Investigating the Performance of Palm Kernel Shells and Periwinkle Shells as Coarse Aggregates in Concrete

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Abstract

Excessive usage of materials is causing fast depletion of natural stone deposit. This study therefore investigates the performance of palm kernel shells (PKS) and periwinkle shells (PS) as alternatives coarse aggregates in concrete. Forty cubes and 40 cylinders each were produced with PKS and PS as replacement materials for granite. Series of tests were conducted to determine their performances. The results showed that, compressive and tensile strengths decrease as PKS and PS content increases, which allow specific area to increase, thus requiring more cement paste to bond effectively with the shells. The result also revealed that for all curing ages, palm kernel shell concrete (PKSC) have lower compressive strength and tensile strength than periwinkle shell concrete (PSC). The compressive strength and tensile strength of the 28-day PKSC with 100% replacement were 4.33 N/mm² and 3.68 N/mm² respectively; that of PSC at 100% replacement were 5.89 N/mm² and 4.95 N/mm² respectively; and granite concrete without any replacement were 25.11 N/mm² and 11.74 N/mm² respectively. It is concluded that both PKSC and PSC satisfied the compressive strength and tensile strength requirement of light weight concrete, although PS has better gradation and bonding to cement than PKS. This implies that PS is best suited as replacement for granite in lightweight concrete than PKS. It is recommended that the mix-ratio should be altered to get higher values of compressive strength; and both PKS and PS should be used for lightweight concretes.

Keywords: Granite, Palm kernel, Periwinkle, Performance, Shells.

Introduction

Concrete is the most popular material used in construction work, its main component is a mixture of cement, fine aggregate, coarse aggregate and water. According to Falade, Ikponmwosa and Ojediran (2010), the volume of concrete is composed of about 70%-80% of coarse aggregate, which means the percentage of coarse aggregate is of considerable importance. Structural lightweight materials can be defined as a type of concrete, which include an expanding agent (i.e. lightweight aggregate) that increase the volume of mixture while giving additional qualities and reduce the dead weight. Although the engineering properties of shells are generally satisfactory, there is little effort made in comparing PKSC with PSC.

Efforts by researchers have been spent on the possible use of shells as coarse aggregate but little or no effort has been made in the construction industry on the possibility of using PKS and PS as coarse aggregates either wholly or partially in structural concrete. The rise in the need for concrete in the construction industry using natural weight aggregate such as granite or gravel reduced the availability of natural stones and has damage the environment leading to imbalance of ecological system (Short and Kinniburg, 1978).

Olugbenga (2016) assessed the properties of lightweight concrete, such as aggregate impact value, aggregate crushing value and compressive strength utilizing periwinkle shell (PS) as partial

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replacement for coarse aggregate. Standard mix of 1:2:4 with varying percentages of 0, 10, 20, 30, 40, 50 and 100% partial replacement of PS using water/cement (W/C) ratio of 0.55 was used. Seventy-two cubes of 150 mm x 150 mm x 150 mm were cast; allowed to set for 24 hours before remoulding and were properly cured. The strength characteristics of each cube were evaluated using Compressive Testing machine at the curing ages of 7, 14, 21 and 28 days. The all commodity volume (ACV) and aggregate impact value (AIV) obtained are 31.59% and 22.61% respectively, which is within the acceptable limit. An optimum compressive strength value of 16.79 N/mm² and 16.71 N/mm² were obtained with the addition 20% and 30% partial replacement of coarse aggregate with PS in 28 days. These values are within 15-25 N/mm² and it is suitable for lightweight concrete. The research demonstrates that the utilization of PS in structural/insulating lightweight concrete, at lower volume of replacement, will reduce the utilization of granite in concrete. Thus, decreasing the production cost of concrete and the ecological contamination brought about by the dumping of periwinkle shell.

In this regard, Ameh, Afuye, and Amusan(2014) assessed the potential usefulness of PS as an alternative replacement of coarse aggregate in concrete work. The mechanical properties of concrete with fine and coarse aggregates components fully and partly replaced with lateritic sand and PS was investigated. A working sample of 135 concrete cubes of 100 mm dimensions were produced and cured in water for 7, 14 and 28 days. The fine aggregates and coarse aggregates were replaced with lateritic sand and PS respectively at 10, 20, 30, 40 and 100%. The mix proportions adopted for this work was 1:1½:3, 1:2:4 and 1:3:7 with water/cement ratio of 0.65. The study therefore recommends that 20% lateritic sand and PS replacement for fine and coarse aggregate in concrete is suitable for use as low strength lightweight concrete.

Similarly, Osei and Jackson (2012), investigate PKS as coarse aggregates in concrete. The shells were flushed with hot water to remove dust and other impurities that could be detrimental to concrete and then sun-dried before being packed in plastic sheets to prevent contact with water. Two mix ratios, 1:2:4 batched by volume and 1:2:4 batched by weight were used. The percentage replacements of the aggregates by PKS were 0, 25, 50, 75 and 100% by volume and by weight respectively. The study found that there exists a high potential for the use of PKS as aggregates in the manufacture of lightly reinforced concrete. PKSC batched by volume replacement and weight replacement of coarse aggregate both show similar trends in the variation of density, workability and strength with increase in percentage replacement. Although PKSC batched by volume performed better than that batched by weight and replacement of 8% crushed granite by PKS in volume batched concrete can be used in reinforced concrete construction, whereas replacement of 13% of crushed granite by PKS in weight-batched concrete can be used in reinforced concrete construction.

Moreover, Williams, Ijigah, Anum, Isa and Obanibi (2014) found that properties of PKS fresh concrete are excellent, workable, consistent and easily placed; and that hardened PKSC developed enough strength suitable for wide range of uses. However, the flexural and compressive strength values of the normal weight concrete is about twice that of the PKS which is normal as PKS is lighter. The study concluded that palm kernel shell concrete is useful as coarse aggregate where they are abundant in order to reduce the cost of building construction.

In view of the above-mentioned studies, this present study compares the performance of PKS and PS using their physical and mechanical properties. It is necessary to look for available materials that can substitute granite and gravel wholly or partially without compromising strength. Investigations

show that the use of agricultural waste materials for conventional materials replacement is very important to curb the shortage of construction materials as well as in the development of low-cost construction materials that will be environmentally friendly. The aim of this study is to compare the performance of PKSC and PSC with crushed rock aggregate concrete with a view to determining the suitability of PKS and PS as aggregate for concrete production. The objective is to determine the performance of PKS and PS at various percentages of granite replacements, as a basis to determine their performances. This study will enhance reduction in construction cost, drive infrastructural development and make engineering construction sustainable. Important properties like dead load in structures will also be minimized in structures. The solution from the research will help lightweight concrete to be used as replacement for normal weights in construction industry after evaluating all necessary properties.

Material and Methods

This study analysed cubes and cylinders made from PKSC and PSC. The PKS used were gotten from Anambra State in the South Eastern Part of Nigeria while the PS was gotten from Lagos State in the South Western Part of Nigeria. The river sands used were obtained through a local supplier from Ogun riverbed located at Ogun state, Nigeria, due to its low chlorine content. The particles size range used are those passing through BS sieve 11mm but retained on BS sieve 0.075mm ensuring that the dust particles were removed from the sand. The coarse aggregate used were crushed granite of igneous origin. They come in different sizes, but the recommended size is between 12mm to 19mm. It helps to improve the strength of the concrete. Water used was portable, clean and free from impurities and organic matter of any type. The cement used was Ordinary Portland Cement (i.e. Dangote Portland Cement). This cement satisfies international standards on cement (BS 12 Portland Cement). This ensures that the cement passes test for which its properties may be determined. Experimental research design was used for this study. This involved control and experimental groups. The control group comprises the concrete cubes and cylinders without replacement that is 100% granite. The experimental groups are the cubes and cylinders with various percentage replacements of granite with PS and PKS. A total of 80 cubes and 80 cylinders were cast in all (see Table 1). Forty cubes and 40 cylinders were cast for each replacement material (PKS & PS). The replacement was done from 0% to 100% in steps of 25% (0, 25, 50, 75, 100%). Two cubes out of the eight cubes cast for each percentage replacement were used to determine the 7, 14, 21 and 28-day strength of the cubes. This also applies for the cylinders. The various tests carried out include slump test (workability), compressive strength test, split cylinder test, sieve analysis, specific gravity, bulk density, dry density, moisture content, and aggregate crushing value.

A single batch mix 1:2:4 (i.e. cement: sand: coarse aggregate) were used during mixing of the concrete cubes for a 0.6 water/cement ratio. The prescribed mix proportion was used (the mixes were specified by weight and are given in BS 8110 (Structural Use of Concrete). The batches were mixed in a tray. The surface of the tray was wetted before mixing to avoid water absorption and to ensure the same mixing conditions for all mixes. Two samples were used for each test and the averages of two results were adopted. The tests were conducted in the concrete laboratory of the University of Lagos, Akoka. Descriptive statistics used in this study involved the construction of frequency distribution tables, mean scores, percentage and standard deviations.

Results and Discussion

The tests carried out for the four materials shows various results. The moisture contents were found to be 2.12, 1.09, 1.53 and 1.82% for sand, granite, PKS and PS respectively. The moisture content is the ratio of the weight of water to the weight of the solids in a given mass of soil. This ratio is expressed as percentage. The conventional moisture contents are 2.3 % and 2% for fine and coarse

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aggregates respectively (Salau and Busari, 2015). It means the moisture contents of the aggregates are satisfactory.

The conventional bulk density of fine and coarse aggregate is between 1520 – 1680 kg/m³ and produce normal weight concrete (NWC). Aggregate with bulk densities less than 1120 kg/m³ are called lightweight (Nemati, 2015). The sand, granite, PKS and PS had a bulk density of 1397.68 kg/m³, 1465.46 kg/m³, 1114.7 kg/m³ and 1376.16 kg/m³ respectively which means the bulk density of granite produce normal weight concrete (NWC) and bulk density of PKS and PS produce light weight concrete (LWC). Since density is an important determining factor in the strength of concrete, Periwinkle Shell is more probable to produce higher strength concrete than Palm Kernel Shell.

Dry density is the dry mass of soil per unit volume. Fine aggregate generally has a conventional dry density of 1442 kg/m³ and the dry density of coarse aggregate is greater than 1442 kg/m³ (Nemati, 2015). The sand, granite, PKS and PS had dry densities of 1368.66 kg/m³, 1449.66 kg/m³, 1097.9 kg/m³, & 1351.56 kg/m³ respectively. Sand and granite are satisfactory but PKS and PS are poor and below the standard. They can be satisfactory when partially used to replace granite in concrete.

Specific gravity of fine aggregate (sand) and coarse aggregates is the ratio of the weight of given volume of aggregates to the weight of equal volume of water. The conventional specific gravity of both fine and coarse aggregates is around 2.65 (Clute, 2003). The sand, granite, PKS and PS had specific gravities of 2.50, 2.76, 1.62 and 1.95 respectively which means the specific gravity of PKS and PS is poor and below the standard 2.65 and are mainly regarded as void in concrete. From the above, in terms of specific gravity PS is a better aggregate than PKS as it is higher and closer to 2.65.

In aggregate crushing test, if the aggregate crushing value is less than 10, it signifies an exceptional strong aggregate. While aggregate crushing value of above 35 would be considered as weak aggregates. According to Uche and Muhammad (2011), ACV of a concrete aggregate should not exceed 30%. The granite, PKS and PS had an aggregate crushing value of 17.39 %, 10.29 % and 11.86 % respectively, which is sufficient.

Sieve analysis

Sieve analysis is used to find the amount of soil variation of the aggregates used in this project. It was carried out by allowing the aggregates pass through a series of sieves. The results of Sieve Analysis tests on the concrete constituent materials show the following trends: The uniformity coefficient C_u is defined as ratio of D_{60} by D_{10} . When C_u is greater than 4 to 6, it is understood as well graded soil and when C_u is less than 4, they are considered poorly graded (Salau and Busari, 2015). Which means the soil have got identical size of the particles. The sand, granite, PKS and PS had uniformity coefficients (C_u) of 2.43, 1.67, 2.04 and 2.39 respectively which mean they are uniformly graded.

The shape of particle size curve is represented by the coefficient of curvature for well graded soil C_c must be between 1 to 3 and poorly graded when C_c is less than 1 (Salau and Busari, 2015). The sand, granite, PKS and PS had a coefficient of curvature (C_c) of 0.84, 1.07, 1.03 and 1.16 respectively which means sand is poorly graded, granite, PKS, and PS are well graded. From the above it can be concluded that the Periwinkle Shell has a better gradation than Palm kernel shell. For the coarse aggregate, it was also observed that 99.7% of the aggregate was retained on the 5mm sieve and 0.3% passed through the sieve. The grain size analyses of the materials are presented in Figure 1.

Figure 1: Particle size distribution for aggregates used

For the specific gravity, PKS had a specific gravity of 1.62 while Williams *et al.* (2014) also found that PKS coarse aggregate had specific gravity relatively low compared to the range of values for different coarse aggregate as a result of the high number of voids within the particles. It can therefore be concluded that PKSC is useful as coarse aggregate where they are abundant in other to reduce the cost of building construction. Palm kernel shell concrete can also be partially replaced with coarse aggregate to get a desired strength in building construction projects.

From this research work, PKS can be used as a replacement material for granite in concrete. This is also the findings of Williams *et al.* (2014) when they investigated the suitability of palm kernel shell as coarse aggregate in lightweight concrete production. The work vividly showed that PKS can be used for concrete production as lightweight aggregate and therefore can be used to produce lightweight concrete. The properties of PKS fresh concrete is however excellent, it is very workable, consistent and easily placed. Hardened palm kernel shell concrete (lightweight concrete) developed enough strength that will help make it suitable for a wide range of uses. However, in this work the compressive strength values of the normal weight concrete are about five times that of the palm kernel shell while in the work of Williams *et al.* (2014), the flexural and compressive strength values of the normal weight concrete is about twice that of the palm kernel shell which is normal as PKS is lighter.

The environmental drivers must not be overlooked as PKS and PS incorporation into concrete on an appropriate selective basis would provide solution to problems encountered in waste management. When used as aggregates to substitute granite, this constitutes a positive response to global environmental problems such as high carbon dioxide emissions generated by Portland cement production. In addition, it would reduce extraction of natural materials such as limestone.

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Workability

Workability is the measure of the amount of useful internal works necessary to be done on a concrete mix to produce full compaction. A standard measure of workability of wet concrete mix is the slump test. The workability of the fresh concrete was determined by the slump test in accordance with section 7.2 of BS 5328. Table 1 presents the slump values for all the mix proportions with different percentages of granite replaced with PS and PKS.

Table 1: Slump values and degree of workability

Percentage Replacement Granite- Replacement Material (%)	PKS Slump Value (mm)	PS Slump Value (mm)
0 - 100	43	43
25 - 75	33	40
50 - 50	28	35
75 - 25	24	28
100 - 0	17	21

From Table 1, it can be observed that the workability decreased from 43 mm to 17mm as the content of replacement increased from 0% to 100% replacement of granite with PKS; and from 43 mm to 21 mm at 0% to 100% replacement of granite with PS. The increase in workability gives an indication that the water absorption property of PKS and PS is high compared to granite, which causes improper bonding in the interfacial transition zone. Hence more water is required to make the mix more workable (Echeta, Ikponmwosa and Fadipe, 2013).

Compressive strengths of PKSC and PSC.

Compressive strength was found out at the ages 7, 14, 21 and 28 days after moist curing of the specimens. Strength of concrete mainly depends on three factors:

- (i) Strength of coarse aggregate;
- (ii) Strength of mortar matrix;
- (iii) Bond strength between mortar part and coarse aggregate;

Two cubes each were cast for each percentage ranging from 0% to 100% in steps of 25%, which was subjected to up to 28days of curing. The test results are presented in Figures 2 and 3.

It can be observed from Figure 2 that the compressive strength decreases as PKS content increases. The compressive strength is maximum at 0% replacement by PKS and minimum at 100% replacement. Similar result was obtained for PS as shown in Figure 3. As PKS and PS content increases, the specific area increases, thus requiring more cement paste to bond effectively with the shells. Since the cement content remains the same, the bonding is therefore inadequate. Strength depends to a large extent on good bonding between the cement paste and the aggregates. The compressive strength reduces because of the increase in percentage replacement of granite.

Figure 2: Variation of compressive strength with percentage replacement (PKS)

The general trend shows a linear relationship between the percentage replacement and the compressive strength and there is general reduction in the compressive strength values when compared to the control. The strength value decreases as the percentage replacement increases from control to 100% replacement. This is an indication that, the substitution of granite with PKS beyond 25% replacement, and 50% for PS is not recommended for use in heavy loaded structure. It was also observed that for every percentage replacement, there is an increasing trend in the compressive strength because of the curing age.

The average value of 15N/mm^2 may be used for Non-Critical Structural Works as stated in CIP- (Concrete in Practice), as well as the American Society for Testing and Materials (ASTM C31/39). However, values higher than 15N/mm^2 are very suitable for Critical Structural Works, but values lower than this benchmark would be suitable for Non-Critical and Non-Structural Works. As shown in Figures 2 and 3, 25% replacement of granite with PKS; while 25% and 50% with PS can be used for non-critical structural works.

Apart from the compressive strengths observed, partial replacement of granite with PKS and PS in concrete production gives significant reduced weight and densities as compared with normal concrete. Use of PKS and PS in concrete production is thus advantageous in concrete production as the dead loads (self-weight) of concrete elements are substantially reduced in a structure.

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Figure 3: Variation of compressive strength with percentage replacement (PS)

PKS and PS can be successfully used only as partial replacement and never as total replacement of granite in concrete production for both structural and non-structural applications.

Tensile strength of PKSC and PSC

The splitting tensile strength is generally greater than direct tensile strength and lower than flexural strength (modulus of rupture). Splitting tensile strength is used to find the tensile strength of concrete. Two cylinders each were cast for each percentage ranging from 0% to 100% in steps of 25% replacement which subjected from 7 days to 28 days of curing in steps of 7 days. The test results are presented in Figures 4 and 5.

From Figure 4, it can be observed that for each percentage replacement, there is variation in the tensile strength of PKSC. At 28 days, the tensile strength for the conventional concrete was found to be 11.74 N/mm² while that of 25% replacement of granite with PKS was 8.35 N/mm² and 50% replacement was 7.08 N/mm². These values are 5.8 N/mm² and 3.68 N/mm² for the 75% and 100% replacements respectively.

Figure 4: Variation of tensile strength with percentage replacement (PKS)

Similarly, From Figure 5, it can be observed that for each percentage replacement with PS, there is variation in the tensile strength. At 28 days, the tensile strength of 25% replacement of granite with PS was 10.33 N/mm² and 50% replacement was 8.35 N/mm². These values are 7.22 N/mm² and 4.95 N/mm² for the 75% and 100% replacements respectively. It was observed for both PKS and PS that tensile strength decreased as percentage replacement increased and the tensile strength of the control was also found to be higher than other replacements.

As curing age increases from 0 to 28 days, a gradual increase in tensile strength was also observed. The general trend also shows a linear relationship between the curing ages and the tensile strength and it was uniform for all percentage replacement along its curing ages. Tensile strength is not usually considered in reinforced concrete design (except in water retaining structures) because concrete is poor in tensile strength. It is however of considerable importance in resisting cracking due to changes in moisture content or temperature.

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Figure 5: Variation of tensile strength with percentage replacement (PS)

From this study, based on required compressive strength, PS could be used as partial replacement of granite in making concrete for reinforced concrete works. This confirms some of the observations of Ettu, Ibearugbulem, Ezech and Anya, (2013). The study concluded that the use of PS for this purpose would greatly reduce the cost of concrete works in riverine communities with plentiful supply of these shells. Ettu *et al* (2013) concluded that as much as 75% replacement could still produce concrete of satisfactory strength for structural members under mild conditions of exposure, given good supervision of the concrete making process. The findings from this study with 75% replacement of granite with PS given strength value of 8.89 N/mm² at 28 days conform to Ettu *et al* (2013). Lower percentage replacements would be suitable for worse conditions of exposure. For example, 50% replacement would be satisfactory for moderate conditions of exposure that require a minimum concrete compressive strength of 30N/mm²; and 25 % and lower percentage replacements could be suitable for severe conditions that require strengths of 35N/mm² or more. The reduced density of concrete produced when granite chippings are partially replaced with periwinkle shells also results in lower self-weight of structure. This is particularly beneficial in coastal communities where the soils have relatively low bearing capacities.

The environmental drivers must not be overlooked as PKS and PS incorporation into concrete on an appropriate selective basis would provide solution to problems encountered in waste management. When used as aggregates to substitute granite, this constitutes a positive response to global environmental problems such as high carbon dioxide emissions generated by Portland cement production. In addition, it would reduce extraction of natural materials such as limestone.

Conclusion

The following conclusion are made based on findings from the study:

- (i) The sand, granite, PKS and PS had uniformity coefficients (C_u) of 2.43, 1.67, 2.04 & 2.39 respectively

- (ii) Palm Kernel Shells and Periwinkle shells have lesser ability to resist crushing, however they can be used for lightweight concretes as partial replacements for granite.
- (iii) Periwinkle Shells has a better gradation than Palm kernel shell. For the coarse aggregate, it was also observed that 99.7% of the aggregate was retained on the 5mm sieve and 0.3% passed through the sieve. This implies that PS is best used as replacement for granite.
- (iv) The 25% and 50% replacement of granite with PS are best suited for non-critical structural works while only the 25% replacement of granite with PKS are best suited for non-critical structural works.
- (v) The values of compressive and tensile strengths are higher for PS compare to PKS for same percentage replacement.

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