RECLAIMED ASPHALT PAVEMENTS-LIME STABILIZATION OF CLAY AS HIGHWAY PAVEMENT MATERIALS

Edeh, J. E.[1] , Eberemu, A. O.[2], Abah, A. B.[1]
[1]Dept. of Civil Engrg., Ahmadu Bello Univ., Zaria 810001, Nigeria.
[2] Dept. of Civil Engrg., Univ. of Agriculture, Makurdi, 970001, Nigeria.

Abstract
Decreasing supplies of locally available quality aggregate in many regions around the world coupled with the growing concern over waste disposal and the unsuitable nature of clay soil as highway construction material have resulted in greater use of RAP-lime stabilized clay for road construction. This paper present the results of the laboratory evaluation of the characteristics of RAP-lime stabilized clay soil, using 2 – 8% lime, subjected to British Standard Light (BSL) compactive effort to determine their index, compaction and california bearing ratio (CBR) results. The result of the laboratory tests show that the properties of clay improved when stabilized with RAP with 2 - 8% lime. The particle size distributions improved from poorly graded clayey SAND for 100% clay which fall under AASHTO classification A-2-6 to well graded sandy GRAVEL which falls under AASHTO classification of A-1-a, using up to 8% lime. The CBR results obtained from the study show that using the Nigerian General Specifications, 180% CBR value criterion, the maximum CBR values of 36.56% (unsoaked) for 90% RAP + 4% clay + 6% lime and 34.23% (soaked for 24 hours) for 90% RAP + 2% clay + 8% Lime mix proportions can be used as subgrade and subbase materials.
Keywords: **California bearing ratio, clay soil, highway pavements, reclaimed asphalt pavements, stabilization.**

INTRODUCTION

In developing countries the biggest handicap to provide a complete net work of road system is the limited finances available to build road by the conventional methods. Therefore there is a need to resort to one of the suitable methods of low cost road construction, followed by a process of stage development of the roads, to meet the growing needs of the road traffic. Thus apart from affecting economy in the initial construction cost of lower layers of the pavement such as sub-base course it should be possible to upgrade the low cost roads to higher specification at a later date without involving appreciable wastage, utilizing the principle of pavement construction in stages. The construction cost can be considerably reduced by selecting local materials including soils for the lower layers of the pavement such as the sub-base course. If the stability of the local soil is not adequate for supporting wheel loads, the properties are improved by soil stabilization. (Khanna and Justo, 2001).

The stability and serviceability of most engineering project or structure depends largely on their foundation and the bearing capacity of the soil that supports them (Chesworth, 2008). The stability and strength of structures would affect standard as stipulated in the engineering code of practices.

A road pavement may serve its intended purpose if the foundation or sub grade meets the minimum standard in the highway codes. From road note 29, (1970), a sub-grade with a California bearing ratio (CBR) of 2% or less is termed a weak material, while those with CBR values between 3 – 15% are normal and those from 15% and above are said to be very stable. However, Nigerian General Specification for Roads and Bridges in Nigeria (1997) however, recommended a minimum CBR value of over 80% for base materials, 30-80% for subbases and 10-30% for subgrade.

Massive road construction has depleted once plentiful aggregate supplies and continuing to exhaust the valuable resources to rebuild existing roads only propagates and accelerates the problem (Hanks and Magni, 1989). Mostly,

aggregates either from distant quarries, at great expense or from local sources offers only marginal quality and conserving virgin construction materials through recycling with lime make not only smart but economic and strategic sense. Additionally, if old asphalt and road base materials are not recycled, they must be disposed of or stockpiled, increasing transportation cost; and utilizing valuable land space and increasing environmental and health hazards. Recycling with lime makes the reconstruction of old roads a largely self-sustaining process. Due to the excessive cost of new materials, a new method of design had to be sought and new materials introduced. Some researchers (Ola, 1983; Schroeder, 1994; Osinubi, 2000; Osinubi et al., 2009; Osinubi and Edeh, 2011) tried with soils, which are available everywhere (Kolhe, 2008).

Reclaimed asphalt pavement (RAP) is an existing asphalt mixture that has been pulverized, usually by milling, and is used like an aggregate in recycled asphalt pavement (Jeff and Miles, 2006). During pavement rehabilitation and reconstruction, large quantities of this materials are generated especially when asphalt pavement are removed. RAP is the term given to reprocessed and/or removed pavement materials containing asphalt and aggregates. These materials are generated when asphalt pavements are removed for reconstruction, resurfacing, or to obtain access to buried utilities. The binder in the RAP after several years of service, becomes aged and much stiffer than desired. The degree of aging depends on many factors, such as temperature, air void content of the mixture, and chemical composition of the binder. The aged bitumen present in a RAP has physical properties that make it undesirable for reuse without modification (Chen et al., 2007). Experience has indicated that the recycling of asphalt pavements is a beneficial approach from technical, environmental, and economical perspectives (Chen et al., 2007). This has made the recycling of pavement materials to become a very viable alternative to be considered in road maintenance and rehabilitation with the conservation of resources, preservation of the environment, and retention of existing highway geometrics; are some of the other benefits obtained by reusing pavement materials (Taha et al., 2002). As a general rule, Engineering Technical Letter, ETL (1999) considers RAP as a non hazardous material except when the pavement is constructed with a hazardous material as one of the components. Properly crushed and screened RAP consists of high-quality, well-graded aggregates coated by asphalt lime (FHWA, 2008).

Reliable figures for the generation of RAP are not readily available from state highway agencies or local jurisdictions. Based on incomplete data, it is estimated that as much as 45 million metric tons (45 million tons) of RAP may be produced each year in the United States of America, USA. (FHWA, 1995) and the percentage of RAP in hot mix normally varies from 10 – 50% (ETL, 1999; Jeff and Miles, 2006; Udelhofen, 2006). This indicates that majority of the RAP generated may be stockpiled for use at a later time or disposed as a waste material. In Nigeria however, RAP generated during highway reconstructions and rehabilitations are spoiled along road alignments and the statistics of the amount of RAP generated is not documented. The safe disposal of waste is increasingly a major concern around the world, even with the awareness of the importance of recycling, the volume of waste materials including RAP, continues to grow. The use of waste materials, particularly RAP in the construction of pavements has benefits in not only reducing the amount of waste materials requiring disposal but can also provide construction materials with significant savings over new materials (Schroeder, 1994). Because of the large volumes of materials required for construction, pavements have been favorable structures for the recycling of a wide variety of waste materials. Hence, the use of RAP can actually provide value to what was once a costly disposal problem. Initially, this recycling was limited to the re-use of materials removed from previous pavement structures such as: recyclable asphalt pavement, recyclable portland cement concrete and various base course materials but recently various other materials, not originating or associated with pavements, have come into use, either as additives or pozzolan to improve the properties of the RAP for use in pavement surfaces or sub-surface materials.

Pavement rehabilitation and reconstruction generates large quantities of reclaimed asphalt pavement (RAP) aggregate, and recycling into new asphalt paving mixtures is the predominant application. Though RAP acceptance in road bases and subbases has been limited because of the lack of laboratory and field performance data (Taha et al., 2002). In the United States of America, more than 50 million tons (45.36 million Mg) of asphalt paving material are milled annually and recycling into new asphalt paving mixtures is the major use (Galal, 2007).

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 may be obtained from any number of old pavement sources, quality can vary. Excess granular material or soils, or even debris, can sometimes be introduced into old pavement stockpiles. The number of times the pavement has been resurfaced, the amount of patching and/or crack sealing, and the possible presence of prior seal coat applications will all have an influence on RAP composition. Quality control is needed to ensure that the processed RAP will be suitable for the prospective application. This is particularly the case with in-place pavement recycling (FHWA, 2008). Stabilizing the old asphalt surface granular base with cement creates a strong foundation for the pavement hence there is little need for material to be removed or added. The old, brittle asphalt when pulverized becomes “black gravel” that will bond to hydrated lime readily (Kallas, 1984). Research has established typical range of particle size distribution, physical, chemical, engineering and mechanical properties of RAP (Hanks and Magni, 1989; FHWA, 2008; Chen et al., 2007; Roberts et al., 1996; Tyrion, 2000; Karlsson and Isaacsson, 2006; FHWA, 1993; Richard and Smith, 1980; Decker and Young, 1996; Noureldin and Wood, 1989; Senior et al., 1994).

Clay soil is one comprised of soil particles that are extremely fine (0.02mm in diameter). The particles are extremely closely packed, which does not allow much "pore space" within the soil (Craig, 1992; Das, 1998). Expansive soils of clay out-crop in large areas and these clays have caused persistent difficulties in road construction that are common occurrences worldwide. The common problem is volumetric change associated with such clay soils when subjected to water content. In the light of the maintenance cost that will follow the road repairs accentuated by the presence of the expansive clay, methods of treatment must be evolved to eliminate or reduce the effect of soil volume change on the overall formation of the road structure. It has been found by several studies that stabilization with lime reduces soil plasticity, increases strength and durability, decreases water absorption and swelling (Bell, 1996; Nalbantoglue, 2000; National Lime Association, 2001) .These chemical processes modify the soil structure whereby larger grain aggregates are formed leading to several advantages in the suitability of the soil for foundations or road construction (Al-Khashab and Al-Hayalee, 2008).

This study considered the characterization of RAP-lime stabilization of clay soil, for use as highway pavement materials.

MATERIALS AND METHODS

Materials

Reclaimed asphalt pavements

The reclaimed asphalt pavement (RAP) used for this study was obtained from Eke-Olengbecho, a community that lies between latitudes 7° 08’ 00” N and 7° 13’ 48” N and longitudes 7° 41’42” E and 7° 49’30”E, along Otukpo – Ugbokolo road in Benue State, Nigeria. The RAP consists of high-quality, well graded aggregate coated with asphalt cement.

Clay soil

The clay soils used for the study were collected from Engineering complex of the university of agriculture, Makurdi (between latitudes 6°25’ and 8° N and longitudes 7°47’ and 10°. E) in Benue state, Nigeria, where clay out-crop at the surface to a great depth beneath the surface. The sample collected was screened of deleterious materials such as roots prior to their use after which they were air-dried in the laboratory.

Lime

Lime used as a stabilizing agent in this mixture is calcium carbonate ($CaCO_3$) bought from a chemical store in Makurdi, Benue state, Nigeria.

Methods

All experimental procedures are carried out in accordance to standard specifications [BS 1377, 1990; Head, 1992). Various proportions of RAP in the range 0 – 100% with the lime content in the range 0 - 8% of the mix proportions were use to stabilize the clay soil passing sieve No. 19 mm (3/4 in) and in the range 0 – 100%. (The appropriate peak proportions was however, determined during the preliminary mix design tests). The RAP used was crushed using hand-hammer, from its "lump" state to smaller sample sizes and only that passing 19 mm (3/4 in) aperture sieve, was air-dried in the laboratory and used for the tests.

Particle size distribution: Particle size distribution or sieve analysis of the various mix proportions were carried out in order to group the particles into separate ranges of sizes, and so determine the relative proportion by mass, of each size range (Head, 1992; Salter, 1979). To achieve this, mixed samples were 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 were calculated (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 British Standard (BS 1377, 1990; Head, 1992). In highway engineering, the consistency parameters are used in soil classification. Generally, soils with low plasticity indices most probably possess little or no cohesion.

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) (Das, 1998). 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 to establish the OMC corresponding to the MDD.

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 clay soil stabilized with various proportions of RAP and 0 – 8% lime (BS 1377, 1990).

California bearing ratio (CBR): California bearing ratio is an empirical test for estimating the bearing value of the base, sub-base and sub-grade materials in highway constructions (Head, 1994). 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). 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 1935mm^2 cross section into the 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 (Head, 1994).

The specification relating to the use of these indices for highway design and construction are given in The Nigerian General Specifications (1997).

RESULTS AND DISCUSSION

Particle Size Distribution

The particle size distribution of 100% RAP, 100% clay soil and the various RAP-lime stabilized clay soil are shown in Figure 1 – 3. The gradation of 100% RAP is composed of 99.17% coarse aggregates with 0.83% fines and can be described as very sandy GRAVELLY material which fall under AASHTO classification system of A-1-a with coefficient of uniformity, Cu = 6 (greater than 4) and the coefficient of grading, Cz = 1.57 (which fall between 1 < Cz <3). Hence 100% RAP is well graded (Craig, 1992). 100% clay is composed of 90% coarse aggregates with 10% fines and plasticity index of more than 7, coefficient of uniformity, Cu = ∞ (greater than 6) and the coefficient of grading, Cz = ∞ (which fall outside 1 < Cz <3) and be described as poorly graded clayey SAND which fall under AASHTO classification of A-2-6 (Craig, 1992). The various RAP-lime stabilized clay proportions are composed of 82.5 – 94.5% coarse aggregates with 5.5 – 17.5% fines and plasticity indices in the range of non-plastic to 12%, coefficient of uniformity, Cu in the range 13 - ∞ (greater than 6) and the coefficient of grading, Cz in the range 0.11 - ∞ and be described as poorly graded clayey SAND to well graded sandy GRAVEL which fall under AASHTO classification of A-1-a to A-2-7 (Craig, 1992).

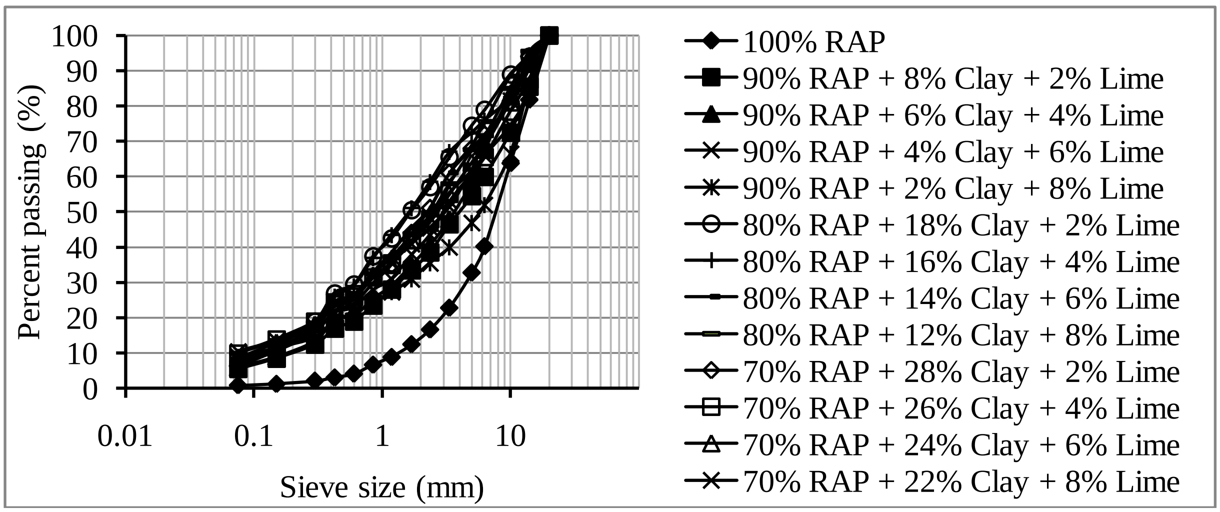

Figure 1 Particle size distribution curves of various proportions of RAP + Clay + Lime mixes

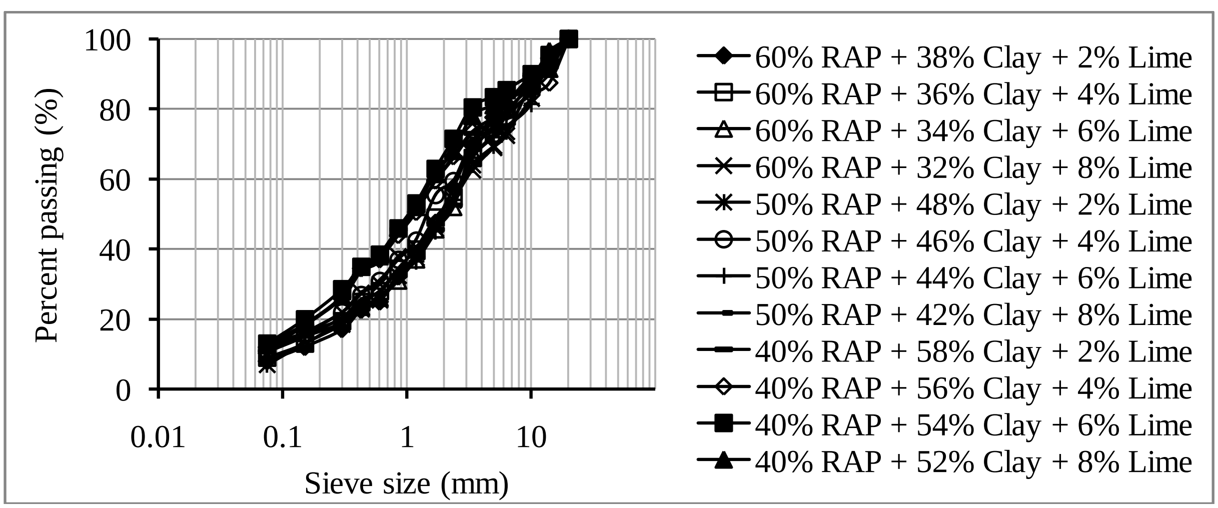

Figure 2 Particle size distribution curves of various proportions of RAP + Clay + Lime mixes

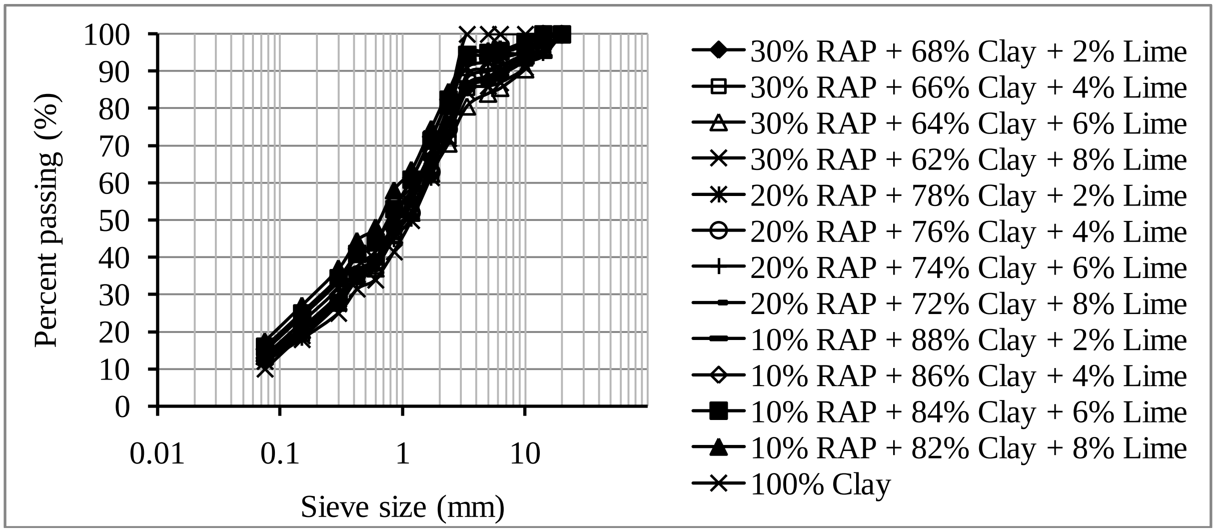

Figure 3 Particle size distribution curves of various proportions of RAP + Clay + Lime mixes

Generally, the particle size grading of the RAP-lime stabilized clay mixes improved. The improved particle grading of the RAP-lime stabilize clay may be due to flocculation-agglomeration of the particles of RAP and clay into larger effective particle sizes facilitated by the lime in the mixes (Little, 1999).

Specific Gravity

From the experimental analysis, the specific gravity for; 100% RAP is 1.98, which falls within the specified range of 1.94 – 2.30 (FHWA, 2008), while 100% clay soil gives the specific gravity (SG) of 2.58. The SG of the clay soil stabilized with the various proportions of the RAP and lime does not show any regular pattern with the addition of lime. The SG of RAP-lime stabilized clay soil, varied from 1.56 for 80% RAP + 12% clay + 8% lime to 2.5 for 60% RAP + 38% clay + 2% lime. This variation in SG may be as a result of variation in compressibility due to exceeding pre-consolidation pressure which leads to sharp decrease in void ratio attributed to soil-lime reaction which produces primary and secondary cementitious materials in the soil-lime matrix (Chew et al., 2004). These are shown in Figures 4 and 5.

Consistency Limits

The consistency limits (Atterberg limits) of RAP-lime stabilized clay, using 0 – 8% lime show that as the lime treatment increased from 0 to 8%, with a corresponding increase in clay content at a fixed proportion of RAP content, the liquid limits (LL), plastic limits (PL) and linear shrinkages (LS) does not show any defined pattern from 0 – 4% lime but the Atterberg limits decreased regularly with increased lime content from 6 to 8% except for the mix proportions with 50 and 60% RAP content that shows increased LL and PL with increased lime content from 6 to 8%. Figures 4 and 5 also show the variation of LL, PL, PI and LS from 54.8% for 70% RAP + 26% clay + 4% Lime, to 17.75% for 90% RAP + 4% clay + 6% Lime mix proportions; 49.3% for 70% RAP + 26% clay + 4% Lime to 14.1% for 30% RAP + 62% clay + 8% Lime; 12% for 40% RAP + 54% clay + 6% Lime to 3.7% for 80% RAP + 12% clay + 8% Lime and 13.57% for 20% RAP + 78% clay + 2% Lime and 10% RAP + 86% clay + 4% Lime to 2.86% for 90% RAP + 8% clay + 2% Lime, respectively.

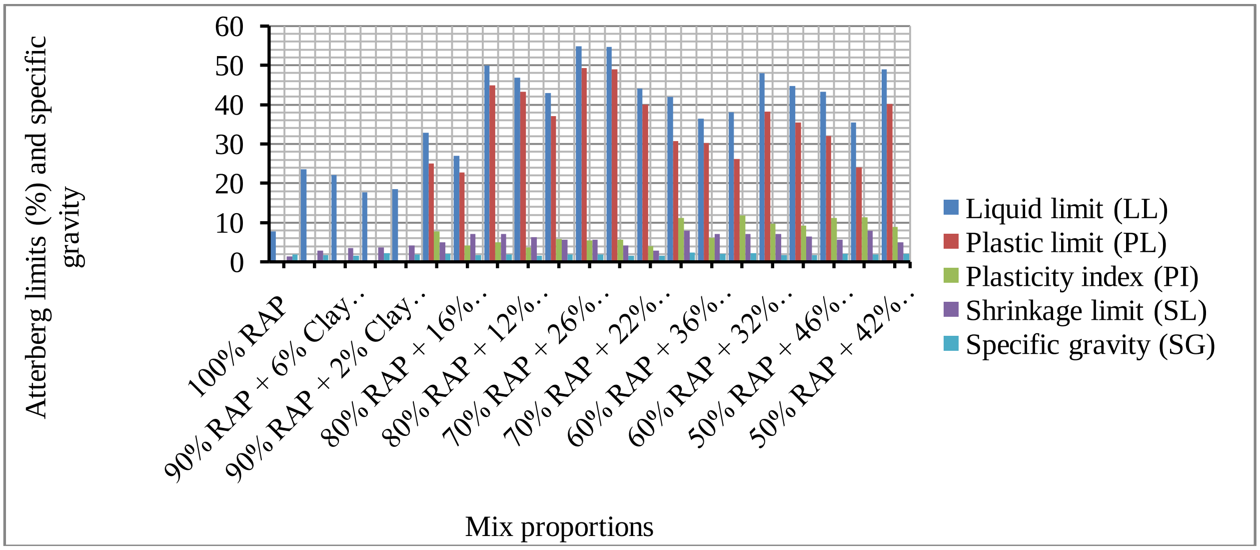

Figure 4 Variation of Atterberg limits and specific gravity with various proportions of RAP + Clay + Lime mixes.

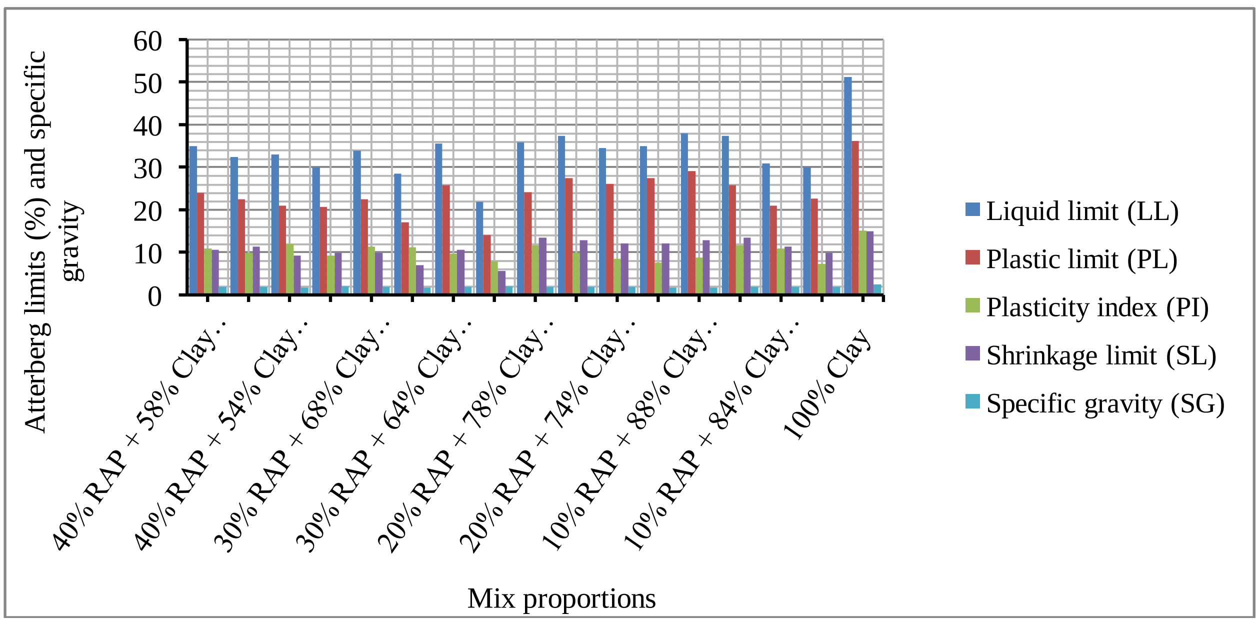

Figure 5 Variation of Atterberg limits and specific gravity with various proportions of RAP + Clay + Lime mixes.

The possible reason for the variations in the consistency limits is aggregation and cementation of particles into larger size clusters (Chew et al., 2004). Another reason for the increased LL and PL for 50 and 60% RAP content may be the water trapped within intra-aggregate pores. The presence of this intra-aggregate water increases the apparent water content without really affecting interaction between aggregates (. Locat et al., 1996).

Compaction Characteristics

Compaction of the samples were carried out with the British Standard Light (BSL) compaction effort, also known as Standard Proctor (SP) in order to establish the optimum moisture contents (OMC) corresponding to their respective maximum dry densities (MDD).

The variation of the maximum dry density (MDD) and the optimum moisture content (OMC) with various RAP + Clay soil + Lime mix proportions are shown in Figures 6 to 9.

The MDD generally decrease as the OMC increased with decreased clay content and increased lime content from 4 to 8%, at constant RAP content in the mix proportions. The MDD also decrease as the OMC increased with decreased RAP content from 90% and increased clay content, for constant lime content in the mix proportions, up to 80% RAP content. The MDD however increase as OMC decreased with lime and clay content from 70 to 30% RAP content after which the MDD decreased as the OMC increased with lime and clay content at decreasing RAP in the mix proportions. The MDD for 100% RAP and 100% clay soil are 2.03 and 1.64 Mg/m^3 with corresponding OMC of 15.01 and 21.02% respectively. The MDD for RAP-lime stabilized clay however increased from 1.71 Mg/m^3 for 20% RAP + 76% clay + 4% lime to 2.02 Mg.m^3 for 70% RAP + 22% clay + 8% lime with corresponding OMC of 18.11 and 12.03% respectively. While the OMC varied from 9.1% for 70% RAP + 26% clay + 4% lime to 18.11% for 20% RAP + 76% clay + 4% lime and 20% RAP + 74% clay + 6% lime mix proportions.

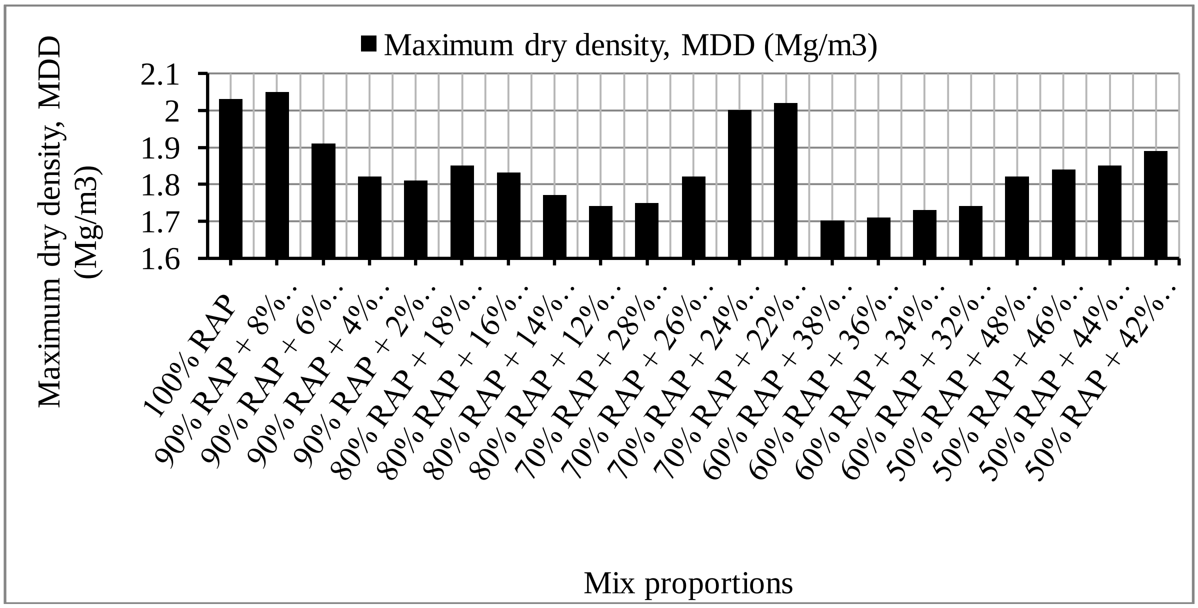

Figure 6 Variation of maximum dry density (MDD) with various proportions of RAP + Clay + Lime mixes.

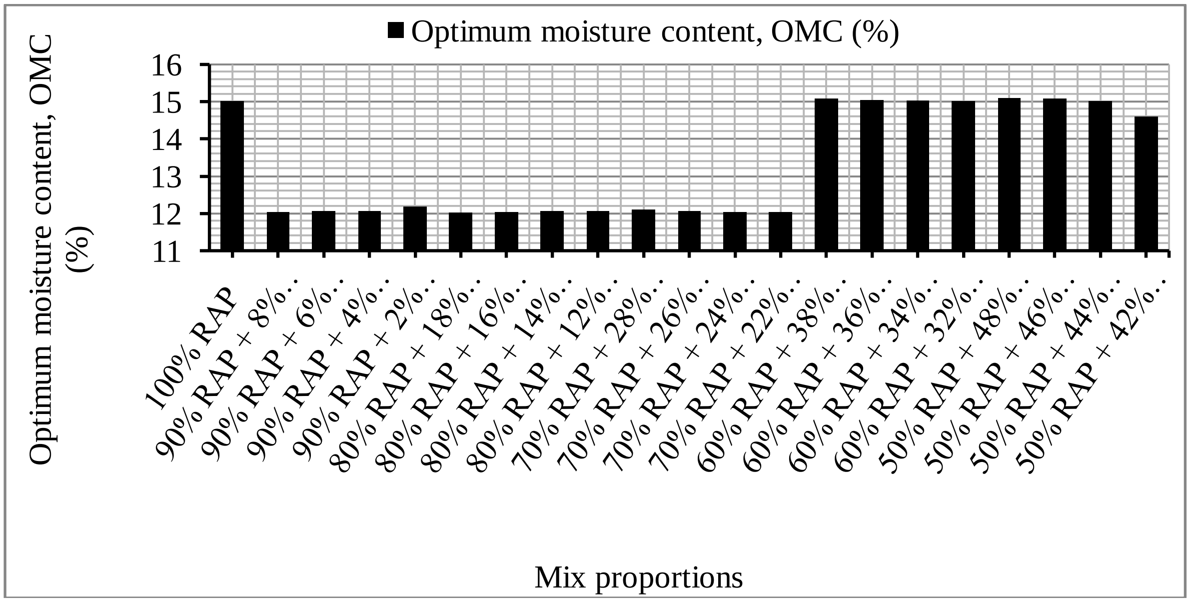

Figure 7 Variation of optimum moisture content (OMC) with various proportions of RAP + Clay + Lime mixes.

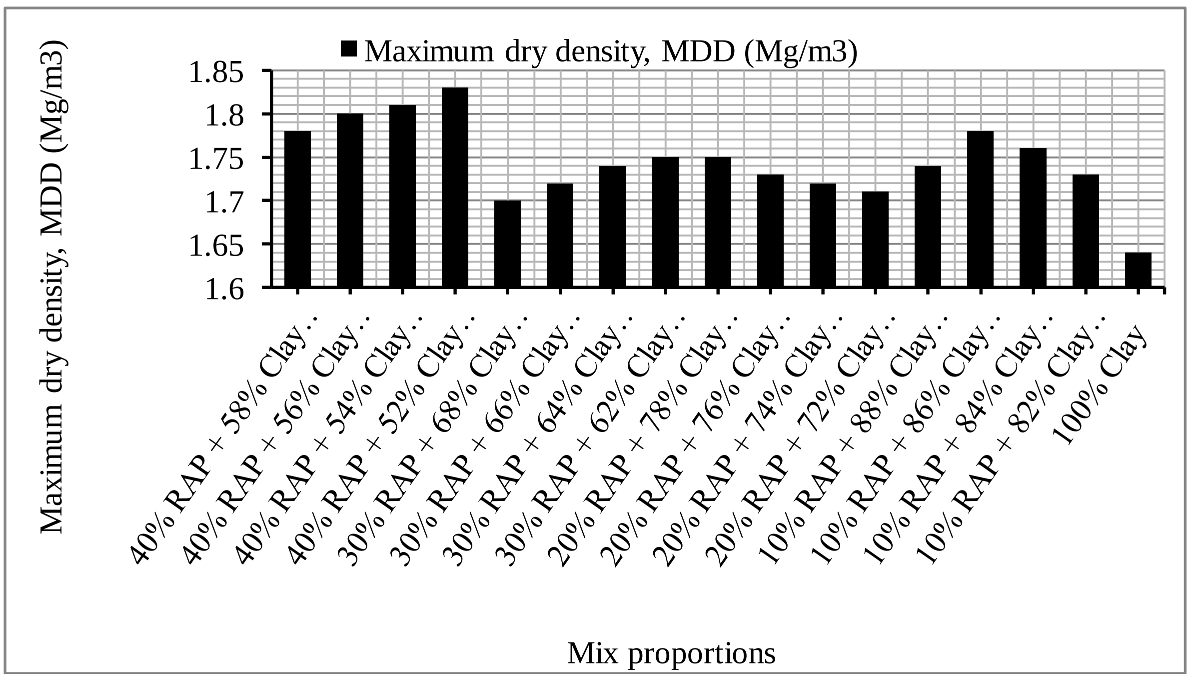

Figure 8 Variation of maximum dry density (MDD) with various proportions of RAP + Clay + Lime mixes.

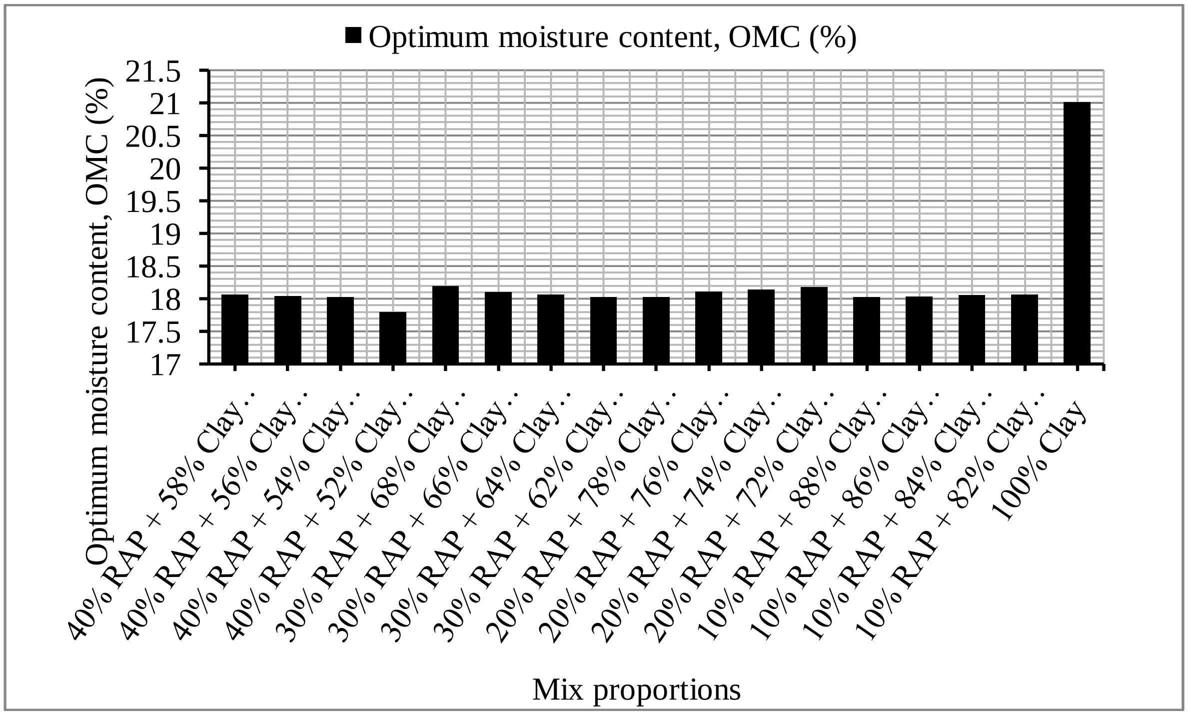

Figure 9 Variation of optimum moisture content (OMC) with various proportions of RAP + Clay + Lime mixes.

The initial increase in OMC with decreased MDD may be due to the increased surface area of particles caused by lime and clay addition. This now need more water to lubricate the entire soil matrix, to enhance compaction, in addition of the water taken up by lime hydration reaction (Osula, 1989), while the decrease in OMC with increased MDD may be attributed to insufficiency of water in the system which led to self-desiccation and consequently lower hydration. It is known that if no water movement to and from lime paste is permitted, the reaction of hydration use up the water until too little is left to saturate the soil surfaces and the relative humidity within the paste decreases (Osinubi, 1998).

California bearing ratio

The unsoaked and soaked california bearing ratio (CBR) values for British Standard Light (BSL) compaction of 100% RAP, 100% clay soil and the various proportions of RAP + clay + lime mixes are presented in Figure 10. Recorded CBR values are generally low, but shows an improved in CBR values (unsoaked and soaked) from; 16.62 and 31.76% for 100%RAP and 9.21 and 4.89% (unsoaked and soaked) for 100%clay soil respectively to CBR values of 36.56% (unsoaked) for 90% RAP + 4% clay + 6% lime mix proportion and 34.23% (soaked for 24 hours) for 90% RAP + 2% clay + 8% Lime. The Nigerian general specification's 180% criterion for base material was not met for the range of mix proportions tested. The highest CBR value recorded was 36.56% (unsoaked) for 90% RAP + 4% clay + 6% lime mix proportion.

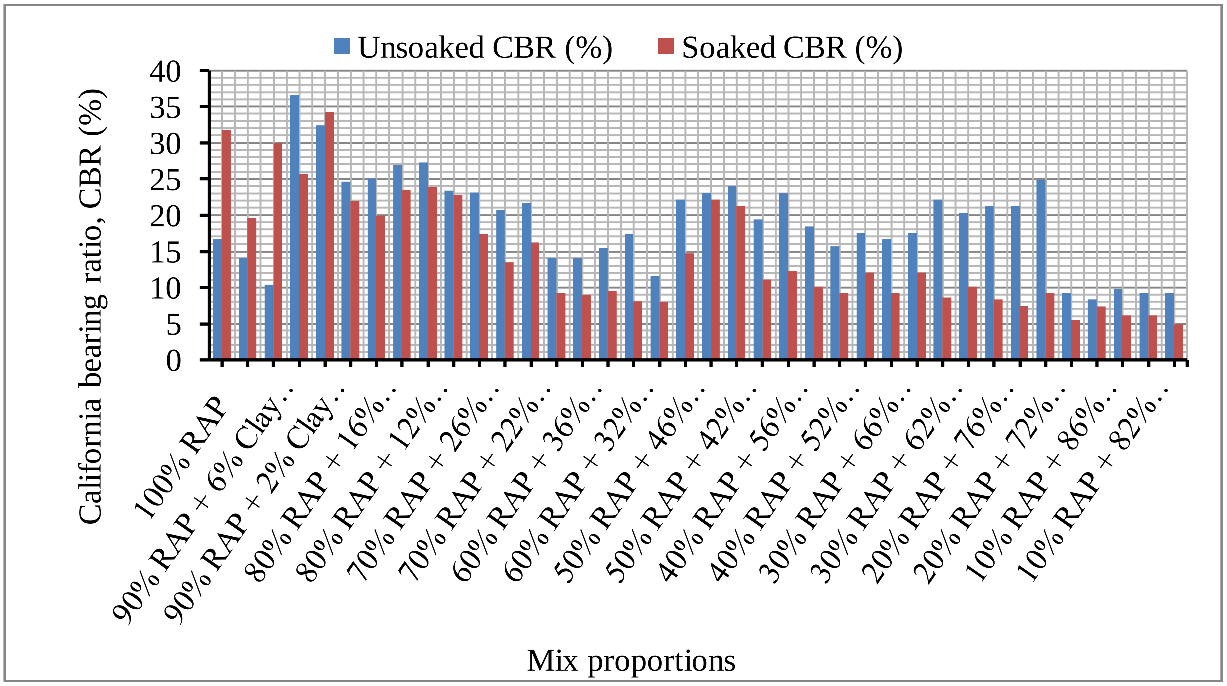

Fig. 10 Variation of california bearing ratios (CBR) with various proportions of RAP + Clay + Lime mixes.

Generally, the CBR values does not show any defined trend across the mix proportions of the various RAP, clay soil, and lime mixture. The recorded results also show some increased values of soaked CBR for 24 hours, an indication of strength gain with time. This reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the calcium from the lime reacts with the aluminates and silicates solubilized from the clay. The initial low CBR may be due to the hydration of tricalcium aluminate, which is one of the main components of lime, is retarded by the hydrated lime liberated by the hydrolysis of tricalcium silicate (Brunauer et al., 1973). This may also be due to the reaction between the hydrated lime with tricalcium aluminate 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 high CRB may have been accentuated by rapid hydration reaction of a typical lime stabilization that may now predominate the initial action that retarded the rapid hydration process.

The later low CBR values recorded may likely continue in parallel to the hydration of tricalcium aluminate; to increase the slow but continued strength-gaining characteristics of soil-lime mixtures (Osula, 1989).

CONCLUSIONS

Experimental approaches have being used to assess the suitability of RAP-lime stabilized clay soil as highway pavement construction materials.

The Nigerian General Specification's criterion of 180% CBR value for highway base materials was not satisfied. However, the maximum CBR values of 36.56% (unsoaked) for 90% RAP + 4% clay + 6% lime and 34.23% (soaked for 24 hours) for 90% RAP + 2% clay + 8% Lime mix proportions can be used as subgrade and subbase materials.

The particle size distributions improved from poorly graded clayey SAND for 100% clay which fall under AASHTO classification A-2-6 to well graded sandy GRAVEL which falls under AASHTO classification of A-1-a.

The plasticity of the material improved with increased lime, decreased clay and at a fixed RAP contents in the mix proportions. The peak specific gravity of 2.5 for the RAP-

lime stabilized clay soil was obtained 60% RAP + 38% clay + 2% lime mix proportion.

The MDD for RAP-lime stabilized clay however increased from 1.71 Mg/m^3 for 20% RAP + 76% clay + 4% lime to 2.02 Mg.m^3 for 70% RAP + 22% clay + 8% lime mix proportions with corresponding OMC of 18.11 and 12.03% respectively. While the OMC varied from 9.1% for 70% RAP + 26% clay + 4% lime to 18.11% for 20% RAP + 76% clay + 4% lime and 20% RAP + 74% clay + 6% lime mix proportions.

REFERENCES

Al-Khashab, M. N. and Al-Hayalee, (2008). “Stabilization of Expansive Clayey Soil Modified by Lime with an Emulsified Asphalt Addition.” *Eng.& Technology*,Vol. 26, No.10, 1247.

Bell, F.G., (1996). "Lime Stabilization of Clay Minerals and Soils." *Engineering Geology 42*, Dept of Geology and Applied Geology, University of Natal, South Africa, pp.223-237.

Brunauer, S., Skalny, J., Odler, I. and Yudenfreund, M. (1973). “Hardened Portland Lime Pastes of Low Porosity. VII Further Remarks about Early Hydration Composition and Surface Area of Tobermorite Gel.” *Summary, Lime and Concrete Research,* 3(3), pp. 279 – 294.

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.

Chen, J. S., Huan, C. C., Chu, P. Y. and Lin, K. Y. (2007). “Engineering Characterization of Recycled Asphalt Concrete and Aged Bitumen Mixed Recycling Agent.” *Springer Science + Business Media,* LLC.

Chesworth, W. (2008). *Encyclopedia of Soil Science.* Dordrecht, Netherland; Springer XXIV.

Chew, S. H., Kamruzzaman, A. H. M. and Lee, F. H. (2004). “Physicochemical and Engineering Behavior of Lime Treated Clays.” *Journal of Geotechnical and Geoenvironmental Engineering.* Vol. 130, No. 7, pp. 696 – 706.

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

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

Decker, D. S. and Young, T. J. (1996). “Handling RAP in an HMA Facility.” *Proceedings of the Canadian Technical Asphalt Association,* Edmonton, Alberta.

Engineering Technical Letter, ETL (1999). Use of Waste Materials in Pavement Construction. ETL 1110-3-503, 15 Sept. 1999, pp. B-1 to B-22.

Federal Highway Administration, FHWA (1993). Engineering and Environmental Aspects of Recycling Material for Highway Construction. *Federal Highway Administration and U.S. Environmental Protection Agency,* Report No..RD-93-008, Washington, DC.

Federal Highway Administration, FHWA (1995). Pavement Recycling. Executive Summary and Report. Report No. FHWA-SA-95-060, Washington, D.C.

Federal Highway Administration, FHWA (2008). User Guidelines for By-products and Secondary Use Materials in Pavement Construction. Information on http://www.rmrc.unh.edu/tools/uguideline/rap133.asp.pdf (Last accessed July 15, 2008).

Federal Ministry of Works and Housings (1997). *Nigerian General Specification for Roads and Bridges.* Abuja, Nigeria.

Galal, A. (2007). “Properties of Reclaimed Asphalt Pavement Aggregate in Road Bases and Subbases. Transportation Research Record.” *Journal of the Transportation Research Board*, Published By Transportation Research Board of the National Academies 0361-198, Volume 1652 /1999.

Giroud, J. P. and Han, J. (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.

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.

Head, K. H. (1992). *Manual of soil laboratory testing Soil classification and compaction tests*. 2nd Ed. Vol. 1. Pentech Press, London.

Head, K. H. (1994). *Manual of soil laboratory testing.* Vol. 2, 2nd Edition, Pentech Press Ltd., London.

Jeff, R. and Miles, P. E. (2006). Guidelines for Use of RAP. *In Materials Operational Memorandum.* No. 13, November, 2006.

Kallas, B. F. (1984). Flexible Pavement Mixture Design Using Reclaimed Asphalt Concrete. FHWA/RD-84/088.

Karlsson, R and Isaacsson, U (2006). "Material-Related Aspects of Asphalt Recycling - State of the Art. *Journal of Materials in Civil Engineering*, American Society of Civil Engineers, Vol. 18, No. 1, pp. 81-92.

Khanna, S. K. and Justo, C. E. G. (2001). Highway Engineering. New Chand and Roorkee (U.A), India, 8th Edition. pp. 463 – 487.

Kolhe, P. (2008). "Use of Limeed Material as Pavement Base or Sub-base."

http://kolhe.pravin.iitk.googlepages.com/thesis. (Last accessed July 15, 2008).

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

Locat, J., Tremblay, H and Leroueil, S. (1996). "Mechanical and Hydraulic Behavior of a Soft Inorganic Clay Treated with Lime." *Can Geotech. J.,* Vol. 33, pp. 654 – 565.

Nalbantoglue, Z., (2000). "Engineering Properties of an Expansive Soil Modified by Lime.".3rd International Conference on Ground Improvement Techniques, Singapore, pp. 277-282.

National Lime Association (2001). "Using Lime for Soil Stabilization and Modification, A Proven Solution." Arlington, Virginia 22203-3728. http://www.lime.org (Last accessed January 12, 2003).

Noureldin, S. A. and Wood, E. L. (1989). "Variations in Molecular Size Distribution of Virgin and Recycled Asphalt Binders Associated with Aging." *Transportation Research Board, Record No.1228*, Washington, DC.

Ola, S. A. (1983). The Geotechnical Properties of Black Cotton Soils of North Eastern Nigeria, edited by S. A. Ola, in *Tropical Soils of Nigeria in Engineering Practice*, A. A. Balkema, The Netherlands, Rotterdam, pp. 85 – 101.

Osinubi, K. J. (1998). "Influence of Compaction Delay on the Properties of Lime Stabilized Clay Soil." *J. of Engineering Research - 6,* No. 1, (1998), p. 13 – 25.

Osinubi, K. J. (2000). "Stabilization of Tropical Black Clay with Lime and Pulverized Coal Ash Admixture." *Advances in Unsaturated Geotechnics,* ASCE Geotechnical Special Publication 99, C. D. Shackelford, S. L. Houston, and N. Y. Chang, eds, pp. 289 – 302.

Osinubi, K. J., Ijimdiya, T. S. and Nmadu, I. (2009). "Lime Stabilization of Black Cotton Soil using Bagasse Ash as Admixture." *Advance Material Research*, pp. 62 – 64. Information on http:www.scientific.net , (Trans Tech Publications. Switzerland).

Osinubi, K. J. and Edeh, J. E. (2011). "Reconstituted Coal Ash Stabilization Of Reclaimed Asphalt Pavement," Advances in Geotechnical Engineering, Geotechnical Special

Publication, J. Han and D. E. Alzamora, Eds., Vol. 211, ASCE Press, Reston, VA, 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.

Richard, W and Smith, J. (1980). "State-of-the-Art Hot Recycling." *Transportation Research Board, Record No. 780,* Proceedings of the National Seminar on Asphalt Pavement Recycling, Washington, DC.

Road note 29 (1970). *A Guide to the Structural Design for New Roads.* Department of Environmental road research laboratory.

Roberts, F. L., Kandhal, P. S., Brown, E. R., Lee, D. and Kennedy, T. W. (1996). *Hot Mix Asphalt Materials, Mixture Design, and Construction*, 2nd Edition, Napa Education Foundation, Lanham, MD.

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

)

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

Senior, S. A., Szoke, S. I. and Rogers, C. A. (1994). "Ontario Experience With Reclaimed Materials for Use in Aggregate." *Presented at the International Road Federation Conference,* Calgary, Alberta.

Taha, R., Al-Harthy, A., Al-Shamsi, K. and Al-Zubeidi, M. (2002). "Lime Stabilisation of Reclaimed Asphalt Pavement Aggregates for Road Bases and Sub-bases." *Journal of Materials in Civil Engineering,* A.S.C.E., Vol. 14. No. 3. pp. 239-245.

Tyrion, F. C. (2000). Asphalt Oxidation. *Asphaltenes and Asphalts, Development in Petroleum Science*, Vol. 40B, Elsevier, NY.

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