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MECHANICAL PROPERTIES OF PALM KERNEL SHELL CONCRETE IN COMPARISON WITH PERIWINKLE SHELL CONCRETE

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Abstract: Comparative analysis of mechanical properties of palm kernel shell concrete with periwinkle shell concrete is presented in the paper. The binder and fine aggregate were Ordinary Portland cement and river sand, respectively, while potable water was used for mixing and curing. The constituent materials were batched by weight. Concrete mix ratio was 1:2:4 and water/cement ratio was 0.5. Three groups of concrete mixes containing different coarse aggregates were tested: 100% palm kernel shells, 100% periwinkle shells, and 100% granite as control. Tests were carried out for bulk density and compressive strength of the concrete cubes at 7, 14, 21, and 28 days curing, respectively. The results revealed that for all curing ages, palm kernel shell concrete had lower bulk density and lower compressive strength than periwinkle shell concrete. The bulk density and compressive strength of the 28-day palm kernel shell concrete were 1840 kg/m^3 and 14.02 N/mm^2, respectively, those of periwinkle shell concrete were 1936 kg/m^3 and 16.90 N/mm^2, while those of granite concrete were 2496 kg/m^3 and 25.95 N/mm^2, respectively. Both palm kernel shell concrete and periwinkle shell concrete satisfied the bulk density and compressive strength requirements for lightweight aggregate concrete.

Keywords: *Coarse aggregate, lightweight aggregate concrete, mechanical properties, palm kernel shell, periwinkle shell*

1.0 Introduction

The urge to explore agricultural and industrial by-products as substitute for conventional natural aggregate in concrete is growing due to environmental and economic considerations. Utilisation of by-products as alternative construction materials is especially needful for a developing country like Nigeria where the cost of construction is relatively high due to factors such as increase in demand of cement and other building materials, relative unavailability of natural coarse aggregate in some parts of the country (e.g. in coastal regions), and high cost of transportation of construction materials. Many agricultural and industrial by-products recognised as possible replacement of conventional aggregates in concrete are lightweight aggregates. Advantages of lightweight aggregate concrete over conventional concrete include decreased dead load, lower rate of depletion of natural resources, lower thermal conductivity, and reduced construction costs. There is a continuing trend towards the use of more lightweight concrete in applications such as prestressed concrete and high-rise buildings (Neville and Brooks, 2010). Some agricultural by-products such as palm kernel shell and periwinkle shell have been identified as potential replacement aggregate in concrete. However, agricultural by-products have not been fully utilised as coarse aggregates in building sustainable concrete structures in Nigeria.

Palm kernel is the principal source of palm oil, a major cooking ingredient in the Southern parts of Nigeria. Palm oil trees thrive in the tropics and are found in tropical regions of Africa, Asia, and America. Table 1 shows the list of global palm oil production in 2015. The top five producers of palm oil in the world – Indonesia, Malaysia, Thailand, Columbia, and Nigeria – account for around 90% of the total production worldwide (Global Palm Oil Production 2015, n.d.). Palm kernel shells are the shell fractions left after the oil, fibres, and nuts have been removed. Periwinkles are edible shell fishes found in estuarine waters and mangrove swamps. In Nigeria, periwinkles are found mainly along the coastal areas in the Niger Delta. Both palm kernel shells and periwinkle shells are inedible agricultural by-products which are usually discarded as waste. Large quantities of palm kernel shells and periwinkle shells are produced daily in Nigeria. Stockpiling agricultural by-products in landfills or open dumpsites causes environmental problems such as contamination and pollution (Mo *et al.*, 2016). A possible way of solving this waste management problem is to use palm kernel shells and periwinkle shells as alternative aggregate for production of concrete.

Table 1: Global palm oil production in 2015

Rank	Country	Production (1,000 MT)
1	Indonesia	33,400
2	Malaysia	19,900
3	Thailand	1,800
4	Columbia	1,200
5	Nigeria	940
6	Ecuador	530
7	Guatemala	520
8	Papua New Guinea	500
9	Other countries	3,600

(Source: Global Palm Oil Production 2015, n.d.)

Palm kernel shell and periwinkle shell seem to be suitable lightweight aggregates in concrete based on their properties such as size, shape, surface texture, toughness, and hardness. The size of broken palm kernel shell varies according to the cracking force. The thickness of palm kernel shell depends on the specie and ranges from 0.5-8 mm (Prusty and Patro, 2015). According to Common Periwinkle (n.d.), the width of a periwinkle shell ranges from 10-12 mm at maturity, the length ranges from 16-38 mm, while the maximum recorded height is 52 mm. Palm kernel shell is fairly smooth-textured and its shape may be flaky, irregular, angular, circular, or polygonal depending on the breaking pattern of the nut. Periwinkle shell is rough-textured and generally has elongated conical shape. The chemical composition of aggregate may affect the properties of concrete to a varying degree (Dhir and Jackson, 1996). Reactive silica in aggregate reacts with alkali present in cement, i.e. K_2O and Na_2O. Alkali-silica reaction can cause deterioration expansion in concrete, but damaging reactions can only occur if the aggregate contains sufficient amount of reactive silica (Islam and Ghafoori, 2013). Malu and Bassey cited in Ohimain *et al.* (2009) reported that periwinkle shells contain the following chemical compounds: SiO_2 (0.014%), Fe_2O_3 (0.019%), Al_2O_3 (0.211%), MgO (18.7%), and CaO (38.4%). Their findings suggest that periwinkle shell contains only traces of silica. Palm kernel shell does not contaminate or leach to produce toxic substances once it is bound in concrete matrix (Alengaram *et al.*, 2008). Palm kernel shell and periwinkle shell bind easily with cement products, just like coventional coarse aggregates.

Researches have been carried out within the last decade on various aspects of palm kernel shell concrete (e.g. Alengaram *et al.*, 2010; Osei and Jackson, 2012; Olusola and Babafemi, 2013; Yew *et al.*, 2014; Foong *et al.*, 2015; Mo *et al.*, 2015a,b; Aslam *et al.*, 2016), and periwinkle shell concrete (e.g. Adewuyi and Adegoke, 2008; Agbede and Manasseh, 2009; Osadebe and Ibearugbulem, 2009; Osarenmwinda and Awaro, 2009; Falade *et al.*, 2010; Adaba *et al.*, 2012; Ettu *et al.*, 2013; Ibearugbulem *et al.*, 2016; Soneye *et al.*, 2016). Results of these studies generally suggest suitability in using both palm kernel shell and periwinkle shell as coarse aggregates for lightweight concrete. However, there is dearth of literature on comparative analysis of the properties of palm kernel shell concrete with periwinkle shell concrete made with the same type and quantity of constituent materials. This study, therefore, compares some of the mechanical properties of lightweight aggregate concrete produced from palm kernel shells with those of periwinkle shells. The results of bulk density and compressive strength tests of both palm kernel shell concrete and periwinkle shell concrete are presented and compared in this paper, using normal weight concrete as control sample. Lightweight aggregate concrete were produced with 100% palm kernel shell and 100% periwinkle shell, respectively, as coarse aggregate, while control concrete was produced using crushed granite. The same type and quantity of cement, fine aggregate, and water were used for all the concrete mixes.

2.0 Materials and Methods

2.1 Materials

Coarse Aggregates: Palm kernel shells were obtained in broken form from a palm oil mill at Umuagwo in Ohaji/Egbema Local Government Area in Imo State, Nigeria. Periwinkle shells were sourced from a dumpsite at Isiokpo in Ikwerre Local Government Area in Rivers State, Nigeria. Crushed granite of 20 mm maximum size was sourced from Lokpa in Umunneochi Local Government Area of Abia State, Nigeria.

Fine Aggregate: River sand was obtained from Otammiri River in Imo State, Nigeria.

Water: Potable tap water obtained from a borehole in Owerri, Imo State, Nigeria was used for mixing and curing of concrete. It was found to conform to the specifications of BS 3148 (1980).

Cement: Ordinary Portland cement complying to NIS 444-1 (2003) was used.

2.2 Preparation and Casting of Samples

The aggregate materials were washed, air-dried, and sieved. For the coarse aggregates, particles retained on the 4.75 mm sieve were used for the experimental study while particles passing through the 4.75 mm sieve were discarded. No special treatment was made to improve the quality of the aggregates. Tests were conducted to determine the particle size distribution, physical properties, and mechanical properties of the aggregates. Test sieves used in determining the particle size distribution were in accordance with BS 410-1 (2000). The physical properties tested for aggregates were specific gravity, uncompacted bulk density, compacted bulk density, and water absorption. Mechanical properties of coarse aggregates determined in this study were aggregate impact value and Los Angeles abrasion value. Fineness modulus of the fine aggregate was obtained.

Concrete mix ratio of 1:2:4 and water/cement ratio of 0.5 were selected for the experimental programme. The constituent materials were batched by weight, and fresh concrete was mixed manually on a concrete pavement using a spade. No admixtures were added to the concrete mixes. The mixes were poured into standard moulds of 150 × 150 × 150 mm to produce concrete cubes. Twelve cubes were cast for palm kernel shell concrete, periwinkle shell concrete, and granite concrete, respectively, giving a total of 36 concrete cubes. All cubes were de-moulded 24 hours later and water-cured until the day of testing.

2.3 Testing of Concrete Properties

The slump of fresh concrete, bulk density of hardened concrete, and compressive strength of hardened concrete were tested. Slump test measures the workability of fresh concrete mix and was performed according to BS 1881-102 (1983). The bulk density and compressive strength of the samples were conducted according to the specifications of BS 1881-114 (1983) and BS 1881-116 (1983), respectively. Bulk density and compressive strength results were obtained for the concrete cubes at 7, 14, 21, and 28 curing days. The bulk density and compressive strength are represented by the mean values of the three concrete cubes for each curing age.

3.0 Results and Discussion

3.1 Particle Size Distribution

The results of the particle size distribution of the palm kernel shell, periwinkle shell, and granite are shown in Figure 1. From the graph, the coefficient of curvature, C_c, of the palm kernel shell, periwinkle shell, and granite are 1.65, 1.70, and 1.62, respectively. The uniformity coefficient, C_u, of palm kernel shell, periwinkle shell, and granite are 3.55, 3.10, and 2.05, respectively. It is observed that the coarse aggregate grains can be arranged such that dense packing is possible since the particle distribution curves are concave upwards (McKinlay, 1996). However, the grading of the granite is more uniform than those of palm kernel shell and periwinkle shell since the range of particle sizes of the granite is smaller. This means that grain sizes of the granite particles can be compacted such that dense packing is possible. The mass of fine particles (less than 4.75 mm) collected after sieving was 13.3% for palm kernel shell and 9.3% for periwinkle shell. Only 0.3% of the mass of crushed granite passed through the 4.75 mm sieve. All the particles of palm kernel shells and granite were less than 20 mm nominal size while 89.5% of the periwinkle shell sizes were less than 20 mm. It is common practice to use coarse aggregate of maximum size 20 mm for reinforced concrete construction from the practical point of view (Shetty, 2012). Although palm kernel shells had a higher proportion of fine particles when compared with periwinkle shells, palm kernel shells seem to be more convenient for use as coarse aggregate in reinforced concrete work based to its maximum aggregate size.

The particle size distribution curve for river sand in Figure 2 shows that the coefficient of curvature, C_c is 0.74, and the uniformity coefficient, C_u is 6.9. The uniformity coefficient indicates that the river sand is well-graded since it is greater than 5 (McKinlay, 1996).

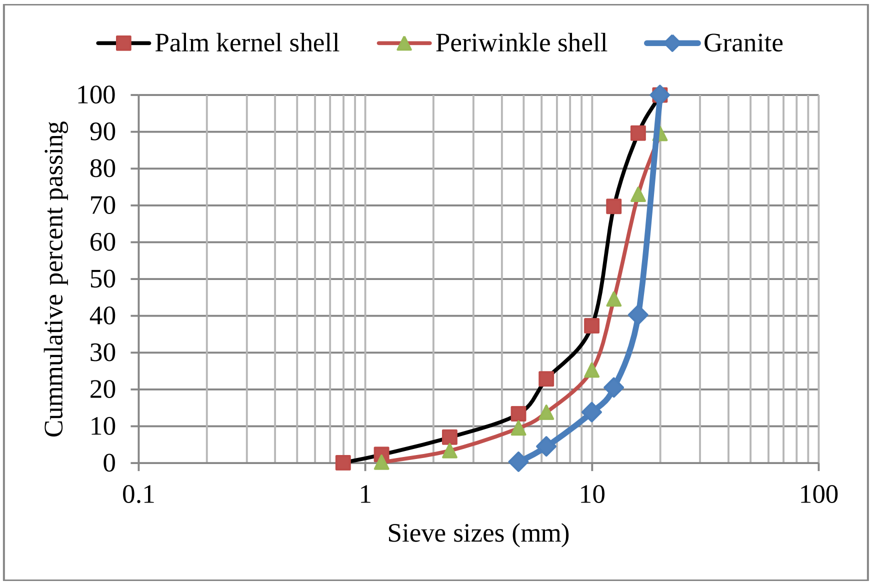

Figure 1: Particle size distribution curves for palm kernel shell, periwinkle shell, and granite

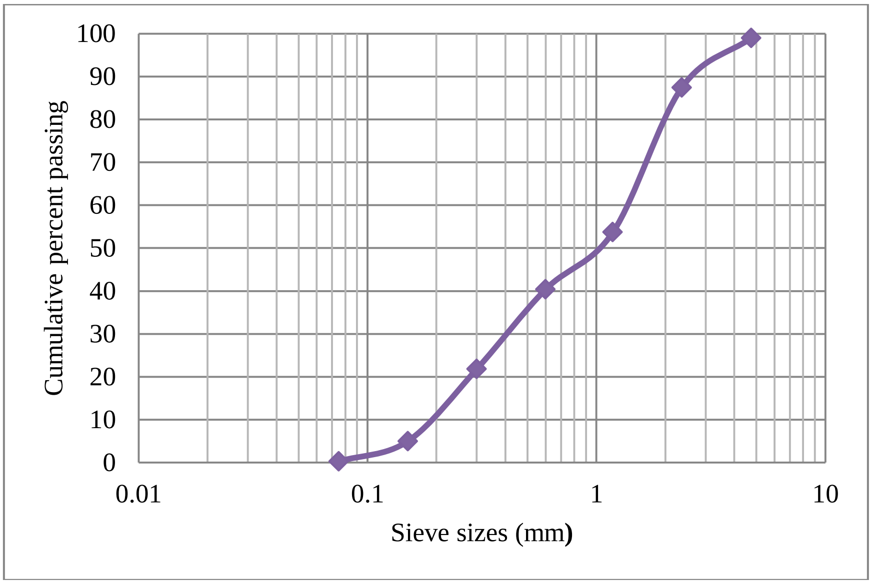

Figure 2: Particle size distribution curve for river sand

3.2 Physical and Mechanical Properties of Aggregates

The physical and mechanical properties of palm kernel shell, periwinkle shell, and granite are shown in Table 2, while the physical properties of river sand are shown in Table 3. From the values of the specific gravity and bulk densities in Table 3, periwinkle shell is denser than palm kernel shell. Majority of natural aggregates have a specific gravity between 2.6 and 2.7 (Neville and Brooks, 2010). The specific gravity of periwinkle shell is higher than the practical range for lightweight aggregates as recommended by ACI 213R-03 (2003), which is about 33-67% of normal weight aggregates i.e. around 0.85-1.80. Nevertheless, the specific gravity of periwinkle shell is less than the specific gravity of normal weight aggregates. Both palm kernel and periwinkle shells met the maximum requirements for loose bulk density and compacted bulk density of lightweight coarse aggregate, which are 880 kg/m^3 (ASTM C 330-04, 2004) and 1000 kg/m^3 (Prusty and Patro, 2015), respectively. Palm kernel shell has a higher capacity to absorb water than periwinkle shell based on the water absorption values. The absorbed water is irrelevant for water/cement ratio and workability, but may have serious consequences if the aggregate is subjected to conditons that may lead to frequent expansion and contraction, such as alternate wetting and drying. The 24-hour absorption of lightweight aggregate ranges from 5-20% while absorption for normal weight aggregate is usually less than 2% (Neville and Brooks, 2010). The 24-hour absorption of palm kernel shell, periwinkle shell, and granite are within the normal range for lightweight aggregates and normal weight aggregates, respectively.

Table 2: Test results for physical and mechanical properties of coarse aggregates

Property	Palm kernel shell	Periwinkle shell	Granite
Specific gravity	1.30	2.05	2.62
Uncompacted bulk density (kg/m^3)	530	570	1480
Compacted bulk density (kg/m^3)	600	660	1560
24-hour water absorption (%)	19.6	4.4	1.2
Aggregate impact value (%)	4.80	32.50	15.60
Los Angeles abrasion value (%)	4.20	45.73	17.28

Table 3: Test results for physical properties of fine aggregate

Property	River sand
Specific gravity	2.65
Uncompacted bulk density (kg/m^3)	1565
Compacted bulk density (kg/m^3)	1590
24-hour water absorption (%)	1.2
Fineness modulus	2.92

Aggregate impact value and Los Angeles abrasion value respectively measure the toughness and hardness of aggregate. According to Shetty (2012), the aggregate impact value and Los Angeles abrasion value should not be more than 30% for wearing surface concrete. For concrete other than wearing surfaces, aggregate impact value and Los Angeles abrasion value should not more than 45% and 50%, respectively (Shetty, 2012). Periwinkle shell has the highest aggregate impact and Los Angeles abrasion values while palm kernel shell has the lowest values. Periwinkle shell did not meet the specifications for aggregate impact value and Los Angeles abrasion value for use in wearing surface concrete, but however, met the specifications for non-wearing surface concrete. Granite has lower impact and abrasion values than periwinkle shell. Palm kernel shell has excellent resistance to abrasion and shock, an important property for coarse aggregate used in concrete surfaces subjected to heavy traffic.

The specific gravity of river sand given in Table 3 is within the range for normal fine aggregate. The compacted bulk density and 24-hour water absorption of river sand are comparable to those for granite listed in Table 2. The fineness modulus indicates that the fine aggregate lie between medium sand and coarse sand, which implies that the river sand is suitable for production of satisfactory concrete (Shetty, 2012).

3.3 Workability

The slump of palm kernel shell concrete, periwinkle shell concrete, and granite concrete were 35 mm, 30 mm, and 50 mm, respectively. The slump of all the concrete groups fell within the range of 25-75 mm, indicating that the concrete mixes have low workability (Shetty, 2012). The relative low workability may be due to the water/cement ratio used in the investigation. Based on the low degree of workability, both palm kernel shell concrete and periwinkle shell concrete may be suitable for mass concrete foundations without vibration, or lightly reinforced sections with vibration. For the concrete mix ratio of 1:2:4 and water-cement ratio of 0.5, fresh concrete mix of palm kernel shell concrete showed higher workability than that of periwinkle shell concrete. Granite concrete gave the highest value of slump. Palm kernel shell and periwinkle shell had finer grading than granite which may be a reason for higher value of slump for granite concrete. With other conditions being equal, workability generally increases when the overall aggregate grading becomes coarser (Dhir and Jackson, 1996).

3.4 Bulk Density

The results of the bulk densities for the various ages of the palm kernel shell concrete, periwinkle shell concrete, and granite concrete are shown in Figure 3. The bulk densities of palm kernel shell concrete and periwinkle shell concrete mixes are less than 2000 kg/m^3, the maximum density of lightweight concrete (Neville and Brooks, 2010). Palm kernel shells can be used to produce concrete members with lower self-weight in comparison with periwinkle shells for 1:2:4 mix ratio and 0.5 water/cement ratio. Lower bulk density was obtained for palm kernel shell concrete as a result of the lower specific gravity and lower bulk density of palm kernel shells. Bulk densities of the 28-day air-dry palm kernel shell concrete and periwinkle shell concrete were 73.7% and 77.6% of the bulk density of the control (granite) concrete, respectively. The bulk density of the control concrete for all the curing ages were within the range of 2200-2600 kg/m^3, the density range for normal weight concrete (Neville and Brooks, 2010).

ASTM C 330-04 (2004) defines the density of structural lightweight concrete as concrete having dry density not exceeding 1840 kg/m^3. This value was the exact numerical value of 28-day air-dry bulk density of palm kernel shell concrete obtained in this study, while that of periwinkle shell concrete exceeded this value by 5.2%.

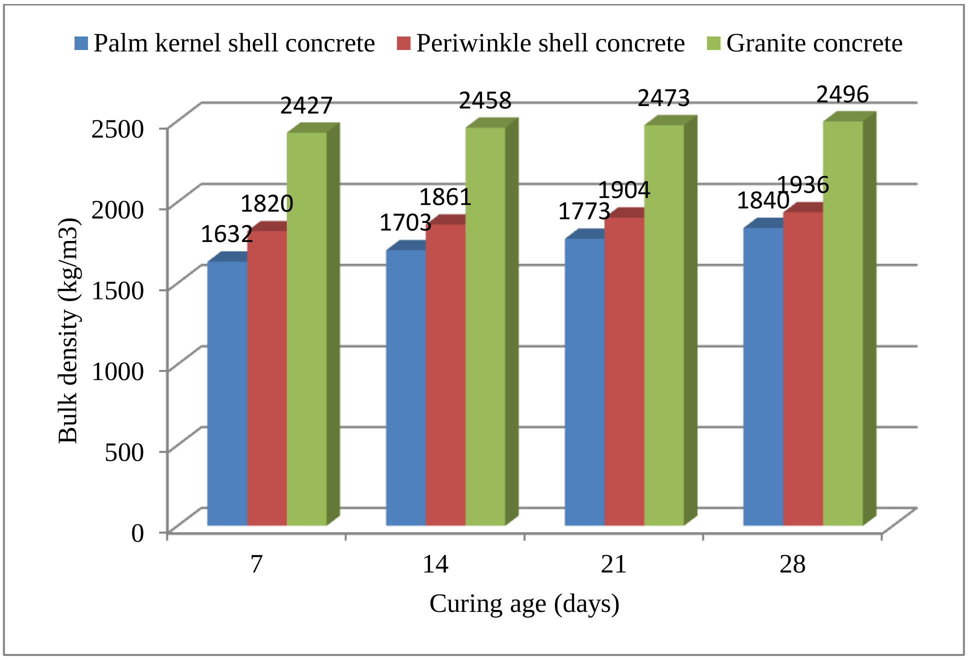

Figure 3: Bulk density of palm kernel shell concrete, periwinkle shell concrete, and granite concrete

3.5 Compressive Strength

The compressive strength results at 7, 14, 21, and 28 days presented in Figure 4 show that the compressive strength of each concrete mix increased with age. As expected, the 7-day concrete cube attained the lowest compressive strength while the 28-day concrete cube had the highest compressive strength for all concrete groups. Compressive strength of concrete generally increases rapidly within the first few days, and the rate of increase in compressive strength later becomes more gradual. From practical assumptions, concrete at 28 days is 1.5 times as strong as at 7 days with the range varying from 1.3-1.7 (Hassoun and Al-Manaseer, 2008). This implies that the 7-day compressive strength of concrete generally ranges from 59-77% of the 28-day compressive strength. The ratio of 7-day compressive strength to 28-day compressive strength of palm kernel shell concrete, periwinkle shell concrete, and granite concrete obtained in this study were 49.2%, 62.7%, and 78.3%, respectively. The granite concrete gained high early strength in comparison with periwinkle shell concrete and palm kernel shell concrete. The ratio of the compressive strength of 7-day palm kernel shell concrete to 28-day palm kernel shell concrete was less than the given range due to physical and bond properties of the palm kernel shells.

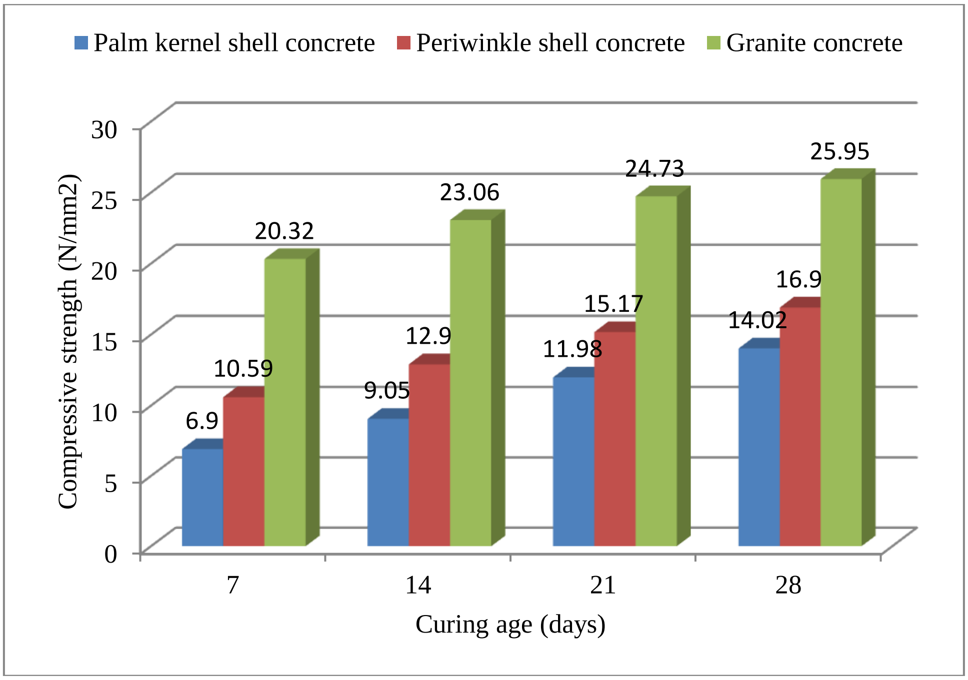

Figure 4: Compressive strength of palm kernel shell concrete, periwinkle shell concrete, and granite concrete

The 28-day compressive strength of the palm kernel shell concrete and periwinkle shell concrete were within the range of 5-19.5 N/mm^2, satisfying the strength criteria for classification as lightweight concrete (Chandra and Berntsson cited in Osei, 2014). For reinforced concrete work, BS 8110-1 (1997) recommends that the minimum compressive strength of lightweight concrete should be equal to 15 N/mm^2 or more.

From Figure 4, the 28-day compressive strength of palm kernel shell concrete is less than the minimum compressive strength of reinforced lightweight concrete by 7% while the 28-day compressive strength of periwinkle shell concrete exceeded the minimum strength of reinforced lightweight concrete by 12.7%. The 28-day compressive strength of palm kernel shell concrete, however, exceeded the characteristic compressive strength of 10 N/mm^2 for plain concrete specified in BS 8110-1 (1997). Compressive strength of palm kernel shell concrete was less than compressive strength of periwinkle shell concrete due to smoother texture and convex shape of the palm kernel shells. The shape and texture of palm kernel shells resulted to relatively weaker bond between the palm kernel shells and cement paste. The compressive strength of granite concrete at 28 days satisfied the characteristic strength for ordinary and reinforced concrete specified in BS 8110-1 (1997). It should be noted that greater values of concrete strength can be attained when higher quality control measures are adopted at longer days of curing.

4.0 Conclusions

Based on the results of the experimental study, the following conclusions are drawn:

1. The physical properties of palm kernel shell and periwinkle shell such as specific gravity, bulk density, and water absorption, indicate that palm kernel shell and periwinkle shell have the properties of lightweight aggregates.
2. Palm kernel shell possesses better mechanical properties than periwinkle shell. Palm kernel shell has excellent resistance to shock and abrasion.
3. Palm kernel shell concrete has higher workability than periwinkle shell concrete. For 1:2:4 concrete mix ratio and 0.5 water/cement ratio, the concrete mixes had low workability.
4. Palm kernel shell concrete has lower bulk density than periwinkle shell concrete. Both the palm kernel shell concrete and periwinkle shell concrete satisfied the bulk density requirement of lightweight concrete.
5. Both palm kernel shell concrete and periwinkle shell concrete satisfied the criteria for 28-day compressive strength of lightweight concrete, with the compressive strength of palm kernel shell concrete being lower than that of periwinkle shell concrete. The 28-day compressive strength of palm kernel shell concrete did not meet the minimum compressive strength requirement of BS 8110-1 (1997) for reinforced lightweight concrete while the 28-day compressive strength of periwinkle shell concrete exceeded the requirement. However, 28-day compressive strength of palm kernel concrete exceeded the compressive strength requirement for plain concrete.

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