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EFFECT OF PALM KERNEL SHELL AS COARSE AGGREGATE ON THE PROPERTIES OF CONCRETE

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The prospective shortage of conventional aggregate and the environmental impact due to its production are some of the driving forces promoting the use of agricultural or industrial wastes as aggregate for concrete production. This study investigated the influence of palm kernel shell (PKS) as partial replacement of coarse aggregates on the properties of concrete. Concrete specimens containing 0-30% PKS to partially replace coarse aggregate (crushed granite stone) were produced and subjected to workability, compressive and tensile strengths, abrasion, absorption and sorptivity tests. The specimen with 0% PKS is the control for comparison. The result showed that PKS improved workability but reduced compressive strength, tensile strength and abrasion resistance of concrete. However, the specimen containing 10% PKS showed comparable performance with the control. Therefore, 10% PKS could be used to partially replace crushed granite stone for concrete production.

Keywords: absorption, aggregates, concrete, durability, palm kernel shell (PKS), sorptivity

INTRODUCTION

Concrete is defined as an artificial material resulting from a carefully controlled mixture of cement, water, fine and coarse aggregates, which takes the shape of its container or formwork when hardened and form solid mass when cured at a suitable temperature and humidity (Alawode & Idowu, 2011). Fine aggregate is generally natural sand and is graded from particles 5mm in size down to the finest particles but excluding dust. Coarse aggregate is a natural gravel or crushed stone usually larger than 5mm and usually less than 160mm in ordinary structure (Mohd,

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Johnson & Hilimi, 2008). Coarse aggregate deposits consist of gravel or crushed granite that can be readily used in concrete after minimal processing.

The prospective shortage and the environmental impact associated with the conventional coarse aggregates are among the driving forces motivating the use of wastes as aggregate in concrete. In addition, the utilization of waste as aggregates in concrete helps to minimize the environmental burden related to its discriminate disposal (Osei & Jackson, 2012). Moreover, the use of agricultural wastes such as Palm Kernel Shell (PKS) as replacement for coarse aggregate in concrete production seems to be a feasible solution to the problems in terms of practical and economic advantages.

The palm oil industry produces wastes in terms of palm kernel shells (PKS) and palm oil fibres which are usually dumped thereby impacting the environment negatively without any economic benefits. Palm kernel shells are hard, carbonaceous and organic by- products of the processing of the palm oil fruit. Palm kernel shells consists of small size particles, medium size particles and large size particles in the range 0-5mm, 5-10mm and 10-15mm respectively (Alengaram, Mahmud, Jumaat & Shirazi, 2010). The shells have no commercial value, but create disposal and waste management problems.

Several research efforts have been carried out into the use of palm kernel shell as replacement of coarse aggregate in concrete production. Alengaram, Jumaat and Mahmud (2008) used palm kernel shells to produced structural lightweight concrete of up to 35 N/mm2 compressive strength. The suitability of sawdust and palm kernel shells as replacement for fine and coarse aggregate in the production of reinforced concrete slabs was investigated (Olutoge 2010). Result showed that 25% sawdust and palm kernel shell substitution reduced the cost of concrete production by 7.45% as well as producing lightweight concrete slabs. Alengaram, Muhit, Mohd and Jumaat (2013) discovered that concrete made from palm kernel shells had low workability, water absorption capacity of more than 10% with higher initial surface absorption than ordinary concrete. It also showed higher ductile behaviour, higher shear strength, had 8 times the normal amount of creep and reached compressive strength values of 48N/mm2. Palm kernel shells concrete had thermal conductivity of 0.43 W/mK (lower than 0.76 - 3.68 W/mK) usually observed for normal weight concrete. Oyedepo, Olanitori and Olukanni (2015) investigated palm kernel shell as partial replacement for aggregate in asphaltic concrete. Results revealed that crushed palm kernel shell up to 20% can be used as partial replacement of coarse aggregate in asphaltic concrete heavy traffic roads and up to 60% in medium traffic roads. Thus, palm kernel shell is suitable in the production of asphaltic concrete there by achieving free-littering environment as well as economic benefit. Gupta, Singh, Ahmad and Ambedkar (2017) compared concrete produced with palm kernel shell as partial replacement of coarse aggregate and found that around 10% partial replacement of coarse aggregate with palm kernel shells in concrete gives a significant decrease in the cost of construction and weight of the concrete without much affecting the compressive strength of concrete. Proportioning based on the principles of absolute volume method was used to obtain specific properties of lightweight concrete using PKS (Gibigaye, Godonou, Katte and Degan 2017). Mix proportions of C:S: PKS in weight of 1:1.60:0.96 and 1:1.53:0.99 with cement content of 450 kg/m3 and WC = 0.45 resulted in obtaining

appropriate values for workability (≥ 20 mm), density (1800 ≤ d ≤ 1900 kg m3) and cylindrical compressive strength (≥ 15 N/mm2). Response surface methodology was used to design constituent mix proportions of light-weight concrete containing Nigerian palm kernel shells (Oyejobi, Jameel, Sulong, Raji and Ibrahim 2019).

Moreover, Fanijo, Babafemi, and Arowojolu (2020) investigated the performance of concrete made with PKS (as a replacement for coarse aggregate), and laterite (as a partial replacement for fine aggregates). Results showed that the concrete mixtures with only PKS show better workability compared to the control mixture or mixture containing laterite with mechanical properties decreasing as percentage content of PKS and laterite increased in the mix. It was concluded that concrete mixtures with PKS and laterite at 20% or less could be considered in concrete production. Analysis of variance of the results showed that an optimum compressive strength could be reliably predicted. The properties of lightweight concrete made with different sizes (6, 8, 10, & 12 mm) of PKS and mix (each consisting of 25% PKS) was investigated by Danso and Appiah-Agyei (2021). Results showed that a specimen produced with 12mm PKS has better compressive and tensile strengths than other samples in addition to having good bond with other constituent materials.

Although, several works have been done on the use of palm kernel shell as replacement for coarse aggregate in concrete production, however, there is need to determine the physical property, mechanical properties and the durability characteristics of such concrete at a go. The PKS could be used for construction purposes in areas where they are easily available and accessible and places where natural occurring aggregates are not readily available or expensive with the view to promoting them as construction material.

MATERIALS AND METHODS

Materials

The materials used in the experiment are as follows

Cement

The cement used in this research was blended cement of Dangote brand (43.5) that satisfied the requirement of BS EN 197-1:2011. The oxides composition and the physical properties of the cement are presented in Table 1.

Aggregates

Naturally occurring river sand with maximum particles size 4.75mm and retained on 150μm was used. Prior to its use, the sand was sieved to reduced impurities, silt content and large particles in accordance with BS EN 12620:2013 and used in the experiment. The coarse aggregates used were crushed granite of 20mm maximum size and retained on 5mm which were obtained from quarry site located at the outskirt of Zaria, Kaduna state. The bulk density of the aggregates as presented in Table 2 shows that the fine aggregate has a bulk density of 1800kg/m^3, crushed granite 1680kg/m^3 and palm kernel shell (PKS) 730kg/m^3. According to ASTM C330 (1999), the bulk density for sand and crushed granite which are normal weight aggregates is 1450 kg/m^3 to 1800 kg/m^3 respectively. The bulk densities obtained are within the stated range. For the PKS, bulk density of 730kg/m^3 is within the

range recommended by ASTM C330 (1999) for light weight aggregates as cited in Neville (2000). Other physical properties are also shown in Table 2.

Table 1: Oxides composition and physical properties of cement

Oxides composition (%)	SiO_2	Al_2O_3	CaO	Fe_2O_3	MnO	TiO_2	ZnO	Total
Dangote cement	9.135	1.357	51.115	2.341	0.04	0.027	0.003	64.018
Physical properties	Soundness	Setting time (m)		Bulk density (Kg/m^3)	Specific gravity			
		Initial	Final					
	2	90	185	1.53	3.11			

Table 2: Sieve analysis and physical properties of aggregates

	Sieve size (mm)	% passing		
		Fine sand	Crush granite	Palm kernel shell
Sieve analysis	19.0	100.00	98.80	99.6
	9.5	100.00	50.20	49.2
	4.75	99.10	1.40	0.90
	2.36	90.00		
	1.00	69.60		
	600 µm	56.20		
	300 µm	7.00		
	150 µm	2.30		
	Pan	0.00		
Physical properties				
Bulk density		1.80	1.68	0.73
Specific gravity		2.61	2.63	1.33
Water absorption (%)		1.77	1.00	21.18
Moisture content (%)		1.50	0.30	9.96
Aggregate impact value (%)			8.72	3.25
Aggregate crushing value (%)			22.29	5.25

Methods

Concrete mix and samples preparation

An absolute volume method of concrete mixes was used in developing the concrete in the ratio of 1:1.90:2.30. Trial test was carried out with water-cement ratios of 0.45, 0.50 and 0.5., in order to obtain the appropriate water-cement ratio that gives desired slump. Based on the outcomes of the trial test, a water-cement ratio of 0.50 was adopted for the actual experiment. The mixing was done mechanically using concrete mixer. The first mix was made up of the conventional materials (cement, sand & coarse aggregate) which served as control. The second mix was produced by partially replacing crushed granite with PKS at 10%, 20%, and 30 % respectively. After mixing, the specimens were then cast into cubes size

100mm × 100mm × 100mm, and cylinders 200mm x 100mm diameter. A total of eighty-four (84) concrete cubes and forty-eight (48) concrete cylinders were produced. The specimens produced were left in the mould for 24hours in the laboratory, after which they were removed and completely immersed in water until 3, 7, 14 and 28 days of curing.

Tests on fresh and hardened properties of concrete samples

Fresh properties tests

Slump test was conducted on fresh concrete samples for all percentage replacements of crushed granite with PKS as well as the control to ascertain the workability of the concrete. Procedures from BS 1881: Part 102: (1983) was adopted in carrying out the slump test.

Hardened properties tests

The compressive strength test of the specimen was conducted using cubes samples in accordance to BS 1881: part 116, (1983). The specimens were surface dried after removal from water and weighed before crushing to determine the strength properties. Each sample was placed between the plates of compression testing machine and loads were exerted until the point of failure. Three replicates 'cubes were made for specimens at each curing age of 3, 7, 14 and 28 days for each percentage replacements of palm kernel shells including the control. This amounted to a total of 48 specimen cubes for the compressive strength test. The average values of the maximum loads, at which each group of the three specimens failed, were used to determine the compressive strength and the formula for the computation of compressive strength is given below:

$$\text{Compressive Strength (N/mm}^2\text{)} = \frac{\text{Failure Loads (N)}}{\text{Cross sectional Area (mm}^2\text{)}}$$

Split tensile strength

The split tensile strength test was carried out using cylinder specimens of 100 x 200 mm size in accordance with ASTM C496. The specimens were surface dried after removal from water and weighed before crushing to determine the tensile strength properties. Each cylinder sample was placed horizontally between the loading surface of compression testing machine and the compression loads was applied until the failure of the cylinder along the vertical diameter. Three replicates cylinders were made for specimens at each curing age of 3, 7, 14 and 28 days for each percentage replacements of palm kernel shells including the control. This amounted to a total of 48 specimen cylinders for the split tensile strength test. The average values of the maximum loads, at which each group of the three specimens failed, were used to determine the split tensile strength and the formula for the computation of tensile strength is given below:

$$\text{Split tensile Strength (N/mm}^2\text{)} = \frac{2P\ (N)}{\pi ld\ (mm^2)}$$

Where, P = Maximum Load Applied (N)

l = Length of Cylinder (mm)

d = Diameter of cylinder (mm)

Durability tests

Abrasion resistance test

Because of lack of instrument for carrying out the abrasion test, method improvised by Ibrahim (2014) was adopted where the cubes after being cured for 28days were dried and weighed. Then 3.5kg load was tied on a metal brush and the brush was used to brush the surface of the specimen cubes to and fro for about 60 counts per minute. The samples were then re-weighted to find the new weight and the percentage loss in weight was then calculated.

Absorption test

The test procedure according to BS 1881-122 :(1983) was adopted which involves drying a specimen to a constant weight in an oven at 1050C for 72 hours. The sample was allowed to cool in the oven, weighed and the mass recorded (W1). Each sample was then immersed in water for 30 minutes. After that, the specimens were removed from the water and dried with a cloth as rapidly as possible until all free water was removed from the surface and re-weighed again (W2). The increase in weight as a percentage of the original weight is expressed as its absorption as shown below.

$$\text{Water Absorption (\%)} = \frac{W2 - W1}{W1} \times 100$$

Where, W1 = Oven dry weight of cubes in grams.

W2 = Wet weight of cubes in grams.

Sorptivity test

Sorptivity test was performed in accordance with ASTM C1585-04. The purpose is to determine the rate of absorption of water by unsaturated concrete (capillary rate of absorption of water). Sorptivity is a function of the increased mass of a specimen resulting from absorption of water, relative to the time that one surface is exposed to water. The specimens of the concrete were removed from the curing tank and allowed to dry. They were then put inside an oven and dried at temperature of 50±2oC for 72 hours. At the end, Abro 2000 RTV silicone sealant was applied on the sides of the specimens in order to prevent water ingress through the sides of the specimens. The specimens were then weighted and the masses recorded. Specimens were subjected to Sorptivity test at 1, 5, 10, 20, 30, 60 minutes, 1, 2, 3, 4, 5 and 6 hours and the change in masses were recorded after each testing period.

RESULTS AND DISCUSSIONS

Workability

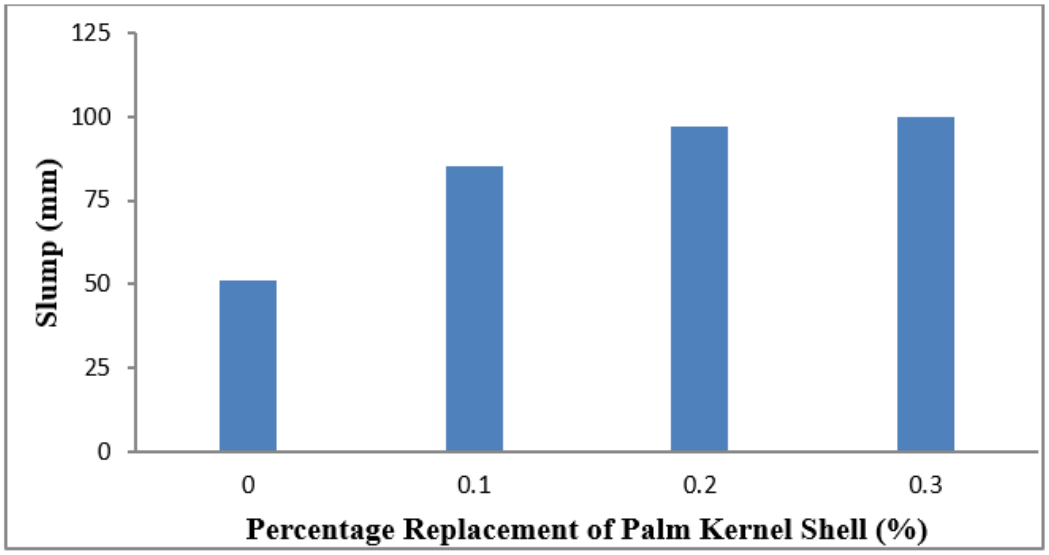


Figure 1: Workability of concrete

Figure 1 shows the slump test result of the concrete at 0%, 10%, 20% and 30% PKS replacement of coarse aggregate concrete specimens. The 0%, 10%, 20% and 30% PKS have slump values of 51mm, 85mm, 97mm and 100mm respectively. An increase of slump value can be observed with increasing partial replacement of crushed granite with PKS in the concrete. The increase in value of slump can be attributed to reduction in crushed granite aggregates that absorbed more water than the PKS. Specimens with PKS absorb less water compare to specimens with crushed granite (Alengaram, Jumaat, Mahmud & Fayyadh 2011).

Compressive strength

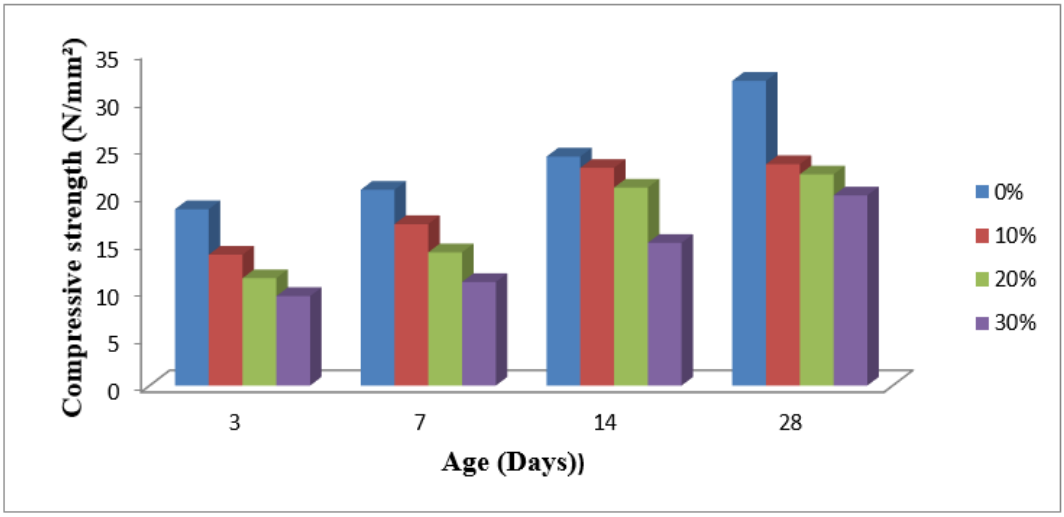


Figure 2: Compressive strength of the concrete specimens

Figure 2 shows the compressive strength of concrete made with palm kernel shell as partial replacement of coarse aggregate at 0%, 10%, 20% and 30% PKS

replacement levels cured at 3, 7, 14 and 28 days. It can be observed that at 3 days, the strengths of 0%, 10%, 20% and 30% PKS specimens are 18.52N/mm², 13.75N/mm², 11.28N/mm² and 9.40N/mm² respectively. At 28 days of curing; the strengths are 32.02N/mm², 23.26N/mm², 22.19N/mm² and 19.98N/mm² respectively. It can be noticed that the compressive strength of all specimens increases with ages and 0% (control) specimen recorded the highest strength compared to other specimens. At early age (3 days curing), the control (0%) is higher than 10%, 20% and 30% PKS replacement of coarse aggregates specimens by 26%, 39% and 49% respectively. At 28 days, the control is higher by 27%, 31% and 38% respectively. The 0% specimen is higher than the target strength (30N/mm2) by 6.7% while 10%, 20% and 30% PKS replacement specimens are 23%, 26% and 33% less than the target strength respectively. It can be observed that the compressive strength of concrete is directly proportional to the unit weight of the corresponding aggregates, the lower the unit weights of the aggregates, the lower the compressive strength of the concrete. The control specimen has higher compressive strength than specimens containing PKS. The decrease in compressive strength could be attributed to the poor bonding between the cement and PKS. Increase in the % of PKS in the mix creates more voids within the concrete matrix leading to decrease in strength. This finding is consistent with the previous works (Khankhaje et al. 2017; Fanijo, Babafemi and Arowojolu 2020). Moreover, the result also shows that the amount and type of coarse aggregate used in the production of concrete has tremendous influence on the compressive strength of the concrete (Alengaram, Almuhit & Jumaat, 2013). The outcome further revealed that PKS could only be suited to grades 20–35N/mm2 (Shafigh, Jumaat and Mahmud 2011).

Split tensile strength

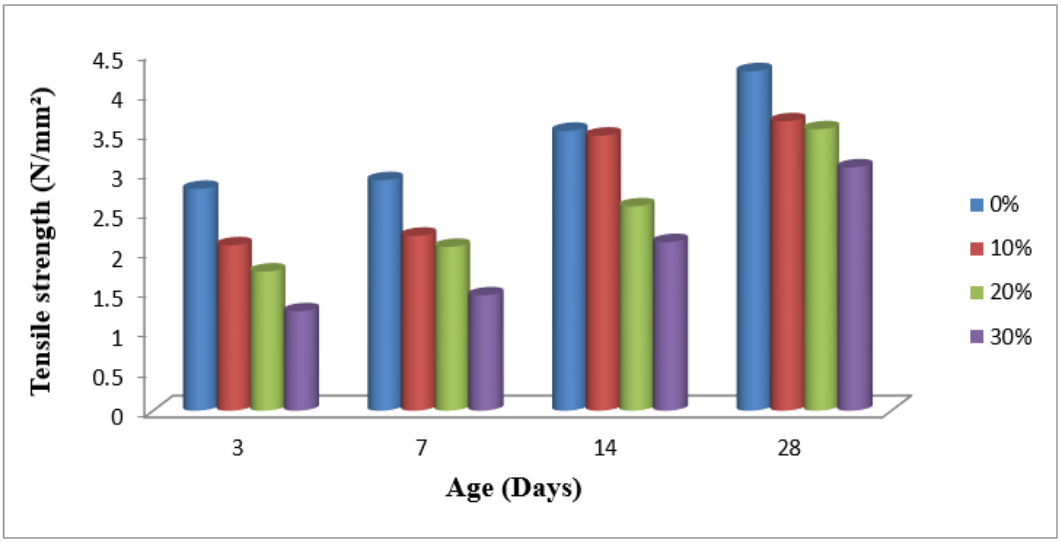


Figure 3: Split tensile strength of the concrete specimens

Figure 3 shows the split tensile strength of concretes made with PKS as partial replacement of coarse aggregates at 3, 7, 14 and 28days of curing. It can be observed that at 3 days of curing, the 0%, 10%, 20% and 30% PKS replacement levels of coarse aggregates achieved tensile strength of 2.79N/mm², 2.08N/mm², 1.75N/mm² and 1.25N/mm² respectively. At 28days, the tensile strength of 0%, 10%, 20% and 30% PKS replacement of coarse aggregates are 4.27N/mm²,

3.62N/mm², 3.54N/mm² and 3.06N/mm² respectively. Generally, outcome of the research showed that the split tensile strength decreases with increase in the percentage replacement of crushed granite with PKS. Similar trend was observed in the compressive strength result. This confirmed the findings of Fanijo, Babafemi and Arowojolu (2020). But from the consideration of the ratio of tensile strength to compressive strength, it can be seen that split tensile strength has very lower values than compressive strength. At 28days, compressive strength was 75% higher than the split tensile strength at 0%, 64% higher at 10%, 63% higher at 20% and 65% higher at 30%. In practice, concrete is not usually expected to resist direct tension because of its low tensile strength. However, the determination of tensile strength of concrete is necessary in order to determine the load at which concrete members may crack.

DURABILITY PROPERTIES

Abrasion resistance

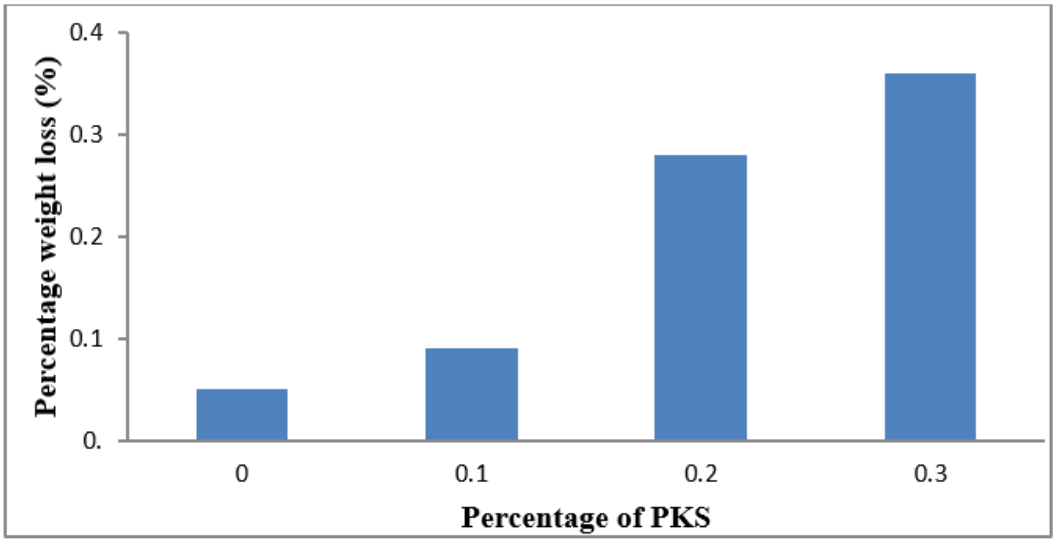


Figure 4: Abrasion resistance of concrete specimens

Figure 4 shows the abrasion resistance of concrete produced with palm kernel shell as partial replacement of coarse aggregate at 28days of curing. The 0%, 10%, 20% and 30% PKS replacement of coarse aggregates abrasion resistance were 0.05%, 0.09%, 0.28% and 0.36% respectively. It can be seen that the level of wearing (in %) increases with increase in the content of palm kernel shell in the concrete. Thus, 0% has the lower wearing value of 18% lower than 10% replacement, 56% lower than 20% replacement and 72% lower than 30% replacement of coarse aggregates. The increase in wearing of palm kernel shell concrete may be due to the lack of proper bonding because of the shapes of palm kernel shell aggregates. It is believed that the compaction strength of concrete is greatly affected by the shape and texture of the aggregates. However, the wearing of palm kernel shell concrete is lower which implies that the concrete possesses good resistance to wear.

Water Absorption

Figure 5 shows the water absorption of concrete produced with palm kernel shell as partial replacement of coarse aggregate at 28days of curing.

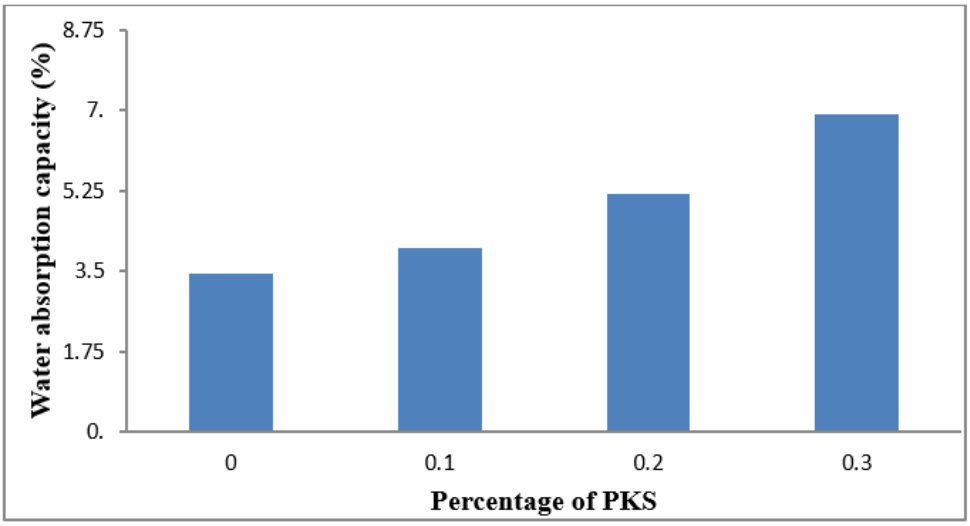


Figure 5: Water absorption of concrete specimens

The water capacity absorption values of 0%, 10%, 20% and30% PKS replacement of coarse aggregates are 3.45%, 4.01%, 5.18% and 6.92% respectively. It can be seen that the water absorption increases with increase in the percentage content of PKS in the concrete (Fanijo, Babafemi and Arowojolu 2020). The 0% (control) replacement has water absorption of 11% lower than 10% replacement, 15% lower than 20% replacement and 20% lower than 30% replacement. The high water-absorption of palm kernel shell concrete can be attributed to the porosity of palm kernel shell aggregates. Results showed that only 0% (control) and 10% specimens with water absorption values of 3.45% and 4.01% satisfied the requirement of ASTM C1585 (2004) standards which specified that the average water absorption of test sample shall not be greater than 5%. However, the average water absorption capacity of 20% and 30% replacement of PKS were 5.18% and 6.92% respectively.

Sorptivity

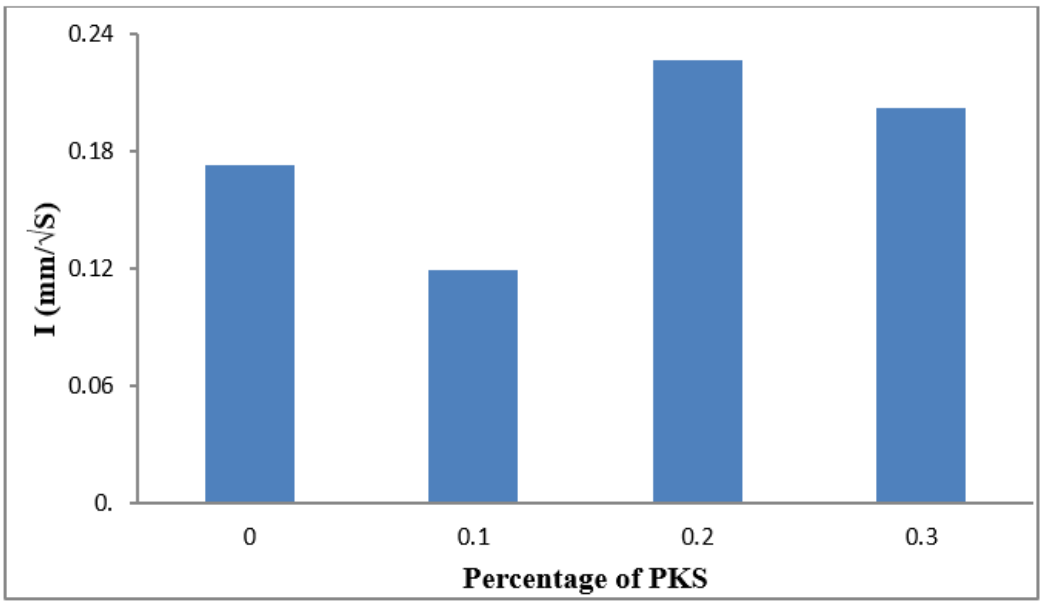


Figure 6: Sorptivity of concrete specimens

Figure 6 shows that the rate of water absorption of concrete produced with 0%, 10%, 20% and 30% PKS replacement of coarse aggregates at 28days of curing. Results show that the rate of water absorption of concrete specimens is 0.173mm/√S, 0.1191mm/√S, 0.2262 mm/√S and 0.2024 mm/√S for 0%, 10%, 20% and 30% PKS replacement of coarse aggregates respectively. It can be observed that the rate of water absorption value of 10% was 45% lower than 0% (control), 53% lower than 20% and 59% lower than 30%. Despite the fact that PKS aggregates absorbs more water than the granites, the concrete specimens with PKS have lower rate of water absorption, which implies that PKS concrete may not absorb more water through capillary.

CONCLUSIONS

Based on the results, analysis and the discussion made, the following conclusions were drawn:

i. Palm kernel shells (PKS) possess good crushing and impact values of 5.25% and 3.25%.

ii. The 28days compressive strength of PKS concrete falls within the standard specification for lightweight concrete, thereby making PKS suitable as aggregates for the construction of lightweight structures. Results showed that PKS increased the void content of the concrete, and in turn also decreased the mechanical properties as the amount of PKS added increased. This was due to angular shape of the PKS particles that disturbed the granular arrangement of concrete.

iii. The use of palm kernel shells as replacement for coarse aggregate in concrete production can give better result at 10% replacement.

iv. Concretes made with palm kernel shells possess good resistance to wearing, thereby encourage its uses in an environment where it will be exposed to wear and tear.

v. The lower rate of absorption of palm kernel shell concrete suggested that palm kernel shell concrete may not absorb more water through capillary when exposed to an aggressive environment.

vi. The use of PKS in concrete would provide a cheap source of coarse aggregate material thereby reducing the demand for naturally occurring coarse aggregates.

vii. It was recommended that further study be carried out to assess the durability of concrete made with PKS exposed to chemically aggressive environment.

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