Review Paper

Compressive strength of concrete with palm kernel shell as a partial replacement for coarse aggregate

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Abstract

Shelter is a basic human need. Unfortunately, decent shelter for the masses; the poor have not materialized over the years. The cost of concrete materials in building and civil engineering project has been a concern to the society. These and other things led to the research on biological local materials that are dumped as waste in our environment, causing pollution and congestion as substitute materials. Therefore, this research work was carried out in respect to that and the research work was carried out to determine the use of palm kernel shell as a partial replacement for coarse aggregate in concrete taking into consideration the compressive strength and water absorption capacity. The following tests were carried out; visual test, sieve analysis, specific gravity test, slump test, water absorption test and compressive strength test. The result of water absorption and compressive strength shows that the water absorption capacity of palm kernel shell is normal compared to plain concrete and a replacement of 10% and 25% gave 4.78 N/mm^2 and 4.44 N/mm^2 compressive strengths respectively which cannot be used for light weight structure.

Keywords Palm shell · Lightweight aggregate · Lightweight concrete · Compressive strength · Mechanical properties

1 Introduction

Concrete is the most commonly used material employed for construction purpose in the world today [1], the expensive cost of concrete constituents such as cement, fine and coarse aggregate has necessitated the need to search for alternative construction materials [1, 2]. The general importance of concrete application in construction projects and civil works cannot be overemphasized. The overwhelming demand for concrete in construction adopting normal weight aggregates (NWAs), such as gravel and sand has led to tremendous depletion in naturally occurring aggregates causing numerous damage to the environment which are irreparable [2]. As a result, the need to search for more sustainable and renewable materials has been intensified. Some waste agricultural materials such as saw dust, maize comb, rice husk, and coconut shell, palm kernel shell etc. can serve as a good substitute or admixture for some of these traditional construction materials. These local materials are in most cases dumped as waste in our environments, causing environmental pollution. Many of which can be used as lightweight aggregate (LWA) to produce light weight concrete which has the advantage of reducing the self weight of concrete structures as compared to conventional concrete which possess heavy dead load, they can also be used for purposes of structural stability and versatility as well as economic viability [3]. Hence incorporating these waste materials will help reduce the rate of exploitation of nonrenewable natural resources [4] and provide more sustainable concrete [5]. Furthermore, the idea of using raw materials as concrete constituents is capable of proffering solution to energy saving problems encountered in many agro industries [6].

An agricultural waste that has proven successful in concrete production is palm kernel shell (PKS). In the last three decades, palm kernel shell (PKS) has been used

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SN Applied Sciences (2019) 1:342 | https://doi.org/10.1007/s42452-019-0334-6

Received: 22 January 2019 / Accepted: 3 March 2019 / Published online: 14 March 2019

by scientists as LWA to substitute conventional NWA in building and road construction in Africa and Southeast Asia. One of the advantages of PKS is that it has better impact resistance compared to NWA [7]. Innumerable articles have been published on the physical, mechanical, structural and functional properties using PKS as Lightweight aggregate. PKS is extracted from the oil palm tree as a waste product [7]. It is majorly located in Eastern and Western Africa with a scientific name of Elaeis guineensis [8]. In the past, growing of palm oil tree was sequestered in the Eastern part of Africa as history records that the founding of palm oil trees dates back to the era of Pharaohs some 5000 years ago but currently, the cultivation of palm oil trees have become a major priority in some South East Asian countries such as Indonesia and Malaysia. In a report by Olanipekun et al. [9] large quantities of palm oil trees can be located in Asia, America and some part of Africa specifically Nigeria. The total production of palm oil in Malaysia alone is 52.8% and about 90% of the world's palm oil exportation comes from Malaysia and Indonesia [8]. The palm oil nut contains two kinds of oil; one is palm oil which is extracted from the fleshy and oily layer called the mesocarp and the other is palm kernel oil which is extracted from the inner core, known as palm kernel (endosperm). A endocarp layer which envelops the Palm kernel is called palm kernel shell [8, 9].

Over 4 million tons of PKS are produced by Malaysia annually [7, 10] and from Ramli [11] investigation a total of 5 million hectare (ha) palm oil trees are expected by the year 2020. By virtue of its position as the second largest palm oil producing country in the world, it is expected that huge amount of palm kernel shell wastes will be found in Malaysia. As part of measures to facilitate and enhance the preservation of the environment, scientists have decided to look into the resourcefulness of PKS as LWA [3, 12, 13]. Proposals were made to alternatively use PKS as road based materials rather than asphalt on numerous accounts [9, 13, 14]. In an investigation by Teo et al. [13, 15] PKS was employed as LWA to construct a building with one suspended floor and a foot bridge and the structural behavior were closely monitored on both accounts. PKS is also used as granular filter material for water treatment [9, 16], road based material and floor roofing [13]. Okpala [7] observed the heat conductivity of 0.19 $Wm^{-1}K^{-1}$ for PKS which is much lower than the value of 1.4 $Wm^{-1}K^{-1}$ for normal coarse aggregate. Hence a more conducive environment and low energy usage can be achieved with lightweight concrete made with PKS as a result of the high insulation capacity and low thermal conductivity. In recent times, experiments have been made to substitute PKS as a replica for poor lateritic soil. But the data analysis indicates that the composite mix of PKS with asphalt is insufficient for sub-grade, sub-base and base course in highway construction [17].

Mohamed et al. [18] investigated the proportioning of mixture for oil palm kernel shell lightweight concrete with batch of 1:1.6:0.96 and 1:1.53:0.99 for C:S:OPKS ratio with cement content of 450 kg/m^3 which yielded minimum slump of 20 mm, density within the range of 1800 and 1900 kg/m^3 and minimum compressive strength of 15 N/mm^2. Yusuf et al. [19] carried out an experiment on the structural application of lightweight concrete incorporated with palm kernel shells adopting a mix ratio of 1:1:2 and w/c of 0.5. PKSC beam at 28 days showed flexural strength of 2.883 N/mm^2 and deflection of 0.947 mm indicating resistance to load of 3981 N. Elnaz et al. [20] tried to compare the effects of cockle and palm kernel shell on pervious concrete pavement. In this research thirteen different mixes where prepared employing 6.3 mm size natural gravel and substituted it at different percentage with 4.75 mm and 6.3 mm CS and PKS respectively. Replacement of natural gravel by CS and PKS showed decrease in compressive strength but recorded strong relationship values between the mechanical and durability properties. The compressive strength value indicates that it can be used as quality control tests to foretell the field properties of pervious concrete pavement upon application. Mohammad et al. [21] replaced nominal concrete constituents with agricultural solid wastes of oil palm shell (OPS) and oil palm fuel ash (OPFA) at 10–15% in a bid to produce a sustainable OPS lightweight concrete of enhance mechanical properties. Increase in percentage addition of POFA led to subsequent decrease in flexural and split tensile strengths of OPSC but gave optimum sustainability performance at 10%. Elnaz et al. [22] developed an economical lightweight pervious concrete by replacing gravel sized 6.3–9.5 mm with palm kernel shell (PKS) sized 4.75–6.3 mm and 6.3–9.5 mm. In the same manner PKS was used to replace limestone from 25 to 75% to reduce cost. Results showed maximum compressive of 12 N/mm^2 and higher permeability values ranging from 4 to 6 mm/s which can be applied in parking lots and roads of light traffic. Oyedepo et al. [23] evaluated the performance of both coconut and palm kernel shells ash (CSA and PKSA) as cement replacements in concrete, adopting mix proportion of 1:2:4 and w/c of 0.63. Maximum compressive strengths of 15.4 N/mm^2 and 17.26 N/mm^2 was achieved at 20% cement replacement with PKSA and CSA while 10% cement substitution with CSA gave a compressive strength of 20.58 N/mm^2 at 28 days. The mechanical properties show that it is suitable for both heavy and lightweight concrete. Okechukwu et al. [24] tested the effect of palm kernel shell aggregate as partial replacement for coarse aggregate on the physical properties of concrete. At the age of 28 the concrete cubes yielded compressive strengths and densities ranging from 12.71–16.63 N/mm^2 to 1562 to 2042 kg/m^3 respectively. Water absorption results at 6, 11 and 21.5% were observed to be 1 h and 24 h, 1 h, 24 h respectively.

The properties of palm kernel shell lightweight concrete (PKSC) and normal weight concrete (NWC) have been compared both mechanically and structurally by a lot of observers to show the efficacy of PKSC [3, 10, 15]. Physical and mechanical properties, and structural behavior with regards to bond, flexure and shear, have been experimented and reported [10, 25]. Durability properties of PKSC such as creep [25] and shrinkage [12, 25] were also compared with NWC. Achieving the minimum concrete grade requirement as well as specify areas where PKSC can be used will promote the application of palm kernel shell in many civil works thereby eradicating the biological and environmental hazards caused as a result of improper disposal of the palm kernel shells and reduce cost of construction. Palm kernel shells could be employed for construction purposes in rural villages where they are easily accessible and places where natural occurring aggregates are expensive. In this paper, the engineering properties of concrete made with varying percentage of palm kernel shells as aggregate is determined. This research will aim to evaluate the performance characteristics of palm kernel shell at different percentage replacements for coarse aggregate to determine the specific civil engineering areas where when the PKSC are applied will perform efficiently. Concrete mix design of 1:2:4 was used for the experiment and the following test were conducted to achieve the above mentioned objectives; Water absorption capacity of both aggregate and concrete; specific gravity of sand, particle size distribution of sand and palm kernel shell, workability of concrete and the compressive strength of the concrete. The values of this test results obtained were compared with normal sample made with normal aggregate.

2 Experimental programme

2.1 Materials

2.1.1 Cement

Ashaka brand of ordinary Portland cement (OPC) was used for the test as a binder as it complies to the requirement in BS EN 197-1 [26], composition, specification and conformity criteria for a common cement.

2.1.2 Coarse aggregate

The coarse aggregate (Gravels) used for the experiment were obtained from the Civil Engineering Department, Federal Polytechnic Bauchi; Materials stock pile. The grading of the gravel are those that pass through 14 mm sieve size and but retained on 10 mm sieve. The gravels were properly washed and dried under the sun for 3 days, to remove impurities and any absorbed water.

2.1.3 Fine aggregate

Fine aggregate (fine sand also known as river sand was equally used for the experiment). The sand was sun dried and impurities removed using 5 mm sieve in which materials retained on the sieve were discarded.

2.1.4 Palm kernel shell aggregate

The major material for the experiment conduct is the Palm kernel shell was obtained from Sri kembangan market in Malaysia and from Benue State, Cross River, middle and south eastern part of Nigeria. A total weight of 100 kg of this material was brought for the practical. The palm kernel shell source was washed to remove fibers and foreign impurities after which it was sun dried for three days to eliminate water and any microbial activity on the shell surface (Fig. 1).

2.1.5 Water

This is an important material which was used for the practical mostly conducted. The source of the water is Civil Engineering Department, Federal Polytechnic Bauchi Tap by visual inspection; the water was clean, odorless, and fit the practical with no significant effect.

Fig. 1 Samples of palm kernel shells

2.1.6 Compressive strength test

This compressive strength test was carried out according to BS EN 12390-4 [27] filling 150 mm cube mould with concrete in three layers of approximately 50 mm with each layer receiving 25 blows for proper compaction. The mix ratio was 1:2:4 with the coarse aggregate being at 100% gravel and replaced by palm kernel shell at 10, 25, 50, 75, and 100%. The concrete cubes were demoulded after 24 h and taking for curing at the curing tank with water temperature of 20 °C the cube were left in the tank until the prescribed age ranging from 7, 14, 21, and 28 days was reached. After removal from the curing tank, the cubes were weight and tested for strength with their cast faces in contact with the plate of the compression machine. The load was then applied at a constant rate of stress within the range of 0.02–0.4 N/mm^2 and crushing strength was reported to the nearest 0.05 N/mm^2.

2.1.7 Water absorption capacity of the concrete

After demoulding, the concrete cube was immersed in water to test for the total amount of water they can absorb and the results were reported. Gunasekeran [28] observed that when concrete cubes are cured for a long period of the incidence of cracking is reduced.

2.1.8 Batching

Being that the process of measuring the quantities of each material i.e. cement, fine and coarse aggregate and water in their relative proportion before they are mixed is known as batching. And there are two methods of this batching; by weight and by volume. This research adopted batching by weight, which involves the application of mathematical concept known as ratio to find out the requirement weight. Weight was used for the measurement.

2.1.9 Batching calculation

The volume of cement, sand, coarse aggregate and palm kernel shell, water base on the ratio of normal 1:2:4 mix (Table 1).

$$Cement = \frac{1 \times 1440}{3.15} = 0.457\ \text{m}^3$$

$$Sand = \frac{2 \times 1650}{3.15} = 1.269\ \text{m}^3$$

$$Coarse\ aggregate = \frac{4 \times 1600}{2.65} = 2.415\ \text{m}^3$$

3 Results and discussions

3.1 Specific gravity of fine sand

Test conducted in accordance to BS EN 1097-3 [29] gives the specific gravity of fine aggregate as shown in the Table 2:

$$G_s = \frac{W_2 - W_1}{\left(W_4 - W_1\right) - \left(W_3 - W_2\right)} \tag{1}$$

specific gravity of the fine sand is 2.67.

Specific gravity of PKS varies from but has never exceeded the value of 2.0 as observed by several scientists [7, 15, 30], the value ranges from 1.17–1.62. Ndoke [30] recorded the highest value of PKS specific gravity

Table 2 Fine sand specific gravity result

Mass of apparatus	Weight	Weight (g)
Mass of density bottle	W_1	29.72
Mass of bottle + dry sand	W_2	40.97
Mass of bottle dry sand + water	W_3	86.30
Mass of bottle + water	W_4	79.25

Table 1 Mix proportion for 1:2:4 concrete mix

Mix design (%)	Concrete volume (m^3)	Cement (kg)	Water (kg)	FA (kg)	CA (kg)	PKSA (kg)
0	0.003375	18.4842	9.24	42.357	82.15	0
10	0.003375	18.4842	9.24	42.357	73.90	08.20
25	0.003375	18.4842	9.24	42.357	61.61	20.54
50	0.003375	18.4842	9.24	42.357	41.07	41.07
75	0.003375	18.4842	9.24	42.357	20.54	61.61
100	0.003375	18.4842	9.24	42.357	0	82.15

1.62 in a research where PKS was used for soil stabilization. On the other hand Okpala [7] recorded the lowest value of specific gravity of 1.14, while Teo et al. [15], Mannan and Ganapathy [31], and Basri et al. [13] recorded equal values of 1.17. This can be compared to the specific gravity NWA of 2.67 reported above. Other artificial LWA such as LECA and Lytag and natural LWA such as pumice and expanded shale all poses specific gravity values ranging from 0.8–0.9 to 1.30–1.7, respectively [32].

3.2 Sieve analysis results

3.2.1 Sieve analysis for fine aggregate

This gives the particle size distribution of the fine sand sample, as shown in Table 3.

For the fine aggregate (sand), the C_u and C_c are calculated below in accordance to BS 812-103.1 [33]

$$Uniformity\ of\ curvature\ C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} \tag{2}$$

$$Uniformity\ coefficient\ C_u = \frac{D_{60}}{D_{10}} \tag{3}$$

From the Fig. 2

$C_u = 4.26 \times 10^9$

$C_c = 6.863 \times 10^{-1}$

From the result obtained; C_u and C_c of the particle size distribution of the fine aggregate is suitable for construction.

Table 3 Sieve analysis for fine aggregate

Bs sieves (mm)	Mass retained on sieve	Mass passing on sieve	% Passing sieve
5.0	22.62	408.86	81.7
4.0	12.62	390.18	79.2
3.15	15.73	380.45	76.0
2.0	48.85	331.60	66.3
1.0	113.83	217.78	43.5
0.800	43.04	174.74	34.9
0.630	19.94	154.50	30.9
0.400	80.60	74.11	14.3
0.300	69.9	4.20	0.84
Pan	4.20	6.00	0.0
Total			

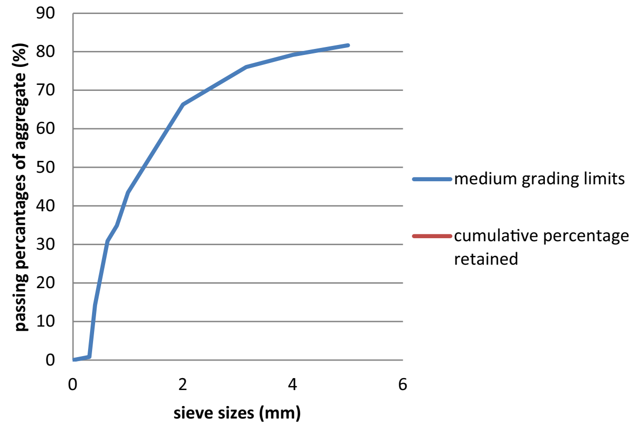

Fig. 2 Grading curve for fine aggregate

3.3 Sieve analysis for palm kernel shell

This give the particle size distribution of the palm kennel shell used as a substitute material for the concrete. Shown in Table 4.

According to Table 4 and Fig. 3, the passing percentage lies within the range of medium grading limit to be used in the mix design making it suitable for construction.

3.4 Moisture content of palm kernel shell

This gives the moisture content present in the material (palm kennel shell) as shown in Table 5.

$$Average\ weight\ of\ wet\ sample = 7.48\ \text{g}$$

$$Average\ weight\ of\ dry\ sample = 7.28\ \text{g}$$

$$Moisture\ content = \frac{Wet\ weight - Dry\ weight}{Dry\ weight} \times 100 = 2.7\% \tag{4}$$

Table 4 Sieve analysis for palm kernel shell

Bs. sieve	Mass retained on sieve (g)	Mass passing on sieve (g)	% passing sieve
25	0.01	2273.72	22.73
20	1.07	2273.65	22.73
16	19.63	2253.02	22.53
12	651.06	1001.96	16.01
10	607.41	525.41	0.73
8	469.14	525.41	0.52
Pan	525.41	0.000	0.000

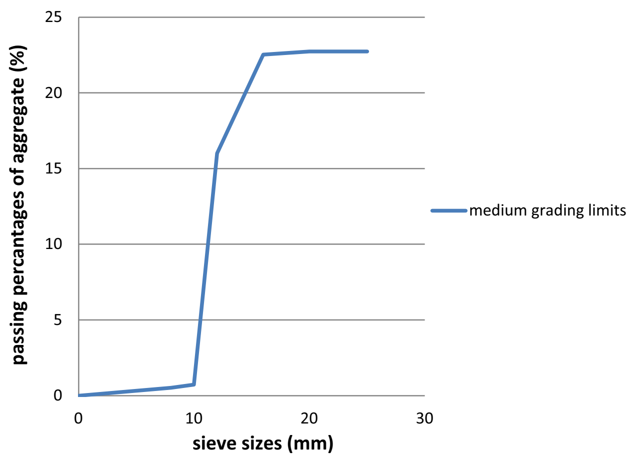

Fig. 3 Grading curve for palm kernel shell coarse aggregate

The moisture content of the palm kernel shell is 2.7% which has no much effect to the concrete per 100% moisture BS EN 1097-3 [29].

3.5 Water absorption capacity

This gives the maximum water absorbed by the palm kernel shell after eight days as shown in the Table 6.

The maximum water absorbed by the palm kernel shell = 0.66/5.48 = 12.0%

Water absorption is defined as the transport of liquids in porous solids caused by surface tension acting in the capillaries [34]. From the result obtained, the maximum amount of water absorbed by the palm kennel shell shows that the absorption capacity of the material is higher than that of the normal coarse aggregate [17].

Water absorption of NWA is typically found to be in the range of 0.5–1% [35]. As a result of higher water absorption of PKS compared to NWA, the mix design differs from that of the conventional mix design of NWC or LWC [35, 36]. In a report by Gunasekaran et al. [37] coconut shell aggregate posses water absorption of 24% which is very similar to that of palm kernel shell aggregate. Due to the fact that PKS is an organic aggregate, its pore content is high resulting in high water absorption. The 24 h PKS water absorption varies in the range of 14–33% as it is dependent on the maturity as well as the species of the tree [7, 15, 30]. Regardless of the fact that PKS posses high water absorption, much higher water absorption of 37% was reported for pumice aggregate [38]. Alengaram et al. [39] observed that with varying PKS sizes, water absorption also varies in the range of 8–15% and 21–25% for 1 h and 24 h, respectively.

3.6 Water absorption capacity of the casted cubes

This gives the water absorption capacity of each cube casted at the different percentages of replacement, as shown in Table 7:

From the result obtained, the water absorption capacity of both the palm kernel shell used as concrete compared with the normal concrete used as control is a bit higher in the absorption capacity as such, the absorption capacity of the material is within the range for construction purpose (Table 8).

3.7 Slump test (workability test)

Table 9 shows the result of slump test carried out on the sample used in the concrete.

Slump test measures the degree of consistency of fresh concrete before setting according to ACI 116R [40]. It is very useful in calculating and checking the

Table 5 Moisture content result (PKS)

Number of container (g)	Weight of empty container (g)	Weight of sample plus container (g)	Oven dry sample plus container (g)	Weight of dry sample only
100	15.04	22.82	22.64	7.6
125	14.67	22.11	21.94	7.27
175	15.05	22.19	22.01	6.96
Total	14.92	22.4	22.2	21.83

Table 6 Water absorption capacity of palm kernel shell

Sample	Weight of concrete before immersion (kg)	Weight of concrete after immersion (kg)	Absorption gain (kg)	% gain of water
A	5.13	6.18	1.05	20.47
B	5.11	8.86	0.75	14.68
C	6.19	7.38	1.19	19.23
Average	5.48	6.14	1.0	18.13

Table 7 Water absorption capacity of the casted concrete at different percentage replacement after 3 days curing

Cube no.	% Replacement of coarse aggregate	Weight before immersion (kg)	Weight after immersion (kg)	Absorption gain (kg)	% Gain in moisture	Average % gain in moisture
A_{11}	10%	7.2	7.5	0.3	4.17	3.48
A_{12}		7.2	7.4	0.2	2.78	
B_{11}	25%	6.5	6.7	0.2	3.08	3.06
B_{21}		6.6	6.8	0.2	3.03	
C_{11}	50%	5.7	5.9	0.2	3.51	3.48
C_{21}		5.8	6.0	0.2	3.45	
D_{11}	75%	5.1	5.3	0.2	3.92	3.89
D_{21}		5.2	5.4	0.2	3.85	
E_{11}	100%	4.1	4.3	0.2	4.88	4.88
E_{21}		4.1	4.3	0.2	4.88	

Table 8 Water absorption capacity for the plain concrete used as control

Cube no.	Weight before immersion (kg)	Weight after immersion (kg)	Absorption gain (kg)	% Gain in moisture	Average
F_1	7.90	8.20	0.3	3.8%	3.14%
F_2	8.10	3.30	0.2	2.47%	

Table 9 Result of slump test at varying % of palm kernel shell used in the concrete

% Replacement of PKS	Slump (mm)	Slump type
10	20	True slump
25	30	True slump
50	30	True slump
75	40	Shear slump
100	50	Shear slump

uniformity of batch improperly mixed [35]. Table 2 shows that the 10, 25, and 50% replacements of coarse aggregate falls within the medium range slump which gave a true slump while, 75% and 100% complete replacement result is harsh which gave a shear slump. Mannan and Ganapathy [31] recorded very low slump (0–4 mm) meaning very low workability [41]. Lightweight concrete of 15 N/mm^2 gave slump in the range of 0–260 mm [25]. It can be said that concrete with low slump doesn't necessarily denote high compressive strength [12, 31]; It was observed that slump value of 105 mm (high workability) was achieved with incorporation of small percentage of super plasticizer [35].

Table 10 Density of concrete cubes (kg/m^3)

PKS coarse agg.	Age (days)			
Replacement (%)	7	14	21	28
0	2326	2311	2400	2429
10	2193	2252	2178	2311
25	1956	2104	2104	2222
50	1719	1629	1659	1636
75	1541	1529	1541	1481
100	1363	1378	1393	1425

3.8 Density

The density of concrete is based on the specific gravity of the aggregate and the properties of the other components of concrete. Density of concrete can affect the dead load of a structure. A total of 40 cubes were produced and the densities were evaluated at 7 days, 14 days, 21 days and 28 days. Average density of concrete cubes is summarized in Table 10.

Density of concrete is a determinant factor as regards to the compressive strength of concrete and is a vital variable in design of structural elements. Table 10 indicates maximum and minimum concrete densities of 2429 kg/m^3 and 1363 kg/m^3 at 0% and 100% PKS replacement respectively. Figure 4 shows corresponding decrease in the density of the concrete mix as replacement of palm kernel shell increased. However, 28-days air-dry densities of 25% PKS concrete of the typical mixes are within the range of structural lightweight concrete of density less than 2000 kg/m^3 [41]. For purposes of construction, reduced concrete density considerably reduces the self-weight of a structure and permits easy handling of large size precast structural units. Clarke [42] observed the density of SLWC ranges between 1200 and 2000 kg/m^3 while Neville [35] noticed the density values between 350 and 1850 kg/m^3 for LWC.

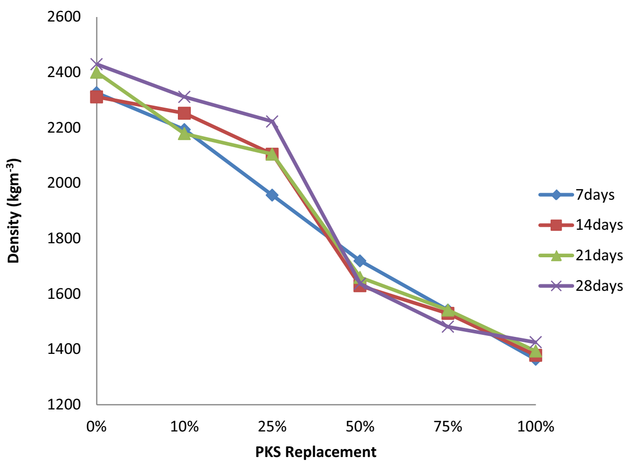

Fig. 4 Variation of density with palm kernel shell content

A number of scientists have tried to alter the density of PKSC without negatively affecting the concrete strength. The density of PKSC is dependent on a number of factors including the specific gravity of PKS, water cement (w/c) ratio, sand and PKS contents and water absorption capacity of PKS. Oven-dry densities are 200–250 kg/m^3 lower than the saturated surface dry (SSD) densities [42].

3.9 Compressive strength

Compression cube test is used to determine the mechanical strength of concrete to sustain the axial force applied on the surface of concrete. Compressive strength is the major parameter which influences other properties of concrete such as flexural strength, splitting tensile strength and modulus of elasticity. To evaluate the effect of replacement of palm kernel shell as coarse aggregates on the compressive strength of concrete plain control concrete is compared with five concrete batch mixes containing different percentage of palm kernel shell aggregates (PKSA).

The average compression strength for all batches is summarized in Table 11. The data also has been plotted and presented in Fig. 5.

In general, the compressive strength of all mixes increased steadily with respect to curing age. At 28 days, compressive strength of concrete specimen with natural fine and coarse aggregate (control specimen) was 13.22 N/mm^2. On the other hand, the compressive strength test shows an increment in the compressive strength of the cube as the day's increases with 28 days recording, the highest value of 4.78 N/mm^2 and 4.44 N/mm^2 for 10% and 25% replacement of coarse aggregate respectively. While that of 50, 75 and 100% were very low compared to the former results. The progressive increase in compressive strength shows that the palm kernel shell aggregate doesn't undergo deterioration once the shells have been imbedded in concrete.

Table 11 Compressive strength of concrete with PKS replacement (N/mm^2)

PKS coarse agg.	Age (days)			
Replacement (%)	7	14	21	28
0	9.45	10.11	11.05	13.22
10	3.20	3.40	3.56	4.78
25	2.00	2.33	2.77	4.44
50	0.60	0.67	1.00	1.67
75	0.40	0.56	0.89	1.11
100	0.00	0.00	0.00	0.00

From Fig. 2; PKS mix compositions poses compressive strengths lower than that of the control sample. As a matter of fact, the compressive strengths at each age decreased with increase in percentages of PKS replacement.

As reported by Amarnath and Ramachandrudu [43], bond between particles is to a large extent dependent on surface texture, cement paste bonds more adequately with rough surface. However, smooth surface on the interior part of the PKS aggregate in addition to the continuous presence of water will deter adhesive bonding between the aggregate, which leads to reduction in the bonding strength. Surface area of contact between the palm kernel shells is increased as the percentage of palm kernel replacement increases, thereby requiring more cement for proper bonding. Since the content of cement in the concrete remained constant, the needed extra bonding was lacking leading to reduction in compressive strength. Furthermore, reduced compressive strength can also be attributed to the mechanical properties of coarse aggregate, since palm kernel shells are weaker in weight than granite, a reduction in the quantity of coarse aggregate

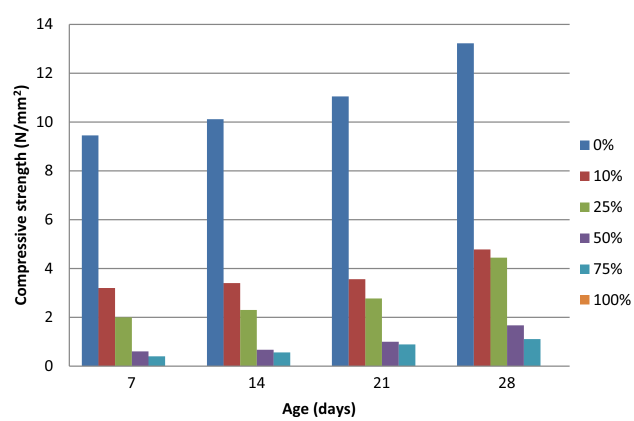

Fig. 5 Development of strength with age

and continual increase of palm kernel shell in the concrete mix led to reduce of compressive strength [44].

Abdullah [14, 25] pioneered the use PKS as LWA and recorded a compressive strength of 20 MPa with w/c ratio of 0.4. This value is very close to the specified cylindrical compressive (fc) strength of 17 MPa by ACI. Teo et al. [15] reported a compressive strength of 22 MPa. Mannan and Ganapthay [13, 26] adopted the ACI method of mixed design for NWC, in their report the compressive strength was 13.65 MPa and was surpassed by the target strength by 28 MPa. Alengaram et al. [45] reported strength of 37 MPa which exceeded the minimum strength of 20 MPa by 85%. Silica fume and class F fly ash was employed to improve the early and later age strengths and sulfonated naphthalene formaldehyde condensate as superplasticizer to disperse the cement grains effectively, reported that the suction of silica fume into the pores of PKS promoted the bond between cement matrix and PKS.

4 Conclusion

In general, palm kernel shell has a good potential as a coarse aggregate in making a light weight structures and can even be used for low to moderate strength application. Base on this investigations, the following conclusions were being drawn:

- The compressive strength of the concrete for the 100% and 25% replacement are 4.78 N/mm^2 and 4.44 N/mm^2 respectively, at an age of 28 days, which did not satisfies the requirement for structural light weight concrete.
- The water absorption capacity obtained for the concrete is within the range of specification for normal concrete.

4.1 Recommendations

From the result obtained, palm kernel shell is recommended to be used as a partial replacement of coarse aggregate (substitute material) in making a light weight concrete. The recommended percentage replacement for possible use in construction should not be more than 25%. because of its high resistant to both impact and crushing load, palm kennel shell can be used in the construction of foot path, German floor, and for self weight structures use for aesthetics purposes.

The uses of other mix ratios are recommended for further research and findings, introduction of additives, improvement of the concrete work ability and batching is also recommended to be carried out by volume.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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