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Size Variation of Palm Kernel Shells as Replacement of Coarse Aggregate for Lightweight Concrete Production

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Abstract

The utilization of palm kernel shells (PKS) as an alternative to conventional materials for construction is desirable to promote sustainable development. The purpose of this study is to investigate the properties of lightweight concrete produced with different sizes of PKS of 6, 8, 10, 12 mm and mix (consisting of 25% each of the four sizes). RPK sizes were used to replace coarse aggregate in the concrete and cured for 7, 14, 21 and 28 days. The tests performed on the concrete are dry density, compressive strength, flexural strength, EDS and SEM. It was revealed that the densities of the concrete specimens were all less than 2000 kg/m^3, which implies that the PKS concrete satisfied the requirement of lightweight concrete for structural application. The compressive strength of the 12 mm PKS concrete specimens at 28-day of curing was 10.2 MPa which was 4% to 15.9% better than the other PKS sizes concrete. The flexural strength of the 12 mm PKS concrete specimens at 28-day of curing was 2.85 MPa which was also 3.2% to 57.07% better than the other PKS sizes concrete. It was also revealed by the SEM analysis that there was a good bond between the palm kernel shells and the mortar. A high calcium-silicate content was found in the concrete which resulted in a Ca/Si ratio of 1.26 and Al/Si ratio of 0.11. The study therefore concludes that size variations of PKS as replacement of coarse aggregate have an influence on the properties of the lightweight concrete and recommends 12 mm PKS for use by construction practitioners for lightweight concrete structural application.

Keywords

Compressive Strength, Dry Density, Flexural Strength, Lightweight Concrete, Palm Kernel Shell

1. Introduction

Production of concrete is a major concern in recent times due to the incessant depletion of the raw materials involved. Concrete is one of the most important materials used on earth, and the aggregate in concrete accounts for about 75% of the entire volume. Concrete mainly consists of cement, water, fine aggregate, coarse aggregate and sometimes admixtures. Due to the increase production of housing infrastructure globally, there is a high demand for natural aggregate utilization. The cost of concrete production is mostly dependent on the constituent of the concrete [1]. According to Ogundipe *et al.* [2], aggregates are the main constituents in concrete and contribute greatly to strength development. The increasing cost of aggregate has contributed to the shortage of housing infrastructure in most developing countries. Danso [3] estimated that, about 60% of the population of Africa resides in favelas and informal settlements, which is primarily caused by the rapid growth of urbanization and increase in population, particularly in Sub-Sahara Africa (SSA) without corresponding increase in housing infrastructure. Hence, there is an urgent need to look for alternative construction materials which can produce low-cost housing and sustainable buildings for everyone [4]. This links with Sustainable Development Goal 11 (SDG 11) which promotes safe sustainable cities and communities. According to Jackson *et al.* [5], the use of alternative building materials as substitute for natural aggregate in concrete contributes to sustainable construction. There is therefore, the need to source alternates materials that are cheaper and environmentally friendly to substitute for natural aggregate in concrete production [6].

Several studies have been carried out recently on the usage of palm kernel shell (PKS) waste in lightweight concrete as a sustainable construction material. Oyejobi *et al.* [1] investigated the effect of mix proportions to predict the compressive strength of lightweight concrete with PKS as a substitute for coarse aggregate. Jackson *et al.* [5] examined the density, workability, and strength properties of concrete with PKS and coconut shells, and obtained compressive strength of between 6.85 to 13.29 MPa for the palm kernel shell concrete. Odeyemi *et al.* [7] studied the flexural strength and bond properties of self-compacting concrete containing PKS as a substitute for coarse aggregate; and recorded the highest flexural strength of 6.88 MPa at 28-day curing. Ogundipe *et al.* [2] studied the strength properties of concrete prepared with PKS and periwinkle as replacement of coarse aggregate; and found a clear trend of decreasing strength development. Azunna [8] investigated the water absorption and compressive strength properties of concrete with PKS as replacement of coarse aggregate; and found between 10% and 25% water absorption and between 4.44 and 4.78 MPa compressive strength. Fanijo *et al.* [9] investigated the strength properties of laterized concrete produced with PKS as a substitute for coarse aggregate; and found that the concrete with PKS partial replacement (20%) obtained better results. Ntenga *et al.* [10] examined the elemental composition and microstructure of PKS and coconut kernel shells.

Furthermore, Olanipekun *et al.* [11] compared the properties of concrete prepared with PKS and coconut shells. The flexural characteristics of PKS concrete with and without mineral admixture were reported by Alengaram *et al.* [12]. Traore *et al.* [13] also reported the durability properties of lightweight concrete using PKS as aggregates. Oyejobi *et al.* [14] examined the influence of the PKS ranges of sizes and mix ratio on lightweight concrete. In the past research works, all sizes or range of sizes of PKS have been used as a complete or partial replacement for coarse aggregate. Conversely, there is a lack of studies on the specific sizes (size variation) of PKS in concrete as a replacement of coarse aggregate. This study therefore intends to determine the influence of specific sizes of PKS on the production of lightweight concrete as coarse aggregate replacement.

PKS is the by-product of the edible seed of the oil palm fruit or palm nut which is obtained from the palm tree (Elaeis guineensis). The PKS is obtained from the nuts of oil palm fruit after the extraction of the palm oil leaving the shells as waste [15]. These waste shells are usually burnt in the open space as a means of disposal which contributes to the pollution of the air resulting in the release of carbon dioxide (CO_2) in the environment. Incorporating the PKS waste in concrete as a replacement of coarse aggregate will therefore provide environmental and economic benefits, thereby contributing to knowledge in sustainable concrete production. The study aims at investigating the engineering properties of lightweight concrete produced with size variations of PKS as replacement of coarse aggregate. In this study, specific sizes (6, 8, 10 and 12 mm, and mix sizes) of PKS were used as the replacement of coarse aggregate in concrete and their engineering properties such as density, compressive strength and flexural strength were determined. Furthermore, scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) analyses were also conducted on the concrete specimens.

2. Materials and Methods

2.1. Materials

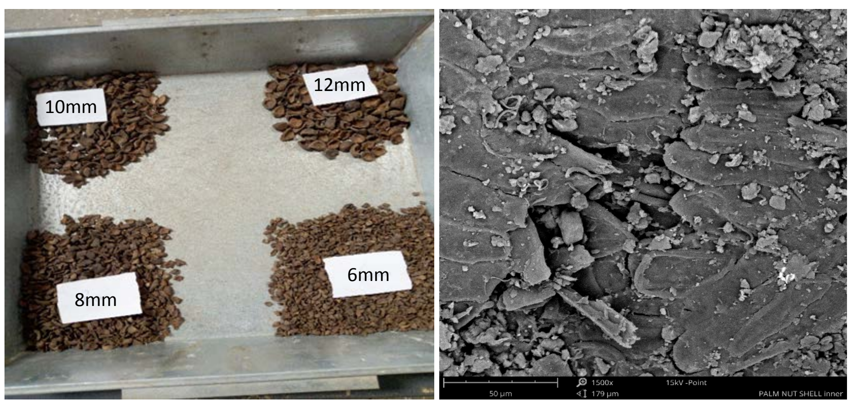
The main materials used for the experimental works are cement, fine aggregate, palm kernel shells (as coarse aggregate) and water. Type I ordinary Portland cement of class 32.5R which met the requirement of BS EN 197-1 [16] was used for the experimental work. The cement was purchased from the building materials market in Kumasi, Ghana. The fine aggregate used for the experimental work was pit sand which conformed to BS EN 12620 [17]. Crushed PKS were used as replacement of coarse aggregate for the experimental work. The PKS were obtained in broken form from Asante-Mampong, Ghana. The shells were loaded in sacks and transported to the laboratory and sieved into specific sizes (6, 8, 10 and 12 mm). Each size of the crushed PKS was washed with warm water to remove any possible oil particles and then dried in the sun for one week before use. **Figure 1(a)** shows samples of the various specific sizes of PKS used in this experimental study. The microscopic image of a palm kernel shell at magnification 1500× is shown in Figure 1(b), indicating a rough texture which is good for bonding with matrix. The physical properties of the PKS used in this experimental study are presented in Table 1. Clean tap water which conformed to BS EN 1008 [18] was used for the experimental work.

2.2. Preparation of Concrete Specimens

The materials were batched by weight with mix ratio 1:2:3 and water-cement ratio of 0.6 was used for all the concrete mixes. Five different concrete mixes prepared were 6, 8, 10 and 12 mm, and mix (consisting of 25% each of the four sizes) of PKS replacement of coarse aggregate. It must be noted that the coarse aggregate replacement by the PKS was 100%. The PKS were soaked in water for 24 hours to saturation before mixing. The mixing was done in accordance with BS 1881-125 [19]. The required quantities of sand and cement were poured into the pan mixer and allowed to rotate for about 1 minute. The quantity of the PKS was added and allowed to mix for 2 minutes before the required quantity of water was added. The pan mixer was allowed to rotate for another 2 minutes when uniform mixture was achieved. The concrete was then poured into steel cube moulds of size 100 × 100 × 100 mm, and steel beam moulds of size 100 × 100 × 500 mm (see Figure 2(a)). The moulds containing the concrete were then vibrated on vibrating table to eliminate trapped air. A total of 90 specimens were prepared consisting of 60 cubes and 30 beams. The specimens were then demoulded after 24 hours and cured under wet jute sacks (see Figure 2(b)) at the laboratory at an average temperature of 27˚C for up to 28 days.

Table 1. Physical properties of PKS.

Properties	Specific weight (g/cm^3)	Bulk density (kg/m^3)	Shell thickness (mm)	Water absorption (%)
value	1.29 ± 0.22	634 ± 42	3.53 ± 0.41	11.64 ± 2.35



(a) (b)

Figure 1. Photograph and microscopic image of PKS of the different sizes of the PKS. (a) Sizes of PKS; (b) Microscopic image (1500×) of PKS.

(a) (b)

Figure 2. Preparation of concrete specimens at the laboratory. (a) Moulding of concrete specimens; (b) Wet jute sack curing of concrete specimens.

2.3. Testing of Concrete Specimens

The concrete specimens were tested on 7, 14, 21 and 28 days of curing. The cube specimens were used to test dry density, compressive strength and SEM/EDS while the beams were used to test flexural strength.

The dry density test was carried out on the cube specimens and determined following BS EN 12390-7 [20]. Three specimens from each mix were selected, weighed using the electronic weighing balance after drying in an oven at a temperature of 105˚C for 24 hours and their sizes measured. The weight and the volume of the specimens were determined and used to calculate the dry density.

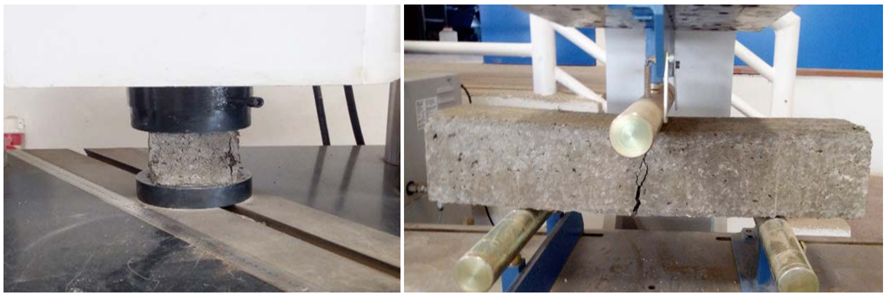
The compressive strength test was carried out on the cube specimens and determined following BS EN 12390-3 [21]. Three specimens from each mix were selected, cleaned with duster and placed in the universal testing machine (WAW-1000H) for testing. A constant load was applied on the specimens until failure (see **Figure 3(a)**). The compressive strengths obtained were recorded and their average values used for plotting the graphs.

A three-point flexural strength test was carried out on the beam specimens and determined following BS EN 12390-5 [22]. Three specimens from each mix were selected, cleaned with duster and placed in the ELE ADR 100 kN flexural machine for testing. A constant load was applied on the specimens until failure (see **Figure 3(b)**). The flexural strengths obtained were recorded and their average values were used for plotting the graphs.

The SEM analysis was carried to visualize the microstructure of the specimens using the TAQ600 Simultaneous TGA/DSC Instrument. The EDS analysis was also carried out to determine the elemental composition of the specimen using the same TAQ600 Simultaneous TGA/DSC Instrument.

3. Results and Discussion

The average result values for dry density, compressive strength and flexural strength for 28-day of curing are presented in **Table 2**. The results represent the average test value for three replicates. The trend of the results is presented and discussed below.



(a) (b)

Figure 3. Testing of concrete specimens at the laboratory. (a) Compressive test; (b) Flexural test.

Table 2. The average result values for dry density, compressive strength and flexural strength for 28-day of curing.

Palm kernel shell size (mm)	Test properties		
	Dry density (kg/m³)	Compressive strength (MPa)	Flexural strength (MPa)
6	1509.73	8.8	1.84
8	1497.27	9.1	1.94
10	1624.13	9.2	2.76
12	1684.67	10.2	2.85
Mix	1610.47	9.8	2.47

3.1. Density of Concrete Specimens

The dry density of the palm kernel shell lightweight concrete is illustrated in **Figure 4**. The result shows that on the 21-day of curing, the lowest density (1447.27 kg/m^3) and the highest density (1714.27 kg/m^3) were recorded respectively for 6 and 10 mm PKS sizes replacement of coarse aggregate in the concrete. The densities of the concrete obtained on the 28-day curing were 1509.73, 1497.27, 1624.13, 1684.67 and 1610.47 kg/m^3 respectively for 6, 8, 10, and 12 mm and mix PKS sizes of coarse aggregate in the concrete specimens. The density values obtained were within the values obtained by Oyejobi *et al.* [14]. Similar results were also obtained by Jackson *et al.* [5] of concrete with 100% replacement of coarse aggregate with PKS. The current study's density values obtained (1440 to 1850 kg/m^3) are within the recommended values for structural lightweight concrete [23]. According to American Concrete Institute [23], lightweight concretes normally have densities lower than 2000 kg/m^3. This implies that the density values obtained for the specimens meet the requirement for lightweight concrete for structural application.

3.2. Compressive Strength

Figure 5 illustrates the compressive strength test result of the PKS lightweight concrete. As expected, the compressive strength of the concrete specimens for all the mixes increased with increase in curing days. It can be seen that the compressive strength of the PKS lightweight concrete increased with increase in the size of the PKS. The 12 mm PKS concrete specimens obtained the highest compressive strength of 10.2 MPa, followed by the mix PKS size with 9.8 MPa for the mix specimens and the least strength of 8.8 MPa recorded by the 6 mm PKS concrete specimens at the 28-day of curing. This suggests that the largest palm kernel shells size (12 mm) replacement of coarse aggregate in concrete produced increased result of 4.0%, 10.9%, 12.1% and 15.9% over the mix, 10, 8 and 6 mm PKS sizes respectively at the 28-day of curing. A study by Jackson *et al.* [5] obtained a similar result of compressive strength between 6.85 to 13.29 MPa for the PKS concrete. Azunna [8] explained that the improvement in the compressive strength of the PKS depends largely on the bond between the particles, the surface texture of the particles and adequate bond of the cement paste and the rough surface of the shells. The larger PKS size achieved better compressive strength because the large particles of the shells, the better they are able to act as bridge within the mortar which therefore control crack propagation and also provide adequate continuous linear rough texture bond with the mortar. Therefore, the contact between the surface area of the large palm kernel shells and the mortar increase the bond properties of the concrete, thereby ensuring improved mechanical performance. To find out if the differences in the compressive strength at the 28-day curing were significant or not, a One-Way ANOVA test was conducted. The result obtained is presented in **Table 3**, which indicates a significant difference ($F = 8.872$; $p = 0.005$) between the compressive strength values. All pairwise multiple comparison procedure using Holm-Sidak method was used to determine which of the mix designs actually had the significant difference between their compressive strengths. The result in **Table 4** indicates that the significant difference existed between the 12 and 6 mm ($t = 5.172$; $p = 0.008$), 12 and 8 mm ($t = 4.162$; $p = 0.028$) and 12 and 10 mm ($t = 3.908$; $p = 0.035$) palm kernel shell lightweight concrete specimens. The remaining pairs achieved no significant difference between them with p-values greater than 0.05. This implies that size variation of the palm kernel shells is an important factor that influence the compressive strength of light weight concrete.

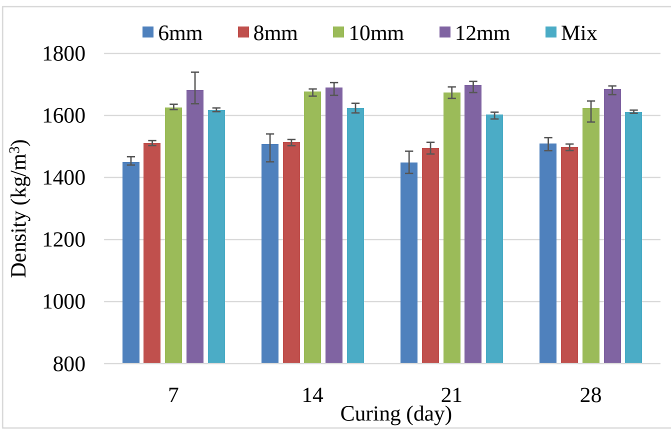


Figure 4. Dry density of concrete specimens with different sizes of PKS.

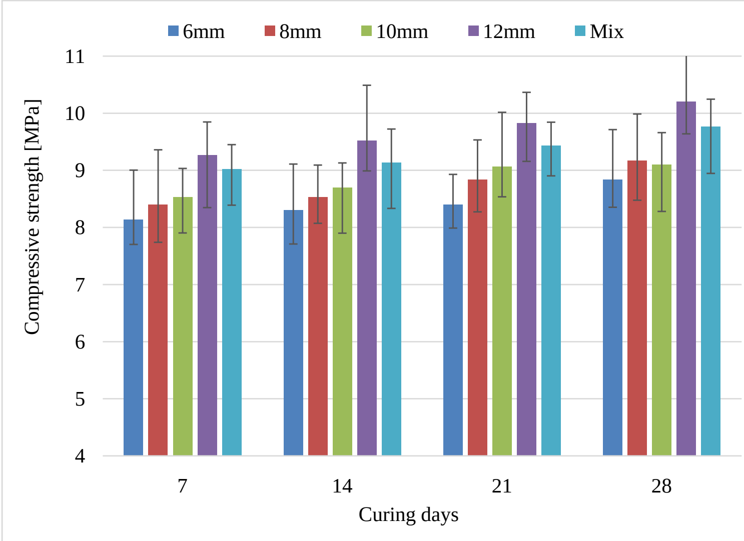


Figure 5. Compressive strength of concrete specimens with different sizes of PKS.

Table 3. One way repeated measures analysis of variance.

	Compressive strength					Flexural strength				
Source of Variation	DF	SS	MS	F	P	DF	SS	MS	F	P
B/t subjects	2	0.168	0.084			2	0.130	0.065		
B/t treatments	4	3.719	0.930	8.872	0.005*	4	2.601	0.650	7.043	0.01*
Residual	8	0.838	0.105			8	0.739	0.092		
Total	14	4.725				14	3.469			

*$p < 0.05$; $t > 2.6$ (5% sig., 2-tailed).

Table 4. All pairwise multiple comparison procedures (Holm-Sidak method).

	Compressive strength			Flexural strength		
Comparison	Mean Diff.	t	p	Mean Diff.	t	p
12 vs. 6 mm	1.367	5.172	0.008*	1.014	4.087	0.034*
12 vs. 8 mm	1.100	4.162	0.028*	0.914	3.684	0.048*
12 vs. 10 mm	1.033	3.908	0.035*	0.088	0.355	0.732
Mix vs. 6 mm	0.934	3.534	0.053	0.631	2.543	0.190
Mix vs. 8 mm	0.667	2.524	0.196	0.531	2.140	0.284
Mix vs. 10 mm	0.600	2.270	0.238	0.295	1.189	0.609
Mix vs. 12 mm	0.433	1.638	0.453	0.383	1.544	0.505
10 vs. 6 mm	0.334	1.264	0.564	0.926	3.732	0.051
8 vs. 6 mm	0.267	1.010	0.567	0.100	0.403	0.908
10 vs. 8 mm	0.0670	0.253	0.806	0.826	3.329	0.071

*$p < 0.05$; $t > 2.6$ (5% sig., 2-tailed).

3.3. Flexural Strength

The flexural strength test result of the PKS lightweight concrete is illustrated in Figure 6. As expected, the flexural strength of the concrete specimens for all the mixes increased with increase in curing days. The 12 mm PKS concrete specimens obtained the highest strength (2.85 MPa), followed by the 10 mm (2.76 MPa), mix (2.47 MPa), 8 mm (1.94 MPa) and the lest was 6 mm (1.84 MPa) PKS concrete specimens at 28-day curing. The 12 mm PKS replacement of coarse aggregate in concrete outperformed the 10 mm, mix, 8 and 6 mm PKS respectively by 3.20%, 15.38%, 46.91% and 57.07%. The result of this study is consistent with the result of the study conducted by Odeyemi *et al.* [7] which obtained similar flexural strength of self-compacting PKS concrete. The flexural strengths of 6 and 8 mm were found to be similar and relatively low, implying that the smaller sizes of the PKS have less flexural impact in the concrete. Conversely, the 10 and 12 mm sizes of the PKS recorded increased flexural strength, which suggest that the larger PKS sizes have better impact on the flexural strength of the concrete. One-Way ANOVA test conducted revealed a significant difference ($F = 7.043$; $p = 0.01$) between the flexural strength values at the 28-day of curing as shown in Table 3. The Table 4 shows that the actual difference existed between the 12 and 6 mm ($t = 4.087$; $p = 0.034$), and 12 and 8 mm ($t = 3.684$; $p = 0.048$) PKS lightweight concrete specimens, while the remaining pairs achieved no significant difference between them with p-values greater than 0.05. This suggests that the larger size (12 mm) of the PKS as replacement of coarse aggregate in concrete has an impact on the flexural strength.

3.4. EDS/SEM Analysis

The energy dispersive spectroscopy (EDS) and scanning electron microscopy (SEM) analysis were conducted on the 12 mm PKS lightweight concrete. The results obtained are presented in Figure 7. The SEM image at 1500× magnification in Figure 7(a) illustrates the internal structure of the concrete specimen, which shows the PKS embedded in the mortar matrix. A good bond between the

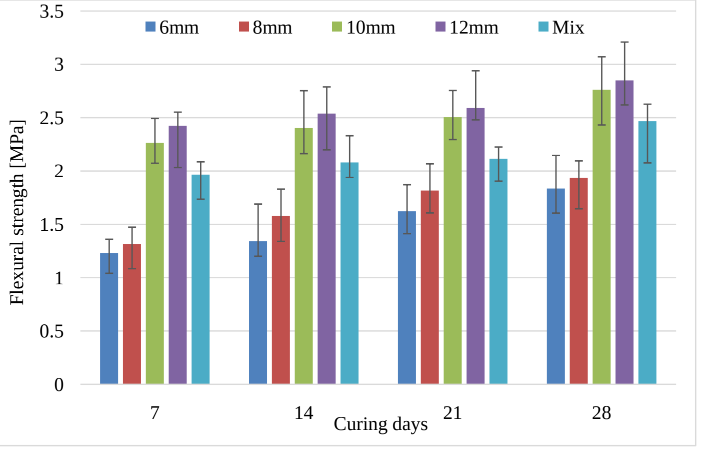
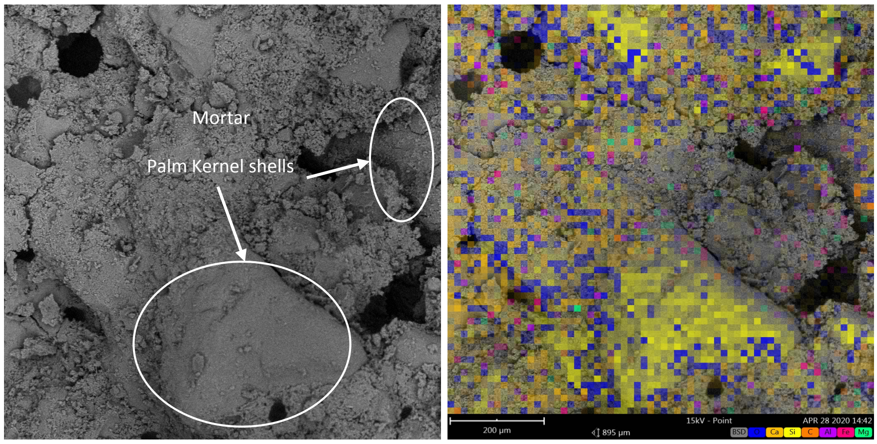
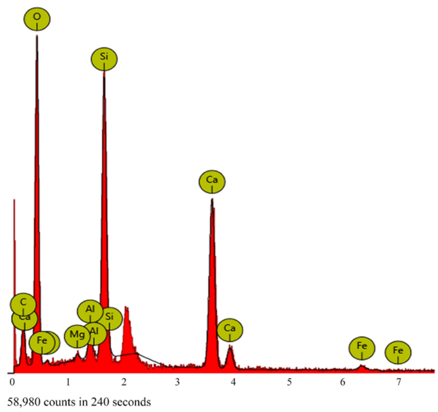


Figure 6. Flexural strength of concrete specimens with different sizes of PKS.



(a) (b)



(c)

Element		Oxide	
Symbol	Wt. conc. (%)	Symbol	Wt. Conc. (%)
O	52.67		
Ca	17.50	Ca	36.98
Si	13.55	Si	28.63
C	13.06	C	27.60
Al	1.46	Al	3.08
Fe	1.44	Fe	3.05
Mg	0.32	Mg	0.67

(d)

Figure 7. SEM/EDS analysis on concrete specimen. (a) SEM image (1500×) of PKS concrete; (b) Colour representation of elements/oxides in PKS concrete; (c) Elemental/oxides graph of PKS concrete; (d) Elemental/oxides content of PKS concrete expressed in percentages.

PKS and the mortar can be seen. This can be attributed to the rough texture of the PKS, which ensures good cohesion with the matrix and therefore resulted in the improved strength properties. The elemental contents of the PKS concrete are expressed in Figures 7(b)-(d). The Figure 7(b) shows the colour representation of elements/oxides in PKS concrete. The elemental/oxides in the palm kernel shell concrete are expressed graphically in Figure 7(c), while the elemental/oxides in the PKS concrete are also expressed in percentages as shown in Figure 7(d). The chemical element contents in the PKS concrete are oxygen (O) 52.67%, calcium (Ca) 17.5%, silicon (Si) 13.55%, carbon (C) 13.06%, aluminium (Al) 1.46, iron (Fe) 1.44 and magnesium (Mg) 0.32. The oxides identified in the PKS include Ca (36.98%), Si (28.63%), C (27.6%), Al (3.08%), Fe (3.05%) and Mg (0.67%). In terms of oxides, it can be seen that there is a high calcium-silicate content in the concrete which resulted in a Ca/Si ratio of 1.26 and Al/Si ratio of 0.11% which falls within the limits for cement-based matrix [24] [25]. These oxides compositions in the concrete contributes to the improvement in the mechanical properties [26] [27] [28].

4. Conclusion

The study aimed at investigating the engineering properties of lightweight concrete produced with size variations of PKS as replacement of coarse aggregate. Different sizes (6, 8, 10 and 12 mm, and mix sizes) of PKS were used as replacement of coarse aggregate in concrete and their engineering properties such as density, compressive strength, flexural strength and EDS/SEM analysis were determined. It was revealed that the densities of the concrete specimens produced were all less than 2000 kg/m^3, which implies that the PKS concrete satisfied the requirement of lightweight concrete for structural application. The compressive strength of the 12 mm PKS concrete specimens at 28-day of curing was 10.2 MPa which was 4% to 15.9% better than the other PKS sizes concrete. The flexural strength of the 12 mm palm kernel shells concrete specimens at 28-day of curing was 2.85 MPa which was also 3.2% to 57.07% better than the other PKS sizes concrete. It was also revealed by the SEM analysis that there was a good bond between the PKS and the mortar. A high calcium-silicate content was found in the concrete which resulted in a Ca/Si ratio of 1.26 and Al/Si ratio of 0.11%. The study therefore concludes that size variations of PKS as replacement of coarse aggregate influence the properties of the lightweight concrete. A recommendation for 12 mm palm kernel shell size is made to construction practitioners for lightweight concrete structural application. As the current study has established that the largest size of PKS used obtained the highest strength, it is possible that the bigger sizes of PKS may continue to improve the properties of lightweight concrete. Therefore, it is recommended that future studies should consider the use of PKS sizes that are beyond 12 mm for the replacement of coarse aggregate in lightweight concrete production.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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