THE EVALUATION OF PALM KERNEL SHELLS AS COARSE AGGREGATES FOR RIGID PAVEMENT IN A COASTAL REGION, NIGERIA

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Abstract: This paper presents the rationalization of the use of palm kernel shells as coarse aggregates for rigid pavements in the coastal region of Nigeria where aggregates are in short supply and palm kernel waste dumps abound, whose disposal constitutes environmental pollution and health hazard. Index and mechanical tests were carried out on samples of palm kernel shell wastes derivable in large quantities in the coastal and forested areas of the southern parts of Nigeria in accordance with relevant European standards. The appropriateness of the resulting nominal mixes of the 'palm kernel shell concrete' for rigid pavement was evaluated accordingly at both fresh and matured ages. Also a cost model, in respect of the haulage distance from the Nigerian coastal region for the granitic coarse aggregates was developed. The results show that palm kernel shell is a lightweight aggregate. Of all the seven index properties evaluated, the Nigerian palm kernel shell satisfies only density criterion for normal concrete but adequate for lightweight. The cost model developed is linear with characteristic slope and intercept values of
-117.2N/km and N4706 respectively and at R2 value of 0.855. The palm kernel shell concrete is marginally appropriate as rigid pavement at a nominal mix of 1:11/2:3.

Keywords: Palm kernel shell, Rigid pavement, Coastal region, Cost model, Lightweight concrete.

1.0 Introduction

Coarse aggregates are in short supply in coastal regions due to the geological vegetative setting of coastal regions with insufficient resource in rocks that are desired for the production of artificial gravels. For instance, large deposit of Precambrian sedimentary rocks consisting of banded cherts, argillites, greywackes, limestone, shales, with sandstone laminae and sandy streaks predominate in coastal regions of North America and Canada. The coastal region of Canada is also covered by bog, drift and marsh with almost no trees. In the United States, gleyed laminated clays, sporadic ice-rafted stones having very low permeability are all over the coastal areas. Aquicludes with perched subsurface water and reaching the surface as seepage springs are also present while Holocene sediments are common scenes in the coastal areas of South America. Rocks, which are main sourse materials for production of artificial coarse aggregates for concreting (gravel), are few and scattered, and besides most parts of the coastal regions are covered with swamps leading to existence of weak subgrades with consequential challenges in road construction (Hun-Dorris, 2005 and Oikonomon, 2003). Similarly the coastal regions of Africa are covered with outwash deltas and plains prograded into lakes with high water tables, and pleistone formations (Jones and Hockey, 1964 and Oikonomon, 2003). Also the coastal regions of West Africa and South America are vegetated with palm and coconut trees (Bandiera Jr. et al, 1979) from which palm kernel shells are derivable in large quantities through the routine processing of the fruits. Nigeria is one of the world major producers and exporters of palm oil and is well known for its palm oil industry. However, one significant problem in the processing of palm oil is the large amount of palm kernel shell wastes produced which is one of the contributors to the nation's pollution and disposal challenges (Okpala, 1990).

Approximately eight to eleven billion tonnes of aggregates (sand, gravel, and crushed rock) are being used for concrete production annually and Canada accounts for fourteen tonnes of aggregate consumed per person each year (Naik and Moriconi, 2005 and Mehta, 2001). However, for every three tonnes of aggregate that is produced, only one tonne is replaced by opening new aggregate sources or through recycling (McMacNaughton, 2004). Also, about 2800 licensed pits and quarries are in existence which produced over 160 million tonnes in 2003 alone in Ontario where currently aggregate is being consumed faster than being made available resulting in an aggregate shortage, which will exacerbate over the next 25years estimated at four billion tonnes (Aggregate Producers Association, 2004). It is also estimated that some urban areas will run out of aggregate by 2010 (Miller, 2005). However, in Nigeria, there are 91 functioning quarries, which produce an average of 14.6 million tonnes of aggregates yearly, whereas a kilometer of road of width 7.3m makes use of 985.5 tonnes of aggregate (Dutta, 1983). This implies that only 15,000 km of roads per annum can be constructed if the entire production were reserved for roads alone.

In view of the fact that the coastal regions have insufficient resource in rocks for the production of artificial gravels as well as the environmental nuisance of disposal of the large quantity of palm kernel shell wastes and the strategic desire of concrete pavement in the region, the need for a replacement with materials which are in abundance and nearness to the region is most desirable for a cost effective provision of pavement. Besides, the environmental and cost advantages of using vegetative sawdust wastes for rigid pavement works have been espoused (Yusuf and Jimoh, 2009 and Ogundipe and Jimoh, 2008a, 2008b). Currently, research efforts have been directed towards the potential use of palm kernel shells as aggregate for the production of lightweight concrete (Olutoge, 1995 and Okpala, 1990). However, the use of palm kernel shell as replacement for conventional aggregate to reduce the cost of production in construction works as well as for rigid pavement in particular and eliminate the environmental hazard caused by its disposal will be a worthwhile venture in technical and construction material strategy and sustainability. In addition, the piece of land occupied by waste generated from palm kernel shell will be available for other economic uses.

The aim of this study is, therefore, to determine the index/classification and the mechanical (strength) properties of the palm kernel shells and the characteristics of resultant palm kernel shell concrete in order to evaluate its appropriateness for rigid pavement works in the coastal area. The objectives are:

To establish the availability of coarse aggregates (in terms of cost) in relation to nearness to the coastal region.

To characterize palm kernel shell as coarse aggregate for concrete.

To determine the appropriate nominal mixes for palm kernel shell rigid pavement.

2.0 Materials and Methods

2.1 Materials

Palm kernel shell (Abiola, 2006) is the hard endocarp of palm kernel fruit that surrounds the palm kernel seed of the oil palm tree (Elaeis guineensis). The palm kernel tree is native of West Africa as well as widely spread throughout the tropics. It grows to about 9 metres in height and characterized with a crown of feathery leaves that are up to 5mm long. Flowering is followed by the development of cluster of egg-shaped red, orange or yellowish fruits, each about 3cm long. Palm kernel shells are obtained as crushed pieces after threshing or crushing to remove the palm seed after the production of palm kernel oil. In the process of extraction from the ripe, fresh fruit bunches at the mills, solid residues and liquid wastes are generated (Olutoge, 1995). These bye-products include empty fruit bunches, fibres, shells and effluent with various uses; such as for prevention of the fibres from insect attacks, in weaving baskets, and as source of energy for domestic cooking. It is estimated that the palm kernel shell constitutes about 34.5% of a single ripe, fresh fruit (Aragbaiye, 2007).

2.2 Assessment of the Palm Kernel Shell for Concrete Works

Sieve analysis, specific gravity, water absorption capacity, moisture content, bulk density and impact value tests were carried out on palm kernel shells in accordance with the European standard EN 932 for the physical and mechanical characteristics of the palm kernel shells.

Table 1 shows the summary of the properties of the palm kernel shells as compared with the bench mark for normal and lightweight concrete aggregates.

Table 1: Evaluation of Palm Kernel Shell as Coarse Aggregate in Concrete Mix

Properties	*PKS Aggregate	Specification for Aggregates		Remarks-Adequacy
		**Normal	**Lightweight	
Specific gravity	1.26	2.5 - 2.9	1.17 – 1.37	Lightweight aggregate only
Thickness (mm)	0.7 – 3.00	4 – 18	0.15 – 4.0	,,
Fineness modulus	6.24	6.57	1.5 -6.4	,,
Water absorption – 24hr (%)	13.7	< 1	5.2 – 24.5	,,
Aggregate impact value (%)	5.02	9 – 20	3.6 – 11.5	,,
Aggregate crushing value (%)	6.5	11 – 24	2.8 – 13.7	,,
Bulk density (kg/m^3)	640	40 - 1600	500 - 850	Normal and lightweight aggregate

Sources: *field (study) results; **www.constructionZ.com, ASTM C127, ASTMC128;

2.3 Assessment of the Strength of Palm Kernel Shell (PKS) Concrete

Slump, compressive strength, shrinkage, flexural strength/Modulus of rupture, splitting tensile strength and modulus of elasticity tests were conducted to determine the strengths of palm kernel shell concrete at varying mixes and maturity age to draw relevance for rigid pavement works. The tests were carried out in accordance with the European standards, EN 12350 (fresh concrete) and EN 12390 (rigid pavement). Fig. 1 shows the compressive strength trend of the palm kernel shell concrete with respect to age for four nominal structural mixes (1:11/2:3, 1:2:4 and 1:3:6) while Table 2 gives the summary of the evaluation of the PKS concrete as a rigid pavement.

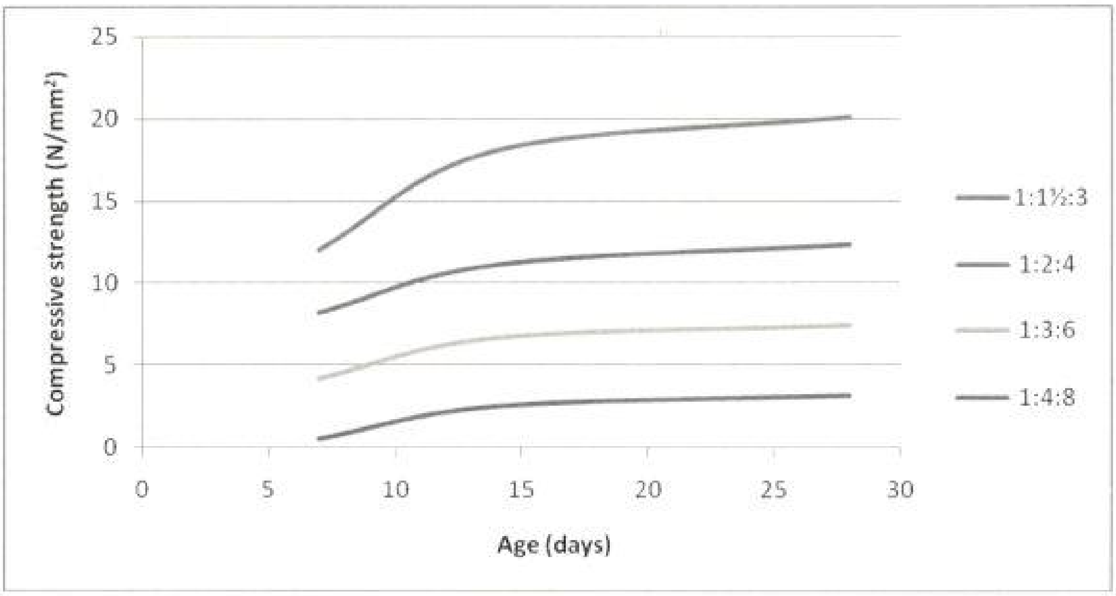

Figure 1: Compressive strength development of PKSC

Table 2: Evaluation of Mechanical Strength of Palm Kernel Shell Concrete

S/N	Property at 28 days	Specifications		***PKS Concrete at 28 days		
		*Normal Aggregate	**Lightweight aggregate	1:3:6	1:2:4	$1:1^1/_2:3$
1.	Density (kg/m^3)	2240 – 2400	1700 -2050	1328	1600	1777
2.	Compressive strength (N/mm^2)	20 – 40	15 – 25	7.40	12.32	20.10
3.	Modulus of Rupture (N/mm^2)	$\geq$ 4.45	2.76 – 4.56	1.50	2.00	2.40
4.	Tensile strength (N/mm^2)	2 – 5	1.5 – 3.2	0.70	1.10	1.40
5.	Modulus of Elasticity (N/mm^2)	$\geq 2.8 \times 10^4$	$0.75\text{-}9.2 \times 10^3$	1.79×10^3	3.14×10^3	5.37×10^3

Source: *Gaynor (1974) and Rigid Pavement Design Manual (2009), **Mohd et al (2008), *** Yusuf (2010).

2.4 Cost Implication of Palm Kernel Shells for Pavement in Coastal Regions

In order to appropriately incorporate the cost of the alternative source of coarse aggregates into technology of rigid pavement in the coastal region, a cost model was developed in relation to the distance of the source. A questionnaire that sought to determine the sources and prices of artificial and natural coarse aggregates, quarry locations and the various labour forces in the processes was prepared and served on the operators of granite quarries in all the state capitals of Nigeria plus the FCT, Abuja. A total of 7,400 questionnaires were distributed through a syndicate system for each data point at the rate of 200 questionnaires to the stake holders; (i) quarry managers, (ii) site agents of road construction projects and (iii) project managers of building projects. The distribution and retrieving of the questionnaires were done in January and February, 2010. The returns for each of the states were analyzed in respect of rate of return and cost variant per ton of the aggregates. A total number of 6685 (90.3%) questionnaires were answered while an average value of 175 (87.5%) of the questionnaires were substantially answered and returned per state capital. The questionnaire covers both fine and coarse aggregates.

The respective locations of the source of the coarse aggregates from the coastal region are described by the distances and longitudes/latitudes, downloaded from the internet through GERMIN Corporation, 1995-2003. The state capitals and Abuja were chosen for the survey because they are (i) centre of heavy construction activities and (ii) locations of the offices of the stake holders. Fig. 2 shows the relationship between aggregate availability (costs) and distances of their location from the coast. The details of the survey of prices for construction aggregates in the states capitals of Nigeria as at February, 2010 are given elsewhere (Yusuf, 2010).

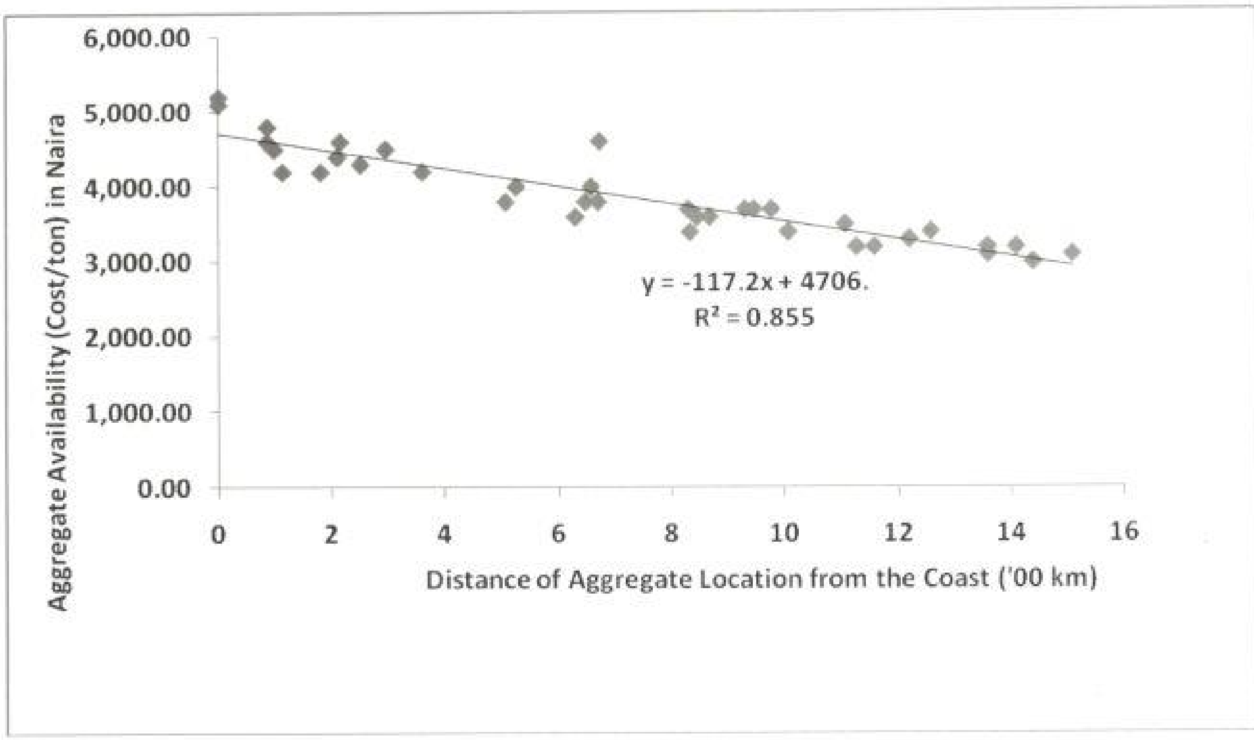

Figure 2: Aggregate Availability (Cost) and Haulage Distance

3.0 Results and Discussions

The results in Table 1 show that specific gravity of 1.26 obtained for palm kernel aggregate confirms its adequacy as both a normal aggregate and lightweight aggregate while the other properties certify it as only a lightweight aggregate. The mechanical properties of PKS concrete for all mix proportions at age 28 days presented in Table 2 indicates that it can be used as a lightweight concrete. However, the values of the mechanical strength for all mix ratios increase with age as it is for normal concrete. One of the advantages of conventional concrete is the high self-weight of concrete. Density of the normal concrete is in the order of 2200-2600kg/m^3. The lightweight concrete has density ranging from 300-1850kg/m^3. Lightweight structural concrete is considered to be a material of specific weight not more than 18.06 kN/m^3 and developing a compressive strength not less than 17 N/mm^2. Palm kernel shells can be used as aggregate substitution for a grade 20 lightweight structural concrete, which is achievable at higher nominal mixes of 1:1$^1/_2$:3.

There is scarcity of coarse aggregates in the coastal region, which normally implies high cost. A quantitative explanation of the scarcity was demonstrated with a linear correlation model at R^2 value of 0.855. See Figure 3, which clearly indicates that there is high correlation between aggregate availability and distances (aggregate location) from the coast, the point of use. The implication is that the pavement construction at the coast will vary as the source of aggregates gets farther. The slump of concrete decreased with nominal mixes as the proportion of the palm kernels increases. For instance, the nominal mix of 1:1½:3 with slump of 10cm is more workable compared to any other nominal mix. The mechanical strength results (Table 2) show that nominal mix of 1:1½:3 has a compressive strength of 20N/mm^2 and density of 1777kg/m^3 at 28 days. This compressive strength value is greater than 17N/mm^2, the 28-day minimum specified strength by ASTM-77 for structural lightweight concretes. In addition, when the density of concrete is lower than 2000 kg/m^3, it is regarded as lightweight concrete. However, compressive strengths for other nominal mixes could not meet the ASTM-77 recommended minimum bench mark. The results of Table 2 show that the values of modulus of rupture and splitting tensile strength follow a similar trend as that for compressive strength.

Palm kernel shell is not a suitable complementary substitute for conventional aggregate in normal weight concretes because all the results obtained did not meet up with those specified for normal concrete (Table 2). The compressive strengths for PKS concrete for 1:3:6, 1:2:4 and 1:1½:3 mixes are 7N/mm^2, 12N/mm^2 and 20N/mm^2 at 28 days respectively while their respective densities are 1328 kg/m3, 1600 kg/m3 and 1777 kg/m^3 at 28 days. PKS concrete can, therefore, be classified as a lightweight structural concrete at nominal mix of 1:1½:3 since the compressive strength of 20N/mm^2 is greater than 17N/mm^2, the minimum value specified by ASTM-77 for structural lightweight concrete. See Figure 2 and Table 3. In addition, when the density of concrete is lower than 2000 kg/m^3, it is regarded as lightweight concrete (Mohd et al, 2008). As a lightweight aggregate, PKS can be used for lightweight structural concrete as well as rigid pavement since it meets the minimum specification. As light weight structural concrete it can be used for lightweight traffic roads, foot bridges, road medians and pavement for pedestrian walk in the urban multilane highways.

The use of palm kernel shell or other waste materials should be encouraged as it provides many advantages, which amongst others include:

(i) Less neglect of rural communities. Road construction materials usually are mined from temporary (1-2 year) sites, but that itself leads to neglect of the local community, indicated by poor notification procedures, negligent operators, and unclaimed mining sites.

(ii) Reduction/elimination of industrial mining traffic in local communities.

(iii) Prevention/reduction of the opening of new mines for sand and gravel materials.

(iv) Reduction of cost of vehicle damage in the vicinities of gravel mines, due to trucks casting gravel onto windshields and bodies.

(v) Ensuring less conflict over siting new landfills, due to reduced demand on them.

(vi) Provision for the development of new business opportunities and jobs.

(vii) Enhancement of reduction in the cost of construction.

4.0 Conclusion and Recommendations

4.1 Conclusion

As an outcome of this study, it can be concluded that:-

There is the dire need for alternative sourcing of coarse aggregates for concrete works in the coastal areas because of the scarcity of rocks for production of artificial aggregates.

The density of Palm kernel shell, a substantial waste bye product in the agricultural palm farming is 1777kg/m3, which makes it as a probable lightweight vegetative coarse aggregate for concrete works at a nominal mix of $1:1^1/_2:3$.

The compressive strength of concrete with palm kernel shell as coarse aggregate (palm kernel shell concrete) increases with age and as the mix proportion increases, ranging from 4.25-7.4N/mm^2, 8.19-13.32N/mm^2 and 12.02-20.1N/mm^2 respectively for 1:3:6, 1:2:4 and $1:1^1/_2:3$.

With a compressive strength of 20N/mm^2 and density of 1777kg/m^3 at age 28 days for $1:1^1/_2:3$ nominal mix, the palm kernel shells can be used as substitutes for coarse aggregates for a grade 20 lightweight structural concrete.

Environmental pollution caused by indiscriminate dumping of PKS as waste can be reduced when used as alternative coarse aggregates in pavement works.

4.2 Recommendations

(i) With the paucity of funds in developing countries for construction purposes, the use of wastes should be encouraged in the neighbourhood where the critical and desired materials are scarce.

(ii) Rigid pavements in service are subjected to dynamic loadings usually and hence, the fatigue behavior as well as cost effectiveness for design and development of PKS concrete at $1:1^1/_2:3$ must be subjected to further studies.

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