PALM KERNEL SHELL ASH STABILIZATION OF RECLAIMED ASPHALT PAVEMENTS, AS HIGHWAY PAVEMENT MATERIALS

[1]Edeh, Joseph Ejelikwu, [1]Manasseh, Joel and [1]Ibanga, Usoro
[1]Dept. of Civil Engineering,
University of Agriculture, Makurdi. 970001, Nigeria.

Abstract
Domestic, agricultural and industrial wastes are generated everyday and in large quantities and the safe disposal of these waste materials are increasingly becoming a major concern around the world. This paper presents results of the laboratory evaluation of the characteristics of palm kernel shell ash (PKSA) stabilized reclaimed asphalt pavement (RAP) with a view to determine its suitability for use as highway material in flexible pavements. The RAP - PKSA mixtures were subjected to British standard light, BSL (standard Proctor) compactive effort to determine the compaction characteristics and California bearing ratio (CBR). Test results show that the properties of RAP improved with PKSA treatment. The particle grading improved from 99.4% coarse aggregate and 0.6% fines, with AASHTO classification of A-1-a for 100% RAP to 95.2 – 99.5% coarse materials and 0.5 – 4.8% fines, with AASHTO classifications of A-1-a and A-1-b (gravelly SAND), for the various RAP - PKSA mix proportions to A-3 (fine SAND) for 100% PKSA. Maximum dry density (MDD) decreased as the optimum moisture content (OMC) of the RAP/PKSA mixes increased with higher PKSA content. The CBR values decreased from the maximum values of 17.11% (soaked for 24 hours) with a corresponding unsoaked CBR value of 21.39% recorded for 90%RAP/10%PKSA with higher PKSA content to a minimum value of 4.31 and 4.2% (soaked and unsoaked, respectively) for 10%RAP + 90%PKSA mix proportion. The 90%RAP/10%PKSA mix that recorded a CBR value of 17.11% (soaked for 24 hours) can be used as sub-grade material in flexible pavements. This research provides an initial lead to the evaluation of PKSA stabilized RAP as highway construction material, as it is based on CBR determination.
Keywords: California bearing ratio, Palm kernel shell ash, Reclaimed asphalt pavements, Stabilization.

INTRODUCTION

In recent times, the demand for good flexible pavement materials accentuated by design guidelines that are based on the assumptions that aggregates are important ingredient of pavement structure, has increased due to increased constructional activities in the road sector and paucity of available construction materials along road alignments. To overcome this problem, the different alternative generated waste materials, including reclaimed asphalt pavements (RAP) scarified from failed highway pavement, deposited in large quantities along reconstructed road alignment, is stabilized with palm kernel shell ash (PKSA). The material is deposited in large quantities, as waste on production sites, which cause not only environmental hazard but disposal problems.

Domestic and industrial wastes are generated everyday and in large quantities and the safe disposal of these waste materials are increasingly becoming a major concern around the world (ETL, 1999; Gardner, 2011; Gomes et al., 2011; Hossain,

et al., 2011; Wen and Wu, 2011; Osinubi and Edeh, 2011). These waste products (Pihl and Milvang-Jensen, 2009), if properly treated, could be modified for use as structural components of the pavement. Among these wastes is the reclaimed asphalt pavement (RAP) that can be stabilized with other waste materials or additives to improve its engineering properties and be used as new construction material.

Reclaimed asphalt pavement (RAP) is the term given to removed and/or reprocessed pavement materials containing asphalt and aggregate. These materials are generated when asphalts are removed for reconstruction, resurfacing, or to obtain access to buried utilities. When properly crushed and screened, RAP consist of high-quality, well-graded aggregates coated by asphalt cement (FHWA, 2008). In developed countries like United State of America (USA), where the concept of asphalt recycling had been in vogue, it is estimated that the amount of excess asphalt concrete that must be disposed is less than 20% of the annual amount of RAP that is generated but in developing countries like Nigeria, RAP is sometimes disposed in landfills or in the right of way, commingled with other materials, as waste, since facilities are not readily available for collecting and processing the RAP.

Recycled RAP is almost always returned back into the roadway structure in some form, usually incorporated into asphalt paving by means of hot or cold recycling, and sometimes used as an aggregate in base or sub base construction (Terrel et al., 1994; Singh, et al., 2011), although not always in the same year that it is produced . The use of RAP in mixed asphalt is generally an accepted process, with an overall positive impact on the environment (Ahmed, 1991). The percentage of RAP in hot mix normally varies from 10 – 50% (ETL, 1999), 10 – 15% (Jeff and Miles, 2006; Udelhofen, 2006). RAP acceptance in road bases and sub-bases has been limited, because of lack of laboratory and field data (Taha et al., 2002). However, the use of stabilized RAP as sub base and base materials of pavement leads not only to economic solution (Kennedy et al., 1998; Anouksak and Direk, 2006) but also offers a potential use of the RAP treated with cemented materials like sawdust ash, thus reducing the amount of waste materials requiring disposal and providing construction materials with significant savings over new materials (Shroeder, 1994).

The properties of RAP are largely dependent on the properties of the constituent materials and asphalt concrete type used in the old pavement. Since RAP can be obtained from any number of old pavement sources, quality can vary, hence, quality control is needed to ensure that the processed RAP is suitable for the prospective application. This is particularly the case with in-place pavement recycling (Anouksak and Direk, 2006). Research has established typical range of particle size distribution, physical, chemical, engineering and mechanical properties of RAP (Shroeder, 1994; Tyrion, 2000; Karlsson and Isaacsson, 2006; FHWA, 2008).

Palm kernel shell is the crash shells housing the palm kernel seed. Palm kernel shells can be considered as a natural pellet and a high grade solid renewable fuel for burning as received both in co-firing with steam coal or burned at biomass power plants, usually blended with other grades of biomass, like wood chips. The palm kernel shell is also used as a source of fuel for the boilers. Unfortunately, the shell contains silicates that form a scale in the boilers if too much shell is fed to the furnace, thus limiting the amount of shell that can be utilized in the boilers. Residual shell is disposed of as gravel for plantation roads maintenance. Blacksmiths also buy the shells to use as fuel material in their casting and forging operations (AbdulAzeez, 2011). Palm kernel shells are derived from the oil palm tree (elaeis guineensis), an economically

valuable tree, and native to western Africa and widespread throughout the tropics (Ndoke, 2006). Palm kernel shell is an industrial waste and it's available in large quantities especially in palm oil producing area of the southern part of Nigeria. Palm kernel shells have very low ash (about 3% weight - ASTM D3174-02, 2002) and sulphur (about 0,09% weight – ASTM D4239-02, 2002) contents. The specification is 20% max of Moisture, 3% max of fiber and dirt. (AbdulAzeez, 2011). Palm kernel shells are used mostly as aggregates in concrete (Sulymon, 2005; Olanipekun, et al., 2006; Alengaram et al., 2008; Alengaram et al., 2010; Olutoge, 2010; Sarman and Omidreza, 2011) and asphalt concrete (Ndoke, 2006).

Fly ash is a pozzalana, which when combined with calcium oxide and water forms cementitious materials. Like the coal fly ash, PKSA can be classified as either class F that contains less than 10% lime (CaO) or class C with more than 10% lime (CaO) content. Class F fly ash (with pozzolanic properties, glassy silica and alumina) requires a cementing agent such as Portland cement, quicklime or hydrated lime in the presence of water to react and produce cementitious compounds. On the other hand, class C fly ash will harden and gain strength over time in the presence of water. While both classes are considered to be pozzalanic, class C fly ash is usually self hardening (Halstead, 1986). Fly ash is one of the few waste materials that have an American Society of Testing and Materials (ASTM C618-92a, 1994) standard for procedures of sampling and testing. Depending on the use and requirements, fly ash can be used to replace some of the cement in admixture treatment of a deficient material.

Researches undertaken with other ashes show that the Laboratory results of the stabilized materials improved in stiffness and strength. When the materials were stabilized with coal fly ash, California bearing ratio (CBR) and resilient modulus (Mr) values increased from 24% and 51 MPa, respectively, for RSG before stabilization to 48 – 90% and 96 – 195 MPa, respectively, after stabilization (Edil et al., 2007; Hatipoglu et al., 2008). Li et al. (2009) reported CBR value of 154% for coal fly ash stabilized RSG, while the CBR and Mr values of RPM, respectively, increased from the ranges 3 – 17% and 45 - 50 MPa before stabilization to 70 – 94% and 78 – 119 MPa after stabilization, respectively (Li et al., 2008). Misra et al. (2007) also reported an improved recycled asphalt base material with CBR value of 120% when treated with coal fly ash. However, the use of palm kernel shell ash (PKSA) as highway construction material is largely not documented.

The current most appropriate document for general pavement design is TRRL report 1132 (2000). This document relate the current "normal" traffic flows, type of traffic and CBR value of the subgrade "1132" to the design of highway pavement. TRL Report TRL615 - Development of a more versatile approach to flexible pavement design (2000). Flexible composite pavement design also deals with the idea of increasing the versatility of road pavement design to give the engineer a wider choice of materials and design configurations. This increased versatility will lead to more economic designs by allowing new materials, recycled materials and a wider range of secondary aggregates and binders to be used. It also offers the potential to enable stronger foundations to be constructed, incorporating hydraulically bound materials and providing the option of reductions in the more expensive surfacing layers. These materials are however chosen to withstand cyclic loads, water absorption and minimize stress formation in the soil. This study considered the characterization of palm kernel shell ash stabilization of RAP as highway pavement construction materials.

MATERIALS AND METHODS

Materials

Reclaimed asphalt pavements

The reclaimed asphalt pavement (RAP) used in this project study was obtained from Otukpo (latitude: 7° 13' 57" N and longitude: 8° 05' 26" E) along Otukpo-Enugu road in Benue State, Nigeria. The RAP used was crushed using a hand-hammer, from its "lump" state to smaller sample sizes passing through 20 mm aperture sieve in accordance to BS 1377 (1990) and transported in bags to the geotechnical laboratory of the University of Agriculture, Makurdi, and air-dried before use for the test. The RAP consists of high-quality, well graded aggregate coated with asphalt cement.

Palm kernel shell ash

Bulk sample of palm kernel shell was obtained from Ikpa-Isong palm oil mill at Ikono L.G.A, Akwa Ibom State (latitude: 4° 56′ 50″ N and longitude: 8° 3′ 42″E), Nigeria. The palm kernel shells were brought to the mechanical laboratory at the University of Agriculture, Makurdi and burnt properly to ashes using blast furnace to about 900°C to ashes. The ash passing through a sieve No. 200 with 0.075 mm aperture was used for this study (ASTM C311-11a, 1994).

Methods

All experimental procedures are carried out in accordance to standard specifications (ASTM C618-92a, 1994; ASTM C311-11a, 1994). Various proportions of palm kernel shell ash (PKSA) passing through a sieve No. 200 in the range 0-100% were used to stabilized the various RAP content in the range 0-100% (the appropriate peak proportions was however, determined during the preliminary mix design tests). The RAP used was crushed using a hand-hammer from its lump state to smaller sample sizes passed through a 20 mm aperture sieve, was air-dried in the laboratory, and used for the tests.

Particle Size Distribution

Particle size distribution or sieve analysis of coarse-grained particles (sand and gravel fraction) was carried out in order to group the particles into separate ranges of sizes, and to determine the relative proportion by mass, of each size range (Salter, 1979; Head,1992; ASTM D6913-04, 2009). To achieve this, sample/stabilized sample was passed through successively smaller mesh sizes. The weight of soil sample retained on each sieve was determined and the cumulative percentage by weight passing each sieve was calculated (ASTM D5319-97, 2008; Craig, 1992).

Consistency Limits

The consistency limits of a soil is the measure of its affinity for water and is measured quantitatively by Atterberg limits tests. These test that include liquid limit (LL), plastic limit (PL) and shrinkage limit (SL) were determined in accordance with ASTM D4318-10 (1994). In highway engineering, the consistency parameters are used in soil classification. Generally, soils with low plasticity indices most probably possess little or no cohesion (Das, 1998).

Compaction

Compaction is the process of densification of the soil by reducing the air voids in the soil. It is aimed at establishing the soil's optimum moisture content (OMC) and maximum dry density (MDD) (Craig, 1992). Usually, materials with high MDD at relatively low moisture content are indicative of good materials that can be used for sub-grade, sub-base or base course and as fill embankments. In this study, British standard light (BSL) compaction was used in accordance to ASTM D698-07e1, (1994), to establish the OMC corresponding to the MDD and to simulate the likely compaction energy encountered in the field (Daniel and Wu, 1993).

Specific Gravity

Specific gravity of a soil is the ratio of the unit weight of a given material to the weight of water (Craig, 1992; Das, 1998). It is used in the computation of void ratio, porosity, degree of saturation, permeability and particle size distribution (by sedimentation). Samples passing sieve with 2.36 mm aperture were used in determining the specific gravity for the varying proportions RAP stabilized with the sawdust ash (ASTM C127-07, 1994).

California Bearing Ratio

California bearing ratio (CBR) is an adhoc penetration test for obtaining a comparative measure of the shearing resistance of the base, sub-base and sub-grade materials in highway constructions. It is a dimensionless index measured in a standard laboratory test or in the field. However, the field CBR value is usually different from the laboratory CBR value due to the difference of test conditions. In the field, the CBR value of the base course is dependent on that of the sub-base which in turn depends on that of the sub-grade. Soft sub-grade soil does not provide the support needed to obtain good compaction of the base and sub-base course materials; therefore, the field CBR can be significantly less than the laboratory CBR (Giroud and Han, 2004). The CBR test is the most widely used method of evaluating soils for pavement design in developing countries despite the criticism of its empirical nature. It is determined as the ratio of the force required to penetrate a circular piston of 1935 mm^2 cross section into soil in a special container at a rate of 1 mm/min, to that required for similar penetration into a standard sample of compacted crushed rock. The ratio is determined at penetrations of 2.5 and 5.0mm and the highest value is used (ASTM D1883-07e2, 1994).

Palm kernel shell ash has not found a known use or application as highway materials but have been used as partial replacement for aggregates in the making of concrete (Sulymon, 2005; Olanipekun, et al., 2006; Alengaram et al., 2008; Alengaram et al., 2010; Olutoge, 2010; Sarman and Omidreza, 2011), whose properties has been explored in Nigeria. However, ASTM C593-06 (2006) can be used to describe the properties of PKSA.

The residue asphalt content would have been determined by centrifuge. However, due to high rate of oxidation in a tropical country like Nigeria, the oil component is almost lost leaving behind the brittle asphaltene, which trip-off with vehicular load (FHWA, 2008).

New techniques of pavement design and evaluation of materials for pavement construction are presently based on other information like resilience modulus, expansion and water absorption, and permanent deformation under cyclic load, now exist for determining pavement strength and consequently its material, CBR method still remain an important empirical means for assessing strength of pavement materials (Nicholson and Kashyap, 1993), particularly in the developing nation. However, the strength property of this study was limited to CBR evaluation of the materials as an initial means to assess the possibility of stabilizing RAP with PKSA.

RESULTS AND DISCUSSION

Oxide Composition of Palm Kernel Shell Ash

The oxide composition of palm kernel shell ash (PKSA) is given in Table 1. Calcium oxide (CaO) content is 10.8% and silicon dioxide (SiO_2) content is 15.1%. CaO/SiO_2 ratio, which is indicative of cementing potential, is 0.715, SiO_2 + Fe_2O_3 = 19.08% and loss on ignition (LOI), that indicates the amount of unburnt carbon in the fly ash is 2.42%. According to ASTM C618-92a (1994), PKSA used for this study is a class F fly ash and is not self-cementing.

Table 1. Oxide composition of palm kernel shell ash

Oxide	Concentration (%)
SiO_2	15.1
SO_3	0.9
K_2O	6.62
CaO	10.8
MnO	0.39
Fe_2O_3	3.98
ZnO	0.48
CuO	0.091
P_2O_5	3.5
BaO	0.44
LOI	2.42

Particle Size Distribution

The particle size distribution curves of RAP, PKSA and PKSA stabilized RAP are shown in Figure 1. The gradation shows that 100% RAP is composed of 99.4% coarse materials with 0.6% fines and falls under AASHTO classification A-1-a described as non-plastic sandy GRAVEL. On the other hand, 100% PKSA is composed of 94.7% coarse materials with 5.3% fines and falls under AASHTO classification A-3 described as non plastic fine SAND. The mix proportions PKSA stabilized RAP contain 95.2 – 99.5% coarse materials (i.e., gravel and sand) with 0.5 – 4.8% fines content, falls under AASHTO classifications A-1-a and A-1-b described as very gravelly SAND (Craig, 1992; Das, 1998). The mix proportions have excellent to good sub-grade rating (Bowles, 1992).

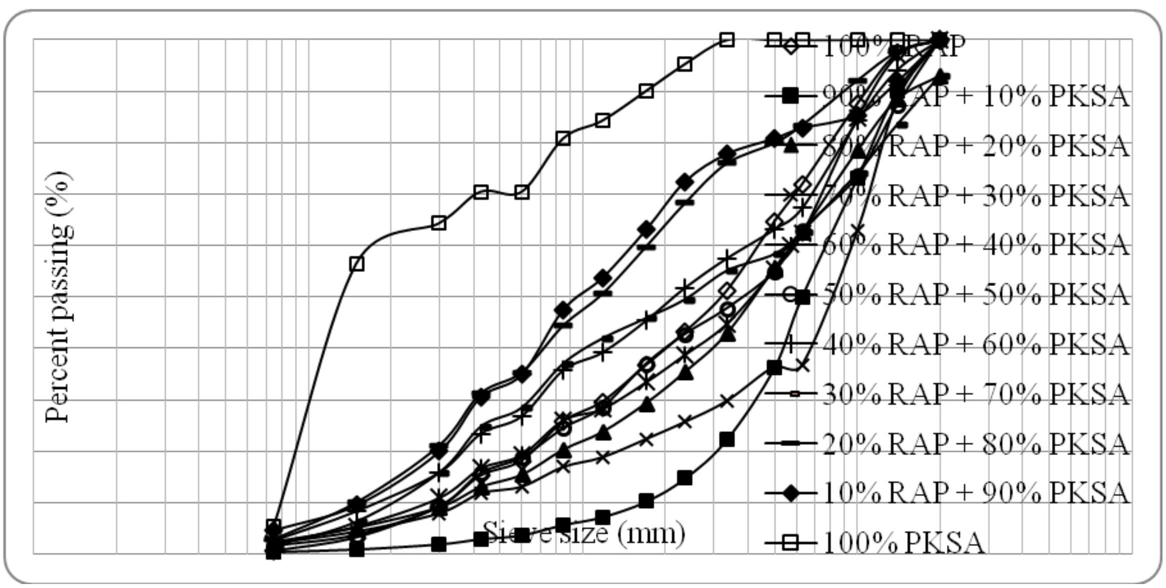

Figure 1. Paricle size distribution curves of various proportions of RAP + PKSA mixes

Specific gravity

The specific gravity values of RAP, PKSA and RAP/PKSA mixes are given in Table 2. The specific gravity value for 100% RAP is 1.81. This value fall outside the range 1.94 – 2.30 specified for RAP (FHWA, 2008), while that of 100% PKSA is 1.31. The specific gravity values of various RAP/PKSA mixes do not show any particular trend but are in the range 1.18 (for 60%RAP + 40%PKSA mix) – 2.42 (for 90%RAP + 10%PKSA mix). The increase in specific gravity value of the PKSA stabilized RAP may be due to fine particles of the PKSA that fill the void spaces between the larger particles of RAP, leading to higher density of the material matrix.

Table 2 Specific gravity and AASHTO classification of sawdust ash stabilized RAP.

Sample proportions	Specific gravity, SG	AASHTO classification
100% RAP	1.81	A-1-a
90%RAP + 10%PKSA	2.42	A-1-a
80%RAP + 20%PKSA	1.77	A-1-a
70%RAP + 30%PKSA	1.32	A-1-a
60%RAP + 40%PKSA	1.18	A-1-a
50%RAP + 50%PKSA	1.54	A-1-a
40%RAP + 60%PKSA	1.25	A-1-b
30%RAP + 70%PKSA	1.52	A-1-a
20%RAP + 80%PKSA	1.35	A-1-b
10%RAP + 90%PKSA	1.41	A-1-b
100% PKSA	1.31	A-3

Compaction Characteristics

The samples were compacted using the British Standard light, BSL (standard Proctor, SP) energy to obtain moisture-density relationships. Test results show that maximum dry density (MDD) decreased as the optimum moisture content (OMC) of the RAP/PKSA mixes increased with higher PKSA content as shown in Figures 2.

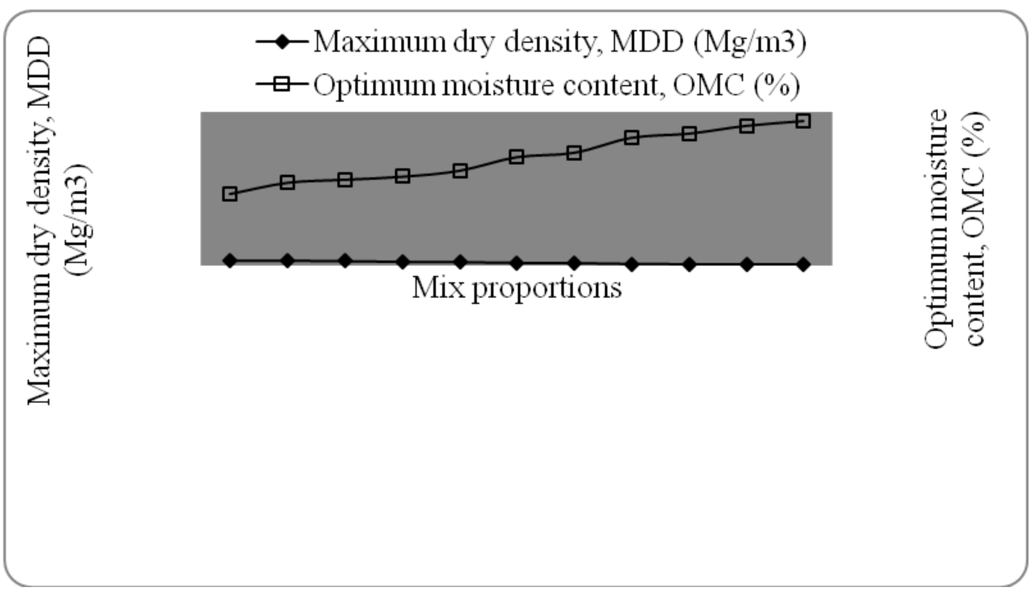

Figure 2. Variation of maximum dry density (MDD) and optimum moisture content (OMC) of various PKSA stabilized RAP mixes.

The MDD values for 100% RAP and 100% PKSA are 1.9 and 1.27 Mg/m^3 with corresponding OMC values of 13.12 and 24 % respectively. The MDD for RAP/PKSA mix proportions decreased from 1.88 Mg/m^3 for 90%RAP/10%PKSA to 1.28 Mg/m^3 for

10%RAP/90%PKSA mix with corresponding OMC values that increased from 15 to 24.5%, respectively. The MDD decreased because of the weak bond between RAP and the non-self-cementing PKSA that plugged the voids to produce denser mixes. The corresponding increase in OMC may be due to the increased surface area of particles caused by increased PKSA content in the mix that required more water to lubricate the entire mix matrix, to enhance compaction, in addition to the water taken up by PKSA hydration reaction (Osula, 1989; Osinubi, 1998).

California bearing ratio

The variation of California bearing ratio (CBR) values with 100%RAP, 100%PKSA and RAP/PKSA mixes is shown in Figure 3. Generally, the CBR trend shows a regular decrease in CBR values with higher PKSA content to minimum values except for lower values observed for 80%RAP/20%PKSA mix (unsoaked and soaked for 24 hours), and for 30%RAP/70%PKSA (soaked in water for 24 hours). The unsoaked and soaked (24 hours) CBR values for 100% RAP are 18.83 and 17.12%, while the values for 100%PKSA are 5 and 4.68%, respectively. The peak soaked CBR value of 17.11% with a corresponding unsoaked CBR value of 21.39% was recorded for 90%RAP/10%PKSA. Variation of CBR with PKSA show that the CBR decreased with increased PKSA in the mixture from CBR of 17.11 and 21.39% (soaked and unsoaked values) for 90%RAP + 10%PKSA mix proportion to CBR of 4.31 and 4.2% (soaked and unsoaked, respectively) for 10%RAP + 90%PKSA mix proportion. Lower CBR values of 15.28 and 9.17% (unsoaked and soaked for 24 hours) with increased PKSA was however observed for 80%RAP/20%PKSA mix, and 4.96% for 30%RAP/70%PKSA when soaked in water for 24 hours. The decreased in CBR with increased PKSA may be due to the low initial reaction between the hydrated lime in the mixture and water to form tetracalcium aluminate hydrate which form protective coating on the surface of unhydrated grains of tricalcium aluminate, thus slowing down the rate of hydration of tricalcium aluminate to form the, strength producing compound of tetracalcium aluminate hydrate (Osinubi, 1998). The higher CBR values after 80%RAP + 20%PKSA may have been accentuated by rapid hydration reaction of the lime from the PKSA that may now pre-dominate the initial action that retarded the rapid hydration process.

The CBR values of all RAP/PKSA mixes except for 10%RAP/90%PKSA and 20%RAP/80%PKSA soaked for 24 hours are lower than unsoaked values. The higher CBR values are indication of the possibility of time-dependent increase in strength under soaked condition (Hank and Magni, 1989). The variation in the CBR is more likely due to agglomeration of the heterogeneous materials of the RAP/PKSA (Hatipoglu et al., 2008) and the uniform distribution of PKSA in the mixture (Li et al., 2009). The main factors responsible for strength of soil are the cohesion and frictional resistance between the soil particles in contact. The higher CBR values for soaked RAP/PKSA mixes compared to those recorded for the unsoaked conditions may also be as a result of pozzolanic strength gain due to complete chemical process of hydration of lime in the mixes (Little, 1999).

The specifications regarding the choice of PKSA stabilized RAP as highway construction materials based on CBR are stated in the Nigerian General Specifications (Nigerian General Specification, 1997).

This research provides an initial lead to the evaluation of PKSA stabilized RAP as highway construction material, as it is based on CBR determination. Further work may be encouraged to assess resilient modulus of this material under cyclic load, as well as the assessment of permanent deformation of PKSA stabilized RAP.

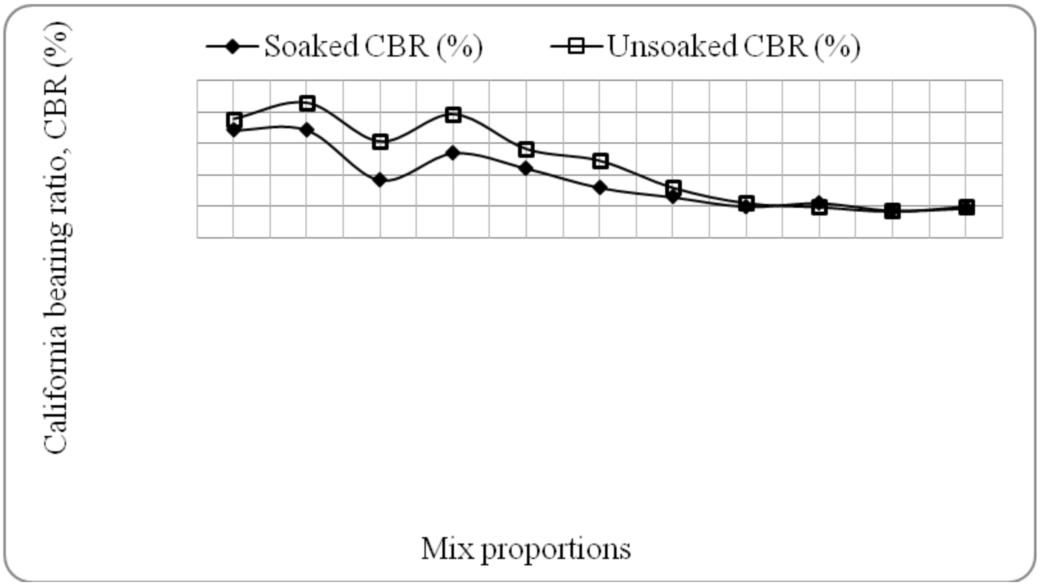

Figure 3. Variation of California bearing ratio (CBR) of various PKSA stabilized RAP mixes.

CONCLUSIONS

An experimental approach was used to assess the suitability of RAP stabilized with non-self-cementing PKSA as highway pavement material. The improved particle size distribution of PKSA stabilized RAP contain 95.2–99.5% coarse materials with 0.5 – 4.8% fines content and falls under AASHTO classifications of A-1-a and A-1-b described as very gravelly SAND. The materials are generally non plastic.

The specific gravity of 100%RAP and 100%PKSA are 1.81 and 1.31, respectively, while the values for the various RAP/PKSA mixes are in the range 1.18 - 2.42.

The maximum dry density (MDD) decreased as the optimum moisture content (OMC) of the RAP/PKSA mixes increased with higher PKSA content. The highest MDD of 1.88 Mg/m^3 with corresponding OMC of 24.5% is obtained for 90%RAP/10%PKSA mix proportion.

The experiments are based on local waste materials of PKSA and RAP generated and deposited in large quantities resulting in environmental problems. The evaluations of the waste are limited to laboratory experiments whose results can be used as a control to field work. The strength empirical parameter of California bearing ratio is still used as a bases to characterizing road construction materials in developing countries of the world.

The 90%RAP/10%PKSA mix with CBR value of 17.11 and 21.39% (soaked and unsoaked values, respectively) achieved using BSL compaction energy can be used as sub grade materials in road construction.

REFERENCES

AbdulAzeez, I. (2011). Palm Kernel Shell Export from Nigeria. www.exportfromnigeria.proboards.com/index.cgi?board=general&action=display&thread=78 (Last accessed 27th December, 2011)

Ahmed, I. (1991). *"Use of Waste Materials in Highway Construction."* Final Report, Joint Highway Research Project, FHWA/IN/JHRP-91/3, Purdue University, West Lafayette, IN.

Alengaram, U. J., Jumaat, M. Z. and Mahmud, H. (2008). "Ductility Behaviour of Reinforced Palm Kernel Shell Concrete Beam." *European J. of Scientific Research,* Vol. 23, No. 3, pp. 406 - 420.

Alengaram, U. J., Mahmud, H., Jumaat, M. Z. and Shirazi, S. M. (2010). "Effect of Aggregate Size and Proportion on Strength Properties of Palm Kernel Shell Concrete." *International J. of Physical Science,* Vol. 5, No. 12, pp. 1848 - 1856.

Anouksak, T. and Direk, L. (2006). "Stabilisation of Reclaimed Asphalt Pavement Using Foamed Asphalt." *Proc. In the Technology and Innovation for Sustainable Development Conference (TISD 2006),* Faculty of Engineering, Khon Kaen University, Thailand. 25-26, January, 2006.

ASTM C127 – 07 (1994). "Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate." American Society for Testing and Materials*, Annual Book of ASTM Standards*, Vol. 04. 02, West Conshohocken, Pennsylvania, www.astm.org. 6 p.

ASTM C311 - 11a. (1994). "Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete." American Society for Testing and Materials, *Annual Book of ASTM Standards,* Vol. 04. 02, West Conshohocken, Pennsylvania, www.astm.org. 10 p.

ASTM C593 – 06 (2006). "Standard Specification for Fly Ash and Other Pozzolans for Use WithLime for Soil Stabilization." American Society for Testing and Materials, *Annual Book of ASTM Standards*, Vol. 04. 02, West Conshohocken, Pennsylvania, www.astm.org. 9 p.

ASTM C618-92a (1994). "Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for use as Mineral Admixture in Portland Cement Concrete." American Society for Testing and Materials, *Annual Book of ASTM Standards,* Vol. 04. 02, West Conshohocken, Pennsylvania, www.astm.org., 3 p.

ASTM D698 - 07e1 (1994) "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))." American Society for Testing and Materials, *Annual Book of ASTM Standards*, Vol. 04. 02, West Conshohocken, Pennsylvania, www.astm.org., 13 p.

ASTM D1883 - 07e2 (1994). "Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils." American Society for Testing and Materials, *Annual Book of ASTM Standards*, Vol. 04. 02, West Conshohocken, Pennsylvania, www.astm.org. 9 p.

ASTM D3174 - 02 (2002). "Standard Test Method for Ash in the Analysis Sample of Coal and Coke from Coal." American Society for Testing and Materials, *Annual Book of ASTM Standards*, Vol. 04. 02, West Conshohocken, Pennsylvania, www.astm.org. 5p.

ASTM D4239 - 02 (2002). "ASTM D4239-02 Standard Test Methods for Sulfur in the Analysis Sample of Coal and Coke Using High Temperature Tube Furnace Combustion Methods" American Society for Testing and Materials, *Annual Book of ASTM Standards*, Vol. 04. 02, West Conshohocken, Pennsylvania, www.astm.org. 10p.

ASTM D 4318 – 10 (1994). "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils." American Society for Testing and Materials, *Annual Book of ASTM Standards*, Vol. 04. 02, West Conshohocken, Pennsylvania, www.astm.org. 16 p

ASTM D5319 – 97 (2008). "Standard Specification for Glass-Fiber Reinforced Polyester Wall and Ceiling Panels." American Society for Testing and Materials, *Annual Book of ASTM Standards*, Vol. 04. 02, West Conshohocken, Pennsylvania, www.astm.org. 4 p

ASTM D6913 – 04 (2009) "Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis." American Society for Testing and Materials, *Annual Book of ASTM Standards*, Vol. 04. 02, West Conshohocken, Pennsylvania, www.astm.org. 34 p

BS 1377 (1990). "Methods of Testing Soils for Civil Engineering Purposes." Technical Information Services Department, CNL Technical Information Services, BSI Publications, 389 Chiswick High Road London W4 4AL.

Bowles J. E. (1992). "*Engineering Properties of Soils and their Measurement.*" Fourth edition. International edition, McGraw-Hill, INC.

Craig, R. F. (1992). "*Soil Mechanics.*" 5th Edition, Chapman and Hall, London, pp.27 – 33.

Daniel, D.E. and Wu, Y.K. (1993). "Compacted Clay Liners and Covers for Arid Sites." *Journal of Geotechnical Engineering ASCE*, Vol. 119, No. 2, pp. 223–237.

Das, B. M. (1998). "*Principles of Geotechnical Engineering.*" 4th Edition, PWS Publishing Company, Boston, USA.

Edil, T. B., and Benson, C. H. (2007). "Sustainable Construction Case History: Fly Ash Stabilization of Road-Surfaced Gravel," *World of Coal Ash (WOCA),* Convington, KY, May 7-10, 2007.

Engineering Technical Letter (1999). *"Use of Waste Material in Pavement Construction."* ETL 1110-3-503. B-1 to B-22.

Federal Highway Administration, FHWA (2008). "*User Guidelines for Byproducts and Secondary use Materials in Pavement Construction."* http://www.rmrc.unh.edu/tools/uguideline/rap133.asp.pdf (Last accessed July 15, 2008).

Gardner, K. H. (2011). "Life Cycle Perspectives of Recycled Materials use in Civil Engineering." *Program and Abstracts of ASTM International Symposium on Testing and specification of Recycled Materials for Sustainable Geotechnical Construction,* Baltimore, U.S.A., 2 – 4 February, 2011, p. 53.

Gomes, C. A., Reis, F. S. and Fortunato, E. (2011). "Case Study to Promote the use of Byproducts: The Relevance of Performance Tests." *Program and Abstracts of ASTM International Symposium on Testing and specification of Recycled Materials for Sustainable Geotechnical Construction,* Baltimore, U.S.A., 2 – 4 February, 2011, p. 25

Giroud, J. P. and Jie Han (2004). "Design of Geogrid-Reinforced Unpaved Roads. 1 Development of Design Method" *J. Of Geotechnical and Geoenvironmental Engineering*, Vol. 130, No. 8, pp. 775 – 797.

Halstead, W. J. (1986). "Use of Fly Ash in Concrete." NCHRP 127 (October), *Transportation Research Board*, National Research Council, Washington D.C.

Hanks, A. J. and Magni, E. R. (1989). *"The use of Bituminous and Concrete Material in Granular Base and Earth."* Materials Information Report MI-137, Engineering Materials Office, Ontario Ministry of Transportation, Downsview, Ontario.

Hatipoglu, B., Edil, T. B., and Benson, C. H. (2008). "Evaluation of Base Prepared from Road Surface Gravel Stabilized with Fly Ash." *Proc. of GeoCongress 2008: Geotechnics of Waste Management and Remediation*. pp. 288–295.

Head, K. H. (1992). *"Manual of Soil Laboratory Testing"* Vol. 1, Pentech Press Ltd., London.

Hossain, Z., Solanki, P., Zaman, M., Lewis, A. S. and Hobson, K. (2011). "Influence of Recovery Processes on Properties of Binders and Aggregates Recovered from Recycled Asphalt Pavement." *Program and Abstracts of ASTM International Symposium on Testing and specification of Recycled Materials for Sustainable Geotechnical Construction*, Baltimore, U.S.A., 2 – 4 February, 2011, p. 13.

Jeff R. and Miles, P. E. (2006). "Guidelines for use of RAP." *Materials Operational Memorandum.* No. 13, Nov. 2006, Idaho Transportation Department, U.S.A.

Karlsson, R., and Isaacsson, U. (2006). "Material-Related Aspects of Asphalt

Recycling - State of the art." *J. Mater. Civ. Eng.* Vol. 18, No. 1, pp. 81-92.

Kennedy, T. W., Tam, W. O. and Solaimanian, M. (1998). "Optimizing use of Reclaimed Asphalt Pavement with the Superpave System." *J. Association of Asphalt Paving Technologists,* Vol. 67, pp. 311 – 333.

Li, L., Benson, C.H., and Edil, T. B. (2008). "Sustainable Construction Case History: Fly Ash Stabilization of Recycled Asphalt Pavement Materials," *Geotech. Geologic. Eng.,* Vol. 26, pp.177–187.

Li, L., Benson, C.H. and Edil, T. B. (2009). "Properties of Pavement Geomaterials Stabilized with Fly Ash." *World of Coal Ash (WOCA) Conference.*May 4 – 7, Lexington, KY, U.S.A.

Little, D. N. (1999). *"Evaluation of Structural Properties of Lime Stabilized Soils and Aggregates."* Prepared for National Lime Association. Vol. 1.

Misra, A., Kumar, S., Patel, S. and Gustin, F. (2007). "Resilient moduli and structural layer coefficient of fly ash stabilized recycled asphalt base." *World of Coal Ash (WOCA), Conference*, May 7 – 10, Convington, Kentucky, U.S.A.

Ndoke, P. N. (2006). "Performance of Palm Kernel Shell as a Partial Replacement for Coarse Aggregate in Asphalt Concrete." *Leonardo Electronic Journal of Practice and Technologies,* Issue 9, July-December, 2006. pp. 145 – 152.

Nicholson, P. G. and Kashyap, V. (1993). "Flyash stabilization of Tropical Hawaiian Soils." *Geotechnical Special Publication* ASCE. No. 36, pp. 15-29.

Nigerian General Specification (1997). "*Roads and Bridges.*" Federal Ministry of Works an Housings, Abuja, Nigeria, pp. 13 – 25.

Olanipekun, E. A., Olusola, K. O. and Ata, O. (2006). "A Comparative Study of Concrete Properties using Coconut Shell and Palm Kernel Shell as Coarse Aggregates." *Building and Environment,* Vol. 41, Issue 3. pp. 297-301.

Olutoge, F. A. (2010). "Investigations of Sawdust and Palm Kernel Shells as Aggregate Replacement." *ARPN Journal of Engineering and Applied Sciences,* Vol. 5, No. 4, ISSN 1819-6608.

Osinubi, K. J. (1998). "Influence of Compaction Delay on the Properties of Cement Stabilized Lateritic Soil." *J. of Eng. Research - 6,* No. 1.

Osinubi, K. J. and Edeh, J. E. (2011). "Reconstituted Coal Ash Stabilization of Reclaimed Asphalt Pavement." *Advances in Geotechnical Engineering.* Edited by Jie Han and Daniel E. Alzamora, Geotechnical Special Publication, GSP 211, pp. 1172 – 1181.

Osula, D. O. A. (1989). "Evaluation of Admixture Stabilization for Problem Laterite. *J. of Transportation Engineering,* Vol. 115, No. 6, pp. 674 – 687.

Pihl, K .A. and Milvang-Jensen, O. (2009). "The Motivation Factors in the Development and Sustainment of a Well-Functioning Recycling Industry for Road and Non-road Byproducts in Denmark" www.uctc.net/papers/683.pdf (Last assessed January 23, 2009).

Salter, R. J. (1979). "*Highway Design and Construction*" The Macmillan Press Ltd., London.

Sarman, D. and Omidreza, S. (2011). "Influence of Oil Palm Shell on Workability and Compressive Strength Concrete." International J. of Engineering, Annals of Faculty of Engineering Hunedoara, Tome IX, Fascicule 2. ISSN 1584-2665.

Schroeder, R. L. (1994). "The use of Recycled Materials in Highway Construction." *Federal Highway Administration*, Vol. 58, No. 2, Washington, D.C.

Singh, D., Zaman, M. and Commuri, S. (2011). "Laboratory Performance Evaluation of Hot Mix Asphalt Mixes with RAP." *Program and Abstracts of ASTM International Symposium on Testing and* *specification of Recycled Materials For Sustainable Geotechnical Construction,* Baltimore, U.S.A., 2 – 4 February, 2011, p. 56

Taha, R., Al-Harthy, A., Al-Shamsi, K. and Al-Zubeidi, M. (2002). "Cement Stabilization of Reclaimed Asphalt Pavement Aggregates for Road Bases and Sub-Bases" *J. Mater. Civ. Eng.,* A.S.C.E., Vol. 14. No. 3, pp.239-245.

Terrel, R. L., Lundy, J. R., and Leahy, R. B. (1994). "Evaluation of Mixtures Containing Waste Materials." Association of Asphalt Paving Technologists (AAPT), *Asphalt Paving Technology 1994,* Vol. 63, pp. 22 – 38, St. Louis, MO.

Tyrion, F. C. (2000). "Asphalt oxidation." *Asphaltenes and Asphalts, Development in Petroleum Science*, Vol. 40B, Elsevier, New York.

TRL Report TRL615 (2000). *Development of a More Versatile Approach To Flexible And Flexible Composite Pavement Design*. www.highwaysmaintenance.com.

Sulymon, N. A. (2005). "Palm Kernel Shell Concrete for Structural Use – A Preliminary Investigation." Global Journal of Environmental Sciences, Vol. 4, No. 1. pp. 87 – 91

2000/11, C.J.Summers.

TRRL Laboratory Report 1132 (2000). *The Structural Design of Bituminous Roads*. www.highwaysmaintenance.com. Copyright © 2000/11, C.J.Summers.

Udelhofen, G. (2006). *"Proving RAP's Performance."* http://www.cygnusb2b.com/pdf (Last accessed July 15, 2008)

Wen, H and Wu, M. (2011). "Evaluate High Percentage RAP as Base Course Material." *Program and Abstracts of ASTM International Symposium on Testing and specification of Recycled Materials for Sustainable Geotechnical Construction*, Baltimore, U.S.A., 2 – 4 February, 2011, p. 15.