Assessment of palm kernel shell as a composite aggregate in concrete

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Abstract: This manuscript presents a report on the physical properties of palm kernel shell used as a coarse aggregate and their effect on the strength properties of palm kernel shell concrete. Laboratory research was carried out to observe the effects of replacing crushed granite by palm kernel shell on the compressive strength and density of palm kernel shell concrete. Mix design of 1:2:4 and a water-cement ratio of 0.6 were used to produce concrete specimen cubes of size 150 mm^3. A total of 60 cubes were made and wholly submerged in water to cure for 28 days at intervals of seven days i.e. seven, 14, 21 and 28 days after which their densities and compressive strengths were determined. Granite was replaced by palm kernel shell in the mix at 25% interval resulting in three replicates of specimen cubes at each curing age. Compressive strength and density decreased continuously as palm kernel shell was added to the mix for all the Curing ages tested. The 28 day compressive strength of the palm kernel shell concrete ranged from 12.71 to 16.63 N mm^{-2}, whereas the density ranged from 1562 to 2042 kg m^{-3}. Physical properties tests conducted include sieve analysis, bulk density, moisture content and specific gravity to describe aggregates. The specific gravities of sharp sand, crushed granite and palm kernel shell were found to be 2.5, 2.76 and 1.301 while their bulk densities are 1650, 1545, and 634 kg m^{-3} respectively. Water absorption capability tests on crushed granite and palm kernel shell were observed to be 6% in both 1 h and 24 h, 11% in 1 h and 21.5% in 24 h respectively. All the aggregates utilized in this research work demonstrated their suitability in concrete production given by the observations as physical properties result presented.

Keywords: palm kernel shells, coarse aggregate, curing, physical properties, compressive strength

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1 Introduction

The management and pollution problems associated with agricultural and industrial wastes have posed a lot of challenges to engineers and experts in different engineering and related fields. The nuisance caused by the dumping of palm kernel shell waste and the quest to investigate its possible utilization has necessitated this work. Recently, research has been conducted by Alengaram et al.(2011), Alengaram et al. (2013), Shafigh et al. (2010), Shafigh et al. (2011), Shafigh et al. (2012) on palm kernel shell and its concrete. Palm kernel shells are inflexible, carbonaceous, and organic by-products of the processing of the palm oil fruit; they consist of small, medium and large sizes of particles in the range 0-5 mm, 5-10 mm and 10-15 mm respectively; they are organic waste materials obtained from crude palm oil producing factories in Asia and Africa (Alengaram et al., 2010). Okiy (1988) reported palm kernel shell to be made up of 33% charcoal, 45% pyroligneous liquor and 21% combustible gas. Basri et al. (1999) observed the hard nature of the shell and went further to report that once it is bound in concrete matrix it does not easily deteriorate and consequently, does not contaminate or leach to produce lethal substances. Basically, composites of concrete are known to be cement, water, fine and coarse aggregates in diverse proportions depending on use for

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which concrete is made. The cement in concrete matrix is what binds all the other components together in the presence of water. Varying proportions of the different composites of concrete in the matrix determine to a great extent the outcome of the structure. Alexander and Mindness (2005) observed and reported the obvious importance of aggregate in a concrete matrix especially in the coarse composite. They reported that aggregate occupies between 70% and 80% of the total volume of concrete. With this large proportion of the concrete being occupied by aggregate, it is expected for aggregate to have an overwhelming effect on the properties of concrete as well as its general performance.

The compressive strength of concrete is one of the most important technical properties. In most structural applications, concrete is employed primarily to resist compressive stress. In those cases where other stresses (tensile, etc.) are of primary importance, the compressive strength is still frequently used as a measure of the resistance because this strength is the most convenient to measure. For the same reason, the compressive strength is generally used as a measure of the overall quality of the concrete, even when strength itself may be relatively unimportant (Popovics, 1998; Kibar and Öztürk, 2015).

Analysing hydraulic mortars from ancient cisterns and baths, Stefanidou et al. (2014) observed that the coherent and dense structure of hydraulic mortars is due to the action of different mechanisms caused by the selection and combination of raw materials and the interaction with the special environment into which they served. This emphasises the importance of selection of raw materials utilized as aggregates.

The objectives of this research include determining the compressive strength of lightweight concrete containing palm kernel shell aggregate in percentage replacements and to determine the physical properties of palm kernel shell, sharp sand and crushed granite.

2 Materials and Methods

2.1 Materials Selection

2.1.1 Palm Kernel Shell

Palm kernel shell used in this study was collected from a local palm oil processing factory at Mbarakpaka village in Ihiala town, Ihiala Local Government Area of Anambra State in Nigeria. In most parts of South-South and South-East of the Country palm kernel shells are dumped in open fields. Due to the organic nature and pore spaces in these shells, they are likely to either enhance or reduce their moisture contents over these periods of exposure due to varying weather conditions in these areas. It is important to determine the moisture content of palm kernel shell especially before use in concrete specimen production. Preparation of palm kernel shell was done first by soaking overnight in water with detergents after which shells were washed and then spread to dry. This is necessary to remove impurities such as oil coating and mud particles which stick to the surface of fresh palm kernel shell during processing. In this investigation, boiling in water as well as washing with detergent was adopted. Washing and rinsing were used to process the palm kernel shell so as to remove the effects of the remnants of the detergent used which if not done properly could reduce the performance of cement and the resultant concrete. The shells were finally exposed to dry under natural sun and air after which they were packed in waterproof sacks and transported to the location of research. Alengaram et al. (2010) reported that with varying palm kernel shell sizes, water absorption also varies in the range of 8%-15% and 21%-25% for 1 h and 24 h, respectively. Alengaram et al. (2011) proposed that due to the high water absorption property of palm kernel shell, pre-soaking of aggregates for about 45 minutes to 1 h is mandatory before use in concrete production. The absorption during this period of pre-soaking was therefore determined in this research and was found to be 11%.

2.1.2 Sharp Sand and Crushed Granite

Clean river sharp sand (fine aggregate) and crushed granite (coarse aggregate) were used for this research. They were sourced from a construction site along Chime Avenue, Enugu in Enugu State of Nigeria. In compliance with the requirements of BS 812 (2002), test on aggregates were carried out. The sharp sand was dried under the sun to control the moisture content during usage to conform to the requirements of BS 882 (1992). It had maximum aggregates size of 4.75 mm, specific gravity of 2.5, and a fineness modulus of 2.69.

2.1.3 Cement

Ibeto 42.5 grade ordinary Portland cement with specific gravity of 3.0 was used for this study. The bags were observed to be airtight from the manufacturer and free from moisture-related fluids. The cement therefore conforms to BS 12 (1996) requirements.

2.1.4 Water

Portable water supplied by Enugu State Water Co-operation was used in mixing the materials. The water was tested using basic sense of smell and taste, observed to be clean and free from any visible impurities hence being in conformity with BS 3148 (1980).

2.2 Research Procedure

The Aggregates in study were characterized with tests like water absorption capacity, bulk density, specific gravity, and gradation test/sieve analysis. Sieve analysis was used to sort palm kernel shell and crushed granite of sizes 10 mm and 14 mm that were used for this study. The water absorption of the palm kernel shell was determined in accordance with the recommendations for testing aggregates in BS 812 (2002). Slump and compressive strength tests were performed to determine the workability and strength of the palm kernel shell concrete at varying percentage replacements of crushed granite with palm kernel shell as well as different curing ages respectively. The slump and compressive tests were carried out in agreement with the British Standards, BS 1881: Part 102 (1983) and BS 1881-116 (BS 1881: Part 116, 1996). Percentage Water Absorption of palm kernel shell in 1 h and 24 h is 11% and 21.5%, respectively while the Percentage Water Absorption of crushed granite in 1 h and 24 h is 6%. Sieve analysis was performed on a weighed sample of crushed granite, sand and palm kernel shells to determine their grading. All samples of aggregates were washed by water and dried under the sun for 2 days before analysis. Sieve analysis provided information on the gradation of aggregates from which grain size distribution curves were drawn. Experimental procedure conformed to the specifications of ASTM C 136 (2003). The dry weight of original sample for sharp sand, crushed granite and palm kernels is all 1000 g. Mix design of 1:2:4 and a water-cement ratio of 0.6 were used to produce concrete specimen cubes of size 150 mm^3. A total of 60 cubes were made and wholly submerged in water to cure for 28 days at intervals of seven days i.e. seven, 14, 21 and 28 days after which their densities and compressive strengths were determined. Granite was replaced by palm kernel shell in the mix at 25% interval resulting in three replicates of specimen cubes at each curing age.

2.3 Physical Properties Test on Aggregates

2.3.1 Specific Gravity

ASTM C 127-07 (2007), a standard that is used to determine the specific gravity of materials, was employed to ascertain specific gravities of sand and cement using the density bottle while the pycnometer was used to determine the specific gravities of palm kernel shell and crushed granite. Specific gravity given with Equation (1),

$$SG = \frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)} \tag{1}$$

where, SG=Specific gravity; W_1=Weight of empty density bottle (g); W_2=Weight of density bottle +Sample (g); W_3=Weight of density bottle + Sample +Water (g); W_4=Weight of density bottle + Water (g).

From Equation (1) and Table 1, the specific gravities of sharp sand, crushed granite, palm kernel shell and cement are 2.5, 2.76, 1.301 and 3.0 respectively.

Table 1 Results for specific gravity determination

Aggregate/Parameter	W_1, g	W_2, g	W_3, g	W_4, g
Sharp sand	33	48	92	84
Crushed granite	480	1492	2011	1366
Palm kernel shell	480	942	1467	1360
Cement	34	43	84	88

2.3.2 Bulk Density

Test carried out on the samples of aggregates used for the research was in accordance with the provisions of ASTM C 29/C29M (2003). Bulk density given with Equation (2),

$$\frac{Weight\ of\ sample}{Volume\ of\ mould} \tag{2}$$

where, W_1 = Weight of empty mould (g); W_2 = Weight of mould + Sample (g); $W_3 = (W_2 - W_1)$ = Weight of Sample (g).

Hence, volume of mould used = 1735.5 cm^3 = 0.0017355 m^3, Where length = 17.3 cm; width = 8.8 cm;

depth = 11.4 cm.

From Equation (2) and Table 2, the bulk densities of sharp sand, crushed granite and palm kernel shell are 1650 kg m^{-3}, 1545 kg m^{-3} and 634 kg m^{-3}, respectively.

Table 2 Results for bulk density determination

Aggregate/Parameter	W_1, g	W_2, g	W_3, kg	Volume, m^3
Sharp sand	622	3486	2.864	0.0017355
Crushed granite	611	3293	2.682	0.0017355
Palm kernel shell	611	1712	1.101	0.0017355

2.3.3 Water Absorption

Water Absorption test on materials was carried out in accordance with BS 1881-Part 122 (BS 1881: Part 122, 1983) and the equation given with Equation (3),

$$\frac{(W_2 - W_1)}{(W_1)} \quad (3)$$

where, W_1 = Weight of sun - dried sample; W_2 = Weight of sample after 1 h divided by 24 h immersion in water. $(W_2 - W_1)$ = Weight of water absorbed.

From Equation (3), Table 3 and Table 4, the percentage water absorption of palm kernel shell in 1 h and 24 h is 11% and 21.5%, respectively while the percentage water absorption of crushed granite in 1 h and 24 h is 6%.

Table 3 Results for water absorption determination for 1 h

Aggregate/Parameter	W_1, g	W_2, g	$(W_2 - W_1)$, g
Palm kernel shell	1000	1110	110
Crushed granite	1000	1006	6

Table 4 Results for water absorption determination for 24 h

Aggregate/Parameter	W_1, g	W_2, g	$(W_2 - W_1)$, g
Palm kernel shell	1000	1215	215
Crushed granite	1000	1006	6

Table 5 Sieve analysis of aggregates used in this research

Parameters	Sharp sand	Crushed granite	Palm kernel shell
Coefficients of curvature (C_c),	1.3	1.6	2.0
Coefficients of uniformity (C_u)	6.0	1.4	1.2
Fineness modulus (*FM*)	2.69	5.74	3.81

Table 6 Comparison of properties of aggregates used in this research

Properties	Crushed granite	Palm kernel shell	Sharp sand
Thickness, mm	-	1.0-3.0	-
Bulk density, kg m^{-3}	1545	634	1650
Specific gravity	2.76	1.30	2.5
Fineness modulus	5.74	3.81	2.69
Water absorption – 1 h, %	0.6	11	-
Water absorption – 24 h, %	0.6	21.5	-
Maximum aggregate size, mm	12	12	4.75

Table 7 Density and Compressive strength developments of palm kernel shell concrete for mix design 1:2:4 and water/cement ratio 0.6

% replacement of palm kernel		0	25	50	75	100
Seven days	Density, kg m^{-3}	2304	1632	1572	1529	1490
	Compressive strength, N mm^{-2}	15.10	12.11	9.16	8.44	3.90
14 days	Density, kg m^{-3}	2337	1684	1608	1556	1504
	Compressive strength, N mm^{-2}	18.97	15.19	13.70	13.03	6.59
21 days	Density, kg m^{-3}	2406	1762	1644	1591	1543
	Compressive strength, N mm^{-2}	19.44	15.58	14.18	13.88	7.95
28 days	Density, kg m^{-3}	2420	2042	1810	1638	1562
	Compressive strength, N mm^{-2}	21.73	16.63	15.60	14.63	12.71

2.4 Strength properties determination

The Slump test was conducted on all the percentage replacements of freshly prepared palm kernel shell concrete as well as the control to determine workability of concrete. Density and compressive strength test were also carried out to determine the strength of concrete. Procedures from BS 1881: Part 102 (1983) was adopted in carrying out the slump test. Excess concrete which could not be contained in the mould for a batch of three was observed when concrete was batched by weight. This is basically due to the differences in specific gravities of palm kernel shell and crushed granite resulting in the batching and concrete specimen cube production in this research being done by absolute volume. Densities of specimens were determined after de-moulding and samples completely immersed in a curing tank of water until the set day for specimen cube crush testing. All specimen cubes were totally immersed in curing tank for a total of 28 days in intervals of 7 days, after which the cubes were brought out of the curing tank and left for two hours to allow for rest and water from the curing tank to dry out from the surfaces of cubes. Cubes were taken to a SEIDNER Compression Testing Machine of maximum capacity 2000 KN to determine compressive strength. The density of each specimen was once more determined before crushing. Three replicates were prepared for specimens at each curing age for the specified 5nos percentage replacements of granite with palm kernel. The specimens were produced with reference to the provisions in BS 1881: Part 108 (1983). A total of 60 specimen cubes were produced for the test for compressive strength, with three cubes representing each designated curing age and percentage palm kernel shell replacement. The maximum loads at which the three replicates fail on the compression testing machine were recorded with their average values computed which is the resultant compressive strength. Prior to this compression testing, the density was calculated as the ratio of the weight to the volume of each specimen. This test was conducted at the Civil Engineering Laboratory of the Institute of Management and Technology (IMT), campus III, Enugu in Enugu State using a SEIDNER machine. Compressive strength was determined in accordance with BS EN 12390-3 (2002).

2.5 Particle Size Distribution Results

The figures below are the particle size distribution for sand, palm kernel shell and coarse aggregate.

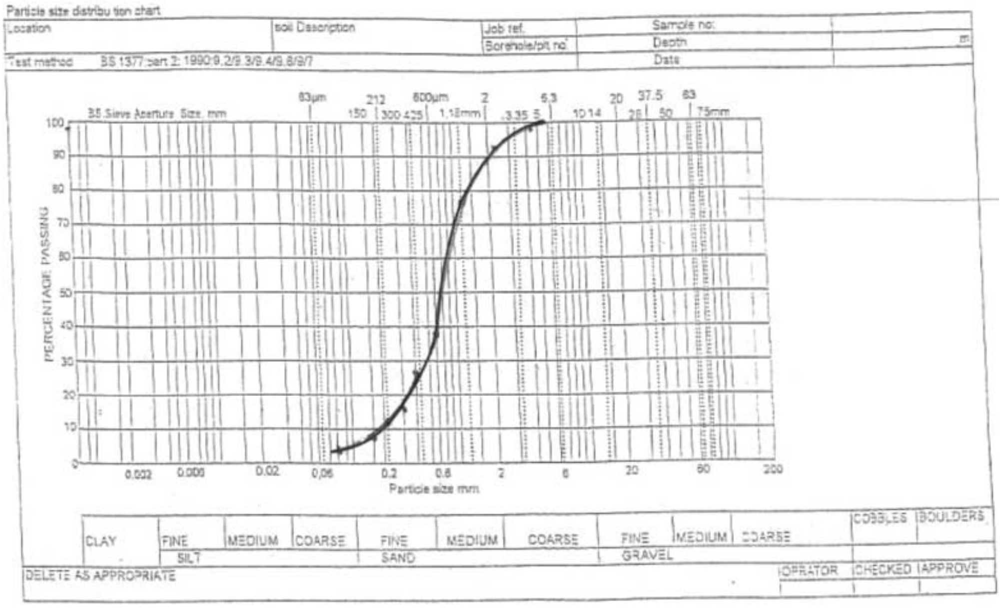

Figure 1 Graph of particle size distribution of fine aggregate (sharp sand)

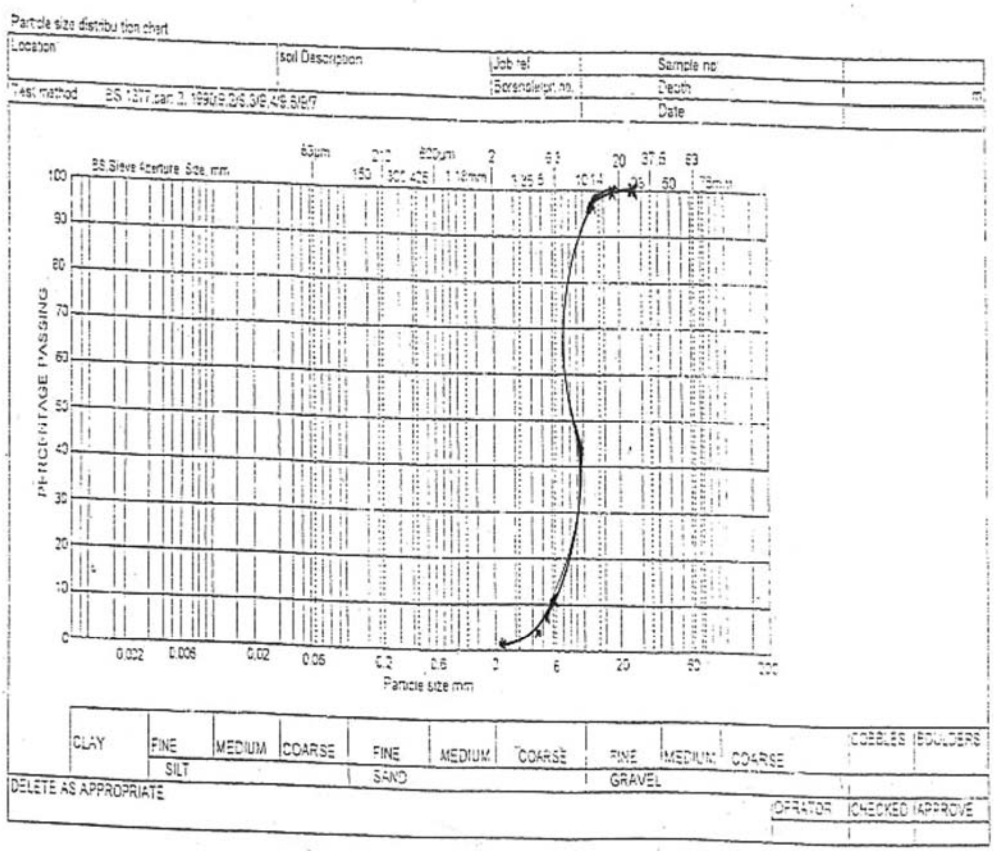

Figure 2 Graph of particle size distribution of palm kernel shell

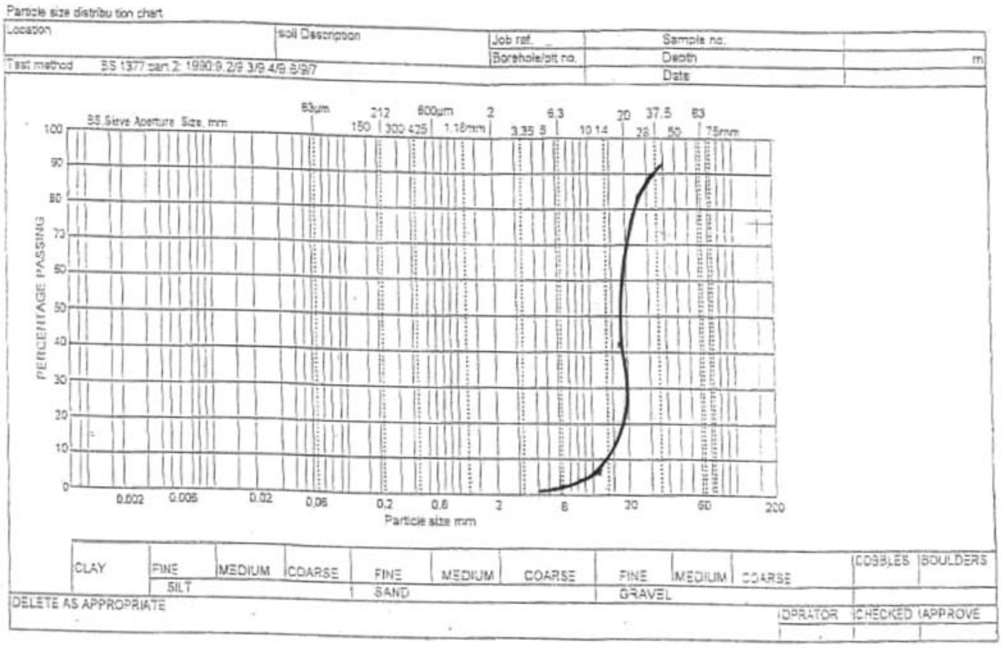

Figure 3 Graph of particle size distribution of coarse aggregate (crushed granite)

3 Results and Discussions

From the results of palm kernel aggregate from Table 6, bulk density and specific gravity is 634 kg m^{-3} and 1.30 respectively. This verifies its adequacy to be used both as a normal aggregate and lightweight aggregate while the other properties confirm only use as a lightweight aggregate. The strength properties of palm kernel shell concrete at age 28 days from Table 7 show that it is appropriate and could be used as a lightweight concrete. However, the values of the mechanical strength for both palm kernel shell concrete and crushed granite concrete increase with age. The density of the normal concrete is in the order of 2304-2420 kg m^{-3}, while the lightweight concrete has density ranging from 1490 to 2042 kg m^{-3}. The results of the density tests presented in Table 7 show an average density of 1763 kg m^{-3} for the palm kernel shell concrete and 2420 kg m^{-3} for normal weight concrete at 28 days. These results show that palm kernel shell concrete is about 27% lower in density than the normal weight concrete. Conversely, the range for density of structural lightweight concrete is 1440 kg m^{-3} to 1850 kg m^{-3} (ACI 213 R-87, 2003). The density of 1562 kg m^{-3} recorded for full replacement at curing age of 28 days falls within the range for structural lightweight concrete and suggests that palm kernel shell can be used as structural lightweight concrete (ASTM C 330, 2004).

From Table 7, the 28 days compressive strength values of all the percentage replacements - 0, 25%, 50%, 75% and 100% - with palm kernel shell are 21.73, 16.63, 15.60, 14.63 and 12.71 N mm^{-2} respectively. This demonstrates the huge influence the amount and type of coarse aggregate used in the production of concrete has on the compressive strength of the corresponding concrete. Grading of aggregates is done using values from coefficient of curvature and coefficient of uniformity. Fineness Modulus which is mainly used for sand is another important determinant in expressing the physical properties of aggregates. Jerry (2008) reports that the values for Coefficient of curvature (Cc) should lie between one and three for well graded gravel and sand whereas the Uniformity coefficient (Cu) should be more than four for well graded gravel and more than six for well graded sand. The range for fineness modulus according to specifications from ASTM C 33 (2003) is 2.3 to 3.1 and from the results presented in Table 5 the fineness modulus of the sand used in this research was found to be 2.69. This value also satisfied the requirement of BS EN 12620:1, (BS EN 12620-1, 2007) for sand to be used for concrete production. Additionally, from the same results of Table 5 the Coefficient of uniformities (Cu) of the sand, gravel and palm kernel shell is 6.0, 1.4 and 1.2, respectively; while their coefficient of curvatures (Cc) is 1.3, 1.6 and 2.0 respectively. Aggregates can be classified as well graded if their *Cc* value is between one and three (Jerry, 2008). Hence, the sand, gravel and palm kernel shell used for the study are well graded and suitable for making good concrete.

4 Conclusion

Palm kernel shell concrete has similar strength properties and relative more structural performance than normal weight concrete from the observations and experimental results presented. However, it can be concluded that the palm kernel shell concrete showed better performance compared to normal weight concrete with respect to cracking from observations from the compression testing machine. Concrete specimen cubes with 0% palm kernel aggregate cracked explosively unlike gradual crack that was experienced with the specimen cubes that had 25% to 100% palm kernel shell content. This could be attributed to the relatively lower density of palm kernel shell concrete as it plays its role in the reduction of dead load as well as its better impact-resistant nature.

Additionally, the density of the palm kernel shell concrete was found to be about 27% lower compared to the normal weight concrete and it is very noteworthy when dead load of the structures is concerned in the design and construction of structural elements. Thus, it can be concluded that palm kernel shell concrete has advantage in both strength and density. The values of 16.63, 15.60, 14.62 and 12.71 N mm^{-2} being compressive strengths obtained for the palm kernel shell concrete at 28 days curing for 25, 50, 75, and 100%, respectively imply that the shell used in this research is suitable for achieving adequate compressive strength. Previously, compressive strengths of palm kernel shell concrete with mix design of 1:2:4 and water/cement ratio 0.6 have been reported to range from 5 to 25 N mm^{-2} (Okafor, 1988). Okpala (1990) and Olanipekun et al. (2006) achieved 16.50 N mm^{-2} and 14.70 N mm^{-2} respectively. Generally, the compressive strength of 13-22 N mm^{-2} was reported for palm kernel shell concrete by many previous researchers. This research has shown that concrete strengths development is directly proportional to curing age and varies inversely with progressive addition of palm kernel shell. The research has also revealed that the physical and mechanical properties of the palm kernel shell aggregates are satisfactory for producing structural concrete.

Additionally, by the prescription of the American Society for Testing of Materials (ASTM) and British Standards Institution (BS), the results of the characterization of the palm kernel shell used in the research for the production of specimen concrete cubes have shown that it met the requirements for use as aggregates in concrete.

Further studies should be conducted with other water cement ratios and mix designs to further evaluate their influences on concrete strength. Subsequent studies on palm kernel shell concrete should allow a curing age of up to 90 days and above. More research is needed to reduce water absorptive nature of palm kernel shell concrete. There is need therefore to intensify studies to reduce the density of palm kernel shell concrete without compromising strength so as to produce medium and high strength concrete. This could be done by crushing the larger original palm kernel shell aggregate so as to improve on the compressive strength of Lightweight aggregate concrete.

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