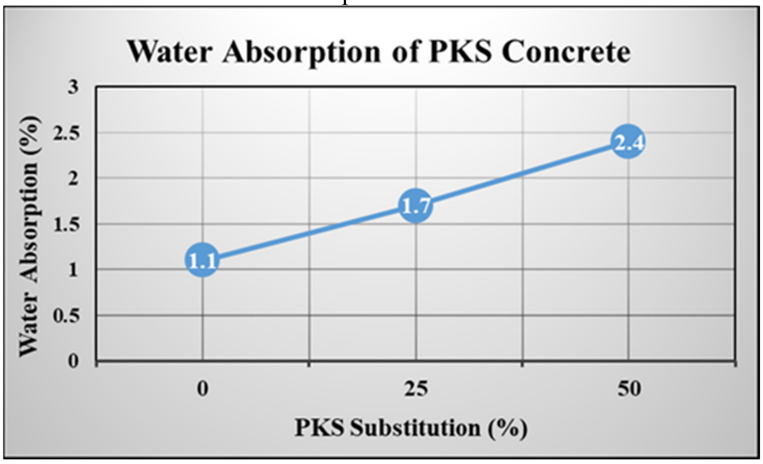

Figure 8: Water absorption of PKS concrete

Though higher than the control, but still considered lower when compared to other lightweight aggregate concrete 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 can be an advantage in concrete as it may serve as an inner reservoir thus enhancing the gradual development of strength. Though the effect of PKS on the water absorption of NWC can be clearly seen on the graph, a one-way ANOVA was also conducted to ascertain the effect. It was also shown statistically that there was a significant effect on the water absorption of the concrete by the inclusion of PKS at different percentages as was determined by a one-way ANOVA (F (2, 6) = 57.211, p = 0.000). From the post hoc test, it was shown that there was a significant difference in the water absorption of the concrete between all PKS percentages. Hence, it can be said that PKS has a significant effect on the water absorption rate of NWA.

4. Conclusions and Recommendations

4.1 Conclusions

Based on the investigation, the following conclusions can be drawn:

1. The specific gravity, ACV, and AIV of PKS all fall within acceptable range for lightweight aggregate and hence can be used to produce low cost concrete by partially replacing NWA,
2. The workability of fresh PKS concrete reduces with PKS content due to the absorptive nature of the material. However, this problem can be handle by incorporating superplasticizer to produce the desire workability.
3. Concrete density, compressive strength, and splitting tensile strength reduce with increase in PKS content. However, PKS substitution up to 50% by volume produces normal and structural concrete with density above 2000kg/m^3.
4. Water absorption increases as PKS content increases in the mix. However, at 50% substitution, water absorption is within acceptable range.
5. PKS can be used as a partial replacement for NWA to produce structural concrete for low cost construction.

4.2 Recommendations

The following recommendations have been made based on the study for consideration:

1. The use of PKS in concrete production should be encourage as it reduces the high demand for NWA hence reducing mining activities for aggregate at the same time minimizing environmental pollution and construction cost.
2. Further studies on the durability performance of PKS concrete should be carried out especially for aggressive environment as PKS is a bio-degradable material.

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