Original Research Article

STABILIZATION OF LATERITIC SOIL FOR ROAD APPLICATION USING LIME AND COW BONE ASH

ABSTRACT

Roads should possess sufficient strength to support wheel loads imposed upon them either during construction or the service life of the pavement. It is sometimes necessary to treat soils to provide a stable subgrade or a working platform for the construction of the road surface. Cow bones scattered in Nigerian meat markets and abattoirs have become an environmental concern, hence the need to seek alternative uses for them. This study is concentrated on the stabilizing potential of cow bone ash (CBA) as an eco-friendly bio-waste material and lime on the stabilization of lateritic soil for road application. It is aimed at achieving the effective utilization of lateritic soil as a practicable construction material by attempting to identify the best percentages of soil stabilizers (binders) needed to improve the soil. Based on this, the study identified the methods that were used on lateritic soil samples obtained from Ado-Ikere road, Ado Ekiti in Ekiti state, Nigeria and the method of stabilization using cow bone ash and lime on the soil sample. The following laboratory tests and experiments were carried out: sieve analysis, atterberg limits, compaction, california bearing ratio (CBR) and thermo-scientific X-ray fluorescence (XRF). They were used to investigate the influence of cow bone ash and lime on lateritic soil. Different percentages of lime and cow bone ash (2%, 4%, 6%, 8% and 10%) respectively were used for the stabilization of the lateritic soil samples. Also, different proportions of addition of lime and cow bone ash were explored to stabilize the soil. The CBR test results showed that the addition of 8%, being the optimum amount or addition of binder of lime and CBA increased the CBR of lateritic soil. It also revealed that cow bone ash and lime can be used for stabilization of lateritic soil.

Keywords: Subgrade, Soil Stabilizers, Soil Sample, Compaction, California Bearing Ratio, Atterberg Limits.

INTRODUCTION

It is a universal practice in Transportation Engineering to reduce the disruption of traffic patterns and the delay caused by today's motorists whenever possible during the construction and restoration of roads and bridges. In doing this, Engineers are often faced with the problem of constructing road beds on or with soils, which do not possess sufficient strength to support wheel loads imposed upon them either during construction or the service life of the pavement. It is at times necessary to treat soils to provide a stable subgrade or a working platform for the construction of the pavement. The result of these treatments are that less time and energy are required in the production, handling and placement of roads, bridge fills and subgrade and therefore, less time to complete the construction process thus reducing the disruption and delays to traffic.

In Civil engineering, soil stabilization is a technique for refining and improving the engineering properties of soils. These properties include: mechanical strength; permeability, compressibility, durability and plasticity. Physical or mechanical improvement is mostly referred to as stabilization in reference to chemical improvement in the soil properties by adding chemical admixtures. The practice of soil stabilization dates back to the Roman empire; other nations such as the United States of America and China among many others adopted this method in the latter half of the twentieth century.

"Lateritic soil is any of a group of zonal soil types developed or formed under conditions of high temperature and heavy rainfall with alternate wet and dry periods of forest vegetation. Lateritic soils are granular dark reddish brown surface soils and are rich in iron and aluminium oxides. Lateritic soil can be defined as weathered tropical or sub-tropical leftover soil, generally covered with sesquioxide rich solidifications" (Oyelami & Van Rooy, 2016). "This soil is defined with high temperature and moisture content prompting exceptional chemical weathering that structures well graded residual soils. Lateritic soils are environmentally friendly materials which are abundant in nature. Lateritic soils have been the most broadly known and utilized construction material in building, road construction and bridge fills. In tropical parts of the world, lateritic soils are utilized as road making materials and they form the structure of subgrade of most tropical roads" (Oyelami & Van Rooy, 2016).

"Soil stabilization can likewise be viewed as the alteration of soils to improve their physical properties. Stabilization can build the shear strength of a soil or potentially control the compaction and consolidating properties of a soil, thereby improving the load bearing capacity of a sub-grade to support pavements and foundations. Soil stabilization accomplishes various goals that are significant in acquiring a dependable structure from locally accessible earth materials and these include better mechanical qualities, better attachment between particles which decrease the porosity and changes in volume because of moisture changes, improved protection from wind, erosion and rain" (Oyelami & Van Rooy, 2016).

Statement of Problem

"In consequence to the rise in high cost of conventional construction materials in most developing countries, the use of local materials is of paramount importance to sustainable construction because of its availability, cost effectiveness and ability to protect the environment. Lateritic soils are one of such locally accessible materials, which is a good option in contrast to regular conventional structural materials aside from a couple of issues. Lateritic soils possess high clay content and lower caution exchange capacity" (Ko, 2014).The plasticity of which may bring about cracks and thereafter damage on roadways, pavements, building foundations, and some other road construction works and application. This gives rise to the need for stabilization as a necessity for lateritic soils in road application. In order to solve this problem, it is essential to research on new ways of producing road construction materials from locally available materials at low cost. Over the years, a serious danger to the sustainability of the human race is environmental pollution. Cow bones are scattered everywhere in Nigerian meat markets and abattoirs, causing problems to humans. This is the reason for utilizing cow bone ash for the stabilization of lateritic soil as a material for road construction.

Aim and Objectives

The aim of this research is to study the behaviour of lateritic soil for road application when stabilized and treated with lime and cow bone ash.

The Objectives include the following:

- To examine the effect of cow bone ash (CBA) and lime on the geotechnical properties of lateritic soil as an alternative stabilizer for road construction applications;
- To determine an appropriate mix proportion of stabilized laterite soil using lime and CBA as stabilization agents;
- To study the effect of lime and CBA on the compaction, CBR, Unconfined Compressive Strength (UCS) and Atterberg limits of lateritic soil sample as a stabilizer for road construction application;

- To determine the effect of CBA and lime on the classification of lateritic soil as regards its particle size distribution by performing sieve analysis test.

Significance of Study

Stabilization of lateritic soils has been successful with both cement and lime, although some soils do not show any marked improvement. Lime has not been used as extensively as cement for stabilizing lateritic soils hence the stabilization of lateritic soil with lime and cow bone ash enhances increase in its strength and durability by decreasing its porosity. This leads to durable roads and structures built with stabilized lateritic soil consequently sparing the expense of maintenance. It also prevents imminent problems like swelling, cracks and damping that might lead to failure of the structures built with untreated lateritic soil. It equally prevents future issues like expanding, damping and cracks that may cause structural failure of untreated lateritic soil. Bone ash was chosen to tackle the issue of environmental pollution. This research has the potential for making sustainable roads from lateritic soil stabilized with cow bone ash and lime.

Scope of Work

Laboratory tests that were performed in the laboratory include: California Bearing Ratio (CBR), compaction test, sieve analysis test, Atterberg limits and Unconfined Compressive Strength (UCS). Thermo-scientific X-ray fluorescence (XRF) test was carried out on the lateritic soil sample and cow bone ash. The scope of this research covers the following:

a. Stabilization of the lateritic soil;
b. Different experimental setup for the application of different levels of the stabilization materials (cow bone ash and lime) to develop lateritic soil for road application;
c. Comparison of the strength of the laboratory stabilized lateritic soils to the raw sample collected;
d. Use of CBR and compaction test to evaluate the effectiveness of the stabilization agents in improving the quality of lateritic soil for road construction application.

Limitation of Study

Raw Nigerian lateritic soil samples were chosen for this research because they are abundantly available and are used in many geotechnical engineering works in Nigeria. As a result of the differences in lateritic formations and mineral constituents, the results obtained from this research will only be applicable to laterite specimen produced from lateritic soils at a borrow pit along Ado-Ikere road, Ado-Ekiti, Ekiti State or any other laterite or soil samples with similar characteristics in Ekiti State, Nigeria.

LITERATURE REVIEW

Formation of Laterite and Lateritic Soil

"Laterite is a soil and rock type rich in iron and aluminium commonly formed in hot and wet tropical areas. Almost all laterites are of rusty-red coloration because of the high iron oxide content. They are referred to as soil type as well as rock type. Laterites are formed from the leaching of parent sedimentary rocks, metamorphic rocks and igneous rocks which leaves the more insoluble ions of mainly iron and aluminium, although some investigators prefer to define laterite as a rock or part of a soil" (Norton, 2000). "Lateritic soil develops by intensive and delayed weathering of the fundamental parent rock leading to tropical weathering (laterization) which is a delayed process of chemical weathering that creates a great variety in the thickness, grade, chemistry and ore mineralogy of the subsequent soils. It has been discovered that lateritic soils are commonly acceptable construction materials in road application and are in this manner widely utilized in construction" (Amu & Adetuberu, 2010). "Lateritic soil is a residual of rock decay that is reddish in colour and has a high substance of oxides of iron and hydroxides of aluminium and low percentage of silica. Lateritic soils are materials with no consistent properties" (Amu & Adetuberu, 2010). The performance of lateritic soils as construction materials for road application is dependent on the engineering properties of the soil.

Soil Stabilization

Soil stabilization is the concept or procedure of improving the mechanical structure of a specific soil to qualify it for civil engineering construction works. Industrial and domestic wastes can be re-used for improving the engineering properties of problematic soils. (Mahajan, 2000). "Soil stabilization from an extensive perspective fuses the different techniques used for changing soil properties to improve its engineering qualities and performance. Stabilization is utilized for different engineering works, the most common application being in road construction and airfield pavements, with the primary goal of building the strength and solidness of soil and reduce cost of construction. Further reasons for soil stabilization are conservation of energy, dust control, soil waterproofing and improved durability" (Mahajan, 2000). The effect of adding certain percentage of cow bone ash (CBA) on the geotechnical properties of a selected residual soil to enhance its hydraulic conductivity and soil strength recommends CBA as a suitable modifier of the geotechnical properties of treated lateritic soil and qualifies it as a suitable alternative material for soil stabilization for road applications. There are numerous methods by which soils can be stabilized; however, all methods fall into two broad categories, namely: Mechanical stabilization and Chemical stabilization.

Stabilizing Agent

These are hydraulic (primary binders) or non-hydraulic (secondary binders) materials that when in contact with water or in the presence of soil (pozzolanic) minerals, reacts with water to form cementitious composite materials. The commonly used soil stabilizers (binders) are:

(a) Cement as a soil stabilizer

Cement is the oldest binding agent since the invention of soil stabilization technology in 1960’s. It may be considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required (Sherwood, 1993).Cement reaction is not dependent on soil minerals, and the key role is its reaction with water that may be available in any soil (Euro SoilStab, 2002). Calcium hydroxide is another hydration product of ordinary Portland cement that further reacts with soil (pozzolanic) materials available in stabilized soil to produce further cementitious material (Sherwood, 1993). Normally the amount of cement used is small but sufficient to improve the engineering properties of the soil and further improved cat ion exchange of clay.

(b) Lime as a soil stabilizer

Lime provides an economical way of soil stabilization. Lime modification defines an increase in strength brought by cat ion exchange capacity rather than cementing effect brought by pozzolanic reaction (Sherwood, 1993). In engineering soil modification, as clay particles flocculate, it transforms natural plate-like clay particles into needle like interlocking metalline structures. Clay soils turn drier and less susceptible to water content changes (Rogers & Glendinning, 1993). Normally, lime stabilization may refer to soil (pozzolanic) reaction in which soil materials react with lime in presence of water to produce cementitious compounds (Sherwood, 1993) and (Euro Soilstab., 2002). The effect can be brought by either quicklime, CaO or hydrated lime, $Ca(OH)_2$. Slurry lime can also be used in dry soil conditions where water may be required to achieve effective compaction (Hicks, 2002). Quicklime is the most commonly used lime.

Cow bone ash as a soil stabilizer

Bone is a dynamic tissue that performs mechanical, biological, and chemical functions. The main constituent of bone is hydroxyapatite as well as amorphous forms of calcium phosphate, possibly including carbonate. The chemical and physical properties of bone are affected by age, nutrition, hormonal status, and diseases (Loveridge, 1999). Cow bones are the source of production of bone ash. Bone ash is grey-white powdery ash obtained from the burning (calcination) of bones. It is primarily composed of calcium phosphate. ***Calcination*** is known as a process of high-temperature heating in the presence of atmospheric oxygen. The end product being pure bone mineral, a compound related to hydroxyapatite. Cow Bone Ash is significant because some of its important properties are due to the unique cellular structure of bones preserved through calcination (Ayininuola & Akiniyi, 2013). Cow Bone Ash has excellent non-wetting properties; it is chemically inert, free of organic matters and has very high heat transfer resistance. According to Ayininuola and Shogunro (2013), calcined bone ash contains the following: CaO (45.53%), P_2O_5 (38.66%), MgO (1.18%), SiO_2 (0.09%), Fe_2O_3 (0.1%), Al_2O_3 (0.06%) and Moisture (0.11%).

Engineering classification of soil

Soils are widely varied in their various grain-size distributions. Also, depending on the type and quantity of clay minerals present, the plastic properties of soils may be very different. Various types of engineering works require the identification and classification of soil in the field. In the design of foundations and earth-retaining structures, construction of highways, and so on, it is necessary for soils to be arranged in specific groups and/or subgroups based on their grain-size distribution and plasticity. The process of placing soils into various groups and/or subgroups is called *soil classification.* For engineering purposes, there are two major systems currently in use by soil engineers for the classification of soil and these are:
(i) The *American Association of State Highway and Transportation Officials (AASHTO) Classification System; and* (ii) The *Unified Soil Classification System (USCS).*

MATERIALS AND METHODS

MATERIALS AND SAMPLES PREPARATION

Selection of materials for this research work involved the collection of lateritic soil, lime and cow bone ash. Lateritic soils are the traditional materials for road construction in Nigeria; this is because of its availability and abundance in Nigeria and Africa in general. Lateritic soils for this research were obtained from a depth of 1.2m below ground level and the laterite material considered was obtained from a borrow pit located along Ado-Ikere road, Ado-Ekiti, Ekiti State, Nigeria. The lateritic soil samples were collected air-dried at room temperature and brought to the soil laboratory at Federal Polytechnic, Ado-Ekiti, Ekiti State. Nigeria, indicating the soil description, sampling depth and date of sampling. The commercial lime was purchased from a chemical shop in Ado-Ekiti while the cow bone ash was produced from calcined cow bones locally purchased from an indigenous community abattoir in Ado-Ekiti and washed with water, cleaned from existing meat particles, contaminations and any impurities. This was later calcinated in a gas furnace at the Glass and Ceramics Department of Federal Polytechnic, Ado-Ekiti, and the calcination temperature was 900°C for a period of 90mins. Thereafter, the calcinated cow bone was milled to a powdery form using ball mills at the Mineral Resources Engineering department of Federal Polytechnic, Ado-Ekiti. It was then passed through 425**µm (U.S.** No. 40**)** sieve before being used to stabilize the lateritic soil. The fresh laterite sample, lime and cow bone ash are shown hereunder in Figures .1, 2, and .3 respectively

Figure .1: Raw (Fresh) Laterite

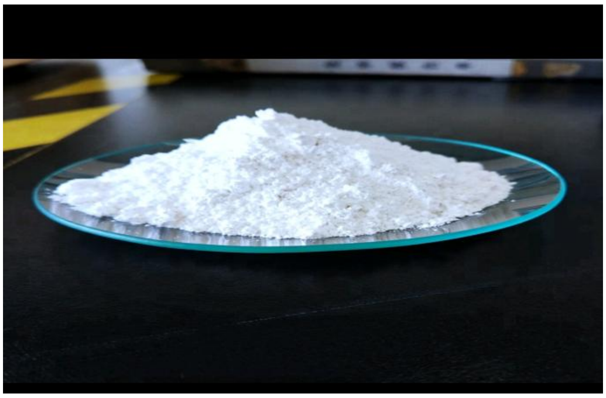

Figure 2: Lime (Soil stabilizer)

Figure .3: Calcinated and Grounded Cow Bone Ash (CBA)

In this study, different percentages of lime (2%, 4%, 6%, 8% and 10%) and cow bone ash (2%, 4%, 6%, 8% and 10%) were used in the stabilization of the lateritic soil samples. The samples obtained were used for the CBR, Compaction, and Atterberg limits tests at various proportions. XRF (X-ray fluorescence) analysis of the soil sample was carried out at Lafarge Quality Assurance and Quality Control Department, Mfamosing cement plant in Cross River State. All the other tests were carried out at the Geotechnical Engineering Laboratory of Federal Polytechnic, Ado-Ekiti, Ekiti State, Nigeria. The properties of the soil samples were initially ascertained through preliminary test carried out in the laboratory. The geotechnical properties of the soil were determined in accordance with the British Standard Institute (BSI, 1990a) while the stabilization test was performed in accordance with the British Standard Institute (BSI, 1990b). Specimens for CBR tests were prepared at the optimum moisture contents (OMC) and maximum dry density (MDD) – British Standard light of the soil. The CBR tests were conducted as specified by the Nigeria General Specifications (1997) for road and bridge works.

EXPERIMENTAL DESIGN AND METHODS

The following tests were carried out on the natural soil sample in order to assess its geotechnical and other essential engineering properties:

i. Natural moisture content
ii. Specific gravity
iii. Sieve analysis
iv. Atterberg limits
v. Compaction
vi. California Bearing Ratio (CBR)
vii. Thermo-scientific X-ray fluorescence (XRF)

Natural moisture content test

Moisture is simply water diffused in a relatively small quantity. Almost all lateritic materials contain at least a little volume of moisture as a component of the molecular makeup. Moisture is assumed in most mass of a lateritic soil; however the relative percentage is dynamic and therefore not constant. Moisture content can be thought of as the amount of water in a material or soil and is required as a guide for classification of natural soils and as a control criterion in compacted soils and is measured on samples used for most field and laboratory tests. The oven-drying method is the definitive procedure used in standard laboratory practice procedure at a temperature not exceeding 110^{o} C according to BS 1377: Part-2: 1990.

Procedure

To carry out the moisture content test, clean and dry the container, then weigh it to the nearest 0.1 g *(M_1)*. A representative sample of crumbled and loosely placed lateritic soil is then placed into the container. The container with the sample is immediately weighed *(M_2)* and placed in the oven to dry at 105^0C for 24 hours; after drying, weigh the container and contents *(M_3)*. The moisture content *(W)* of the soil sample is then calculated as a percentage of the dry soil mass to the nearest 0.1%, using the equation below:

$$W = \frac{(M_2 - M_3)}{(M_3 - M_1)} \times 100\ (\%)$$

Specific gravity test

The knowledge of specific gravity is essential in soil stabilization since the relationship and investigation of the compaction and consolidation properties of lateritic soils is important. The specific gravity of a given lateritic soil material is defined as the ratio of the weight of a given volume of the material to the weight of an equal volume of distilled water. In soil mechanics, the specific gravity of soil solids (which is often referred to as the specific gravity of soil) is an important parameter for calculation of the weight-volume relationship.

Procedure

A portion of the lateritic soil was used to determine the amount of water present in soil at natural state. The weight of empty dry density bottle (W_P) was recorded, after which 10g of dry soil sample (passed through sieve No 10) was placed in the density bottle. The weight of the density bottle containing the dry soil was then recorded (W_{PS}). Distilled water was thereafter poured into the density bottle up to three quarter of its capacity and allowed to soak for 10 minutes. A partial vacuum was applied to the contents of the density bottle for 10 minutes in order to remove any trapped air. More distilled water was added to the density bottle to fill it up completely; the weight of the density filled with soil and water was recorded (W_B). The density bottle was then emptied and filled with distilled water only. The weight of the density bottle containing distilled water was taken (W_A).

Specific gravity, G_s is computed as:

$$\mathbf{G_s} = \frac{W_O}{W_O + (W_A - W_B)}$$

Where W_O = weight of dry soil = $W_{PS} - W_P$

Sieve analysis test

Sieve analysis test was carried out to determine the grain or particle size of fine aggregates.

Procedure

The soil sample was oven dried, pulverized and placed in a mechanical sieve shaker for which the weight of sieves have been predetermined and arranged in order of sizes. The mechanical sieve shaker was turned on for about 10 minutes and the soil retained on each sieve was weighed. The coefficient of uniformity is calculated according to BS 1377: Part-2, (1990).

Atterberg limits test

The Atterberg limits test was used to determine the plastic limits (PL) and liquid limits (LL) of soil sample. The plasticity index (PI) was thereafter computed.

Liquid Limit: The liquid limit is the empirically established moisture content at which the soil passes from the liquid state to the plastic state. The liquid limit was carried out using the cone penetrometer apparatus as recommended in BS 1377: part-2 (1990).

Procedure

A soil sample of 300g from thoroughly mixed portion of soil material, passing 0.425mm (No.40) sieve was placed in a porcelain dish and mixed with 20ml distilled water by alternatively and repeatedly stirring, kneading and chopping with spatula. Further water increment of 3ml was added and the process repeated until sufficient water was thoroughly mixed with the soil. A portion of the mix was pressed into the cone penetration cup using a spatula with entrapment of air bubbles. The cup was placed under the penetrometer while the point of the cone was set to touch the surface of the soil in the cup. The cone penetration reading was taken and a little sample was taken for the determination of moisture content of the soil. The same mixed sample was turned on the mix tray with little amount of water added and the test was repeated until more than 20 actual penetrations were attained. Liquid limit was taken as the moisture content corresponding to 20 actual penetrations on the graph of actual penetration against moisture content.

Plastic Limit: Plastic limit is described as the water content when a thread of soil being rolled shear at 3mm diameter (i.e. the first crumbling point or appearance of a little cracks). The test was conducted as stated in BS 1377: Part-2, (1990). The plastic limit is used together with the liquid limit to determine the **plasticity index (PI)** which when plotted against the limit on the plasticity chart provides a means of classifying cohesive soils.

Procedure:

The soil sample that was retained through the 0.425mm (No. 40) sieve was collected and water was added to about 20g of the retained soil in order to mould it. The moulded lump of soil was broken into smaller samples and each of them rolled on a glass plate using the fingers to obtain a thread of uniform diameter 3mm as required.

Plasticity index (PI):

The Plasticity index is the difference between the liquid limits and the plastic limit. The plasticity index is the range of moisture content in which a soil is plastic; the finer the soil the greater the plasticity index.

Plasticity Index (PI) = Plastic Limit (PL) - Liquid Limit (LL)

Compaction test

The standard proctor was adopted for this study according to test reference procedure BS 1377: Part-4 (1990).

Procedure

A cylindrical metal mould (proctor mould) of about 1000cm^3 volume and a rammer of 2.5kg weight with a height drop of 300mm was used as the given compactive effort. Twenty five (25) blows were given on each of the three layers and the moisture content of the sample was determined from samples taken from the top and bottom of the mould and oven-dried. The process was repeated till the weight of the soil reduced. The maximum dry density (MDD) was determined as the peak point of the curve of dry density and its corresponding moisture content which is also known as the optimum moisture content (OMC).

California Bearing Ratio (CBR) test

Focus is on the soaked method according to BS 1377 Part-2 (1990). The specimens were prepared in five (5) layers.

The CBR value is calculated by expressing the corrected values of the forces on the plunger for a given penetration as a percentage of a standard force. The 2.5mm and 5.0mm penetration caused by 13.24KN and 19.96KN loads were used in comparing the loads that caused the same penetration on the specimens. The California Bearing Value was determined using:

$$\textbf{CBR} = \frac{\text{Test Load} \times 100}{\text{Standard load}}$$

X-Ray Fluorescence (XRF) test

X-ray fluorescence (XRF) test is an elemental analysis technique that provides quantitative chemical information. It is a fast, accurate and non-destructive technique used to identify and detect oxide composition. This was used for the cow bone ash and lateritic soil samples to determine their characterization and collection of their chemical composition and constituents.

RESULTS AND DISCUSSIONS

RESULTS

Specific gravity

Table 1: Summary of specific gravity for lateritic soil

S/No	Material	Specific gravity
1	Lateritic soil	2.65

Sieve analysis

Table 2: Physical and Chemical Properties of the Soil

Properties of Soil	**Soil Sample**
Colour	Reddish Brown
Percentage of Silt	48.60%
Percentage of Clay	20.70%
Percentage of Sand	25.60%
Percentage Gravel	2.25%.
Percentage Passing BS No 200 sieve (%)	69.60
Liquid Limit (%)	56.80
Plastic Limit (%)	30.48
Linear Shrinkage	9.52
Plasticity Index (%)	26.32
Specific Gravity	2.65
Maximum Dry Density (KG/M^3)	18.30
Optimum Moisture Content (%)	17.46
California Bearing Ratio (%)	14.65(Top) 14.15 (Bottom)
AASHTO Classification	A-7-5
Laterite class ($SiO2)/(Al2O3 + Fe2O3)$	2.37 (It is non-lateritic soil)

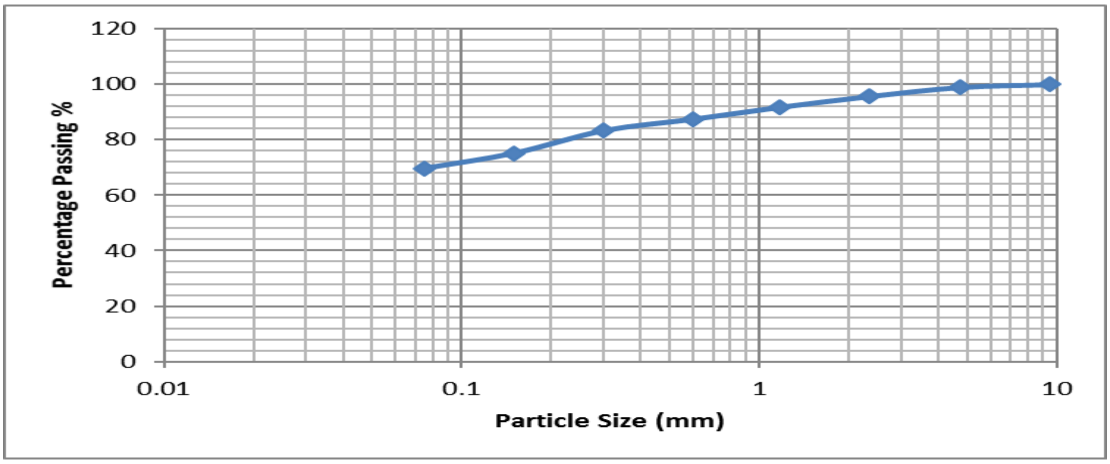

Figure 4: Graph of particle size distribution of Lateritic soil

Atterberg limits

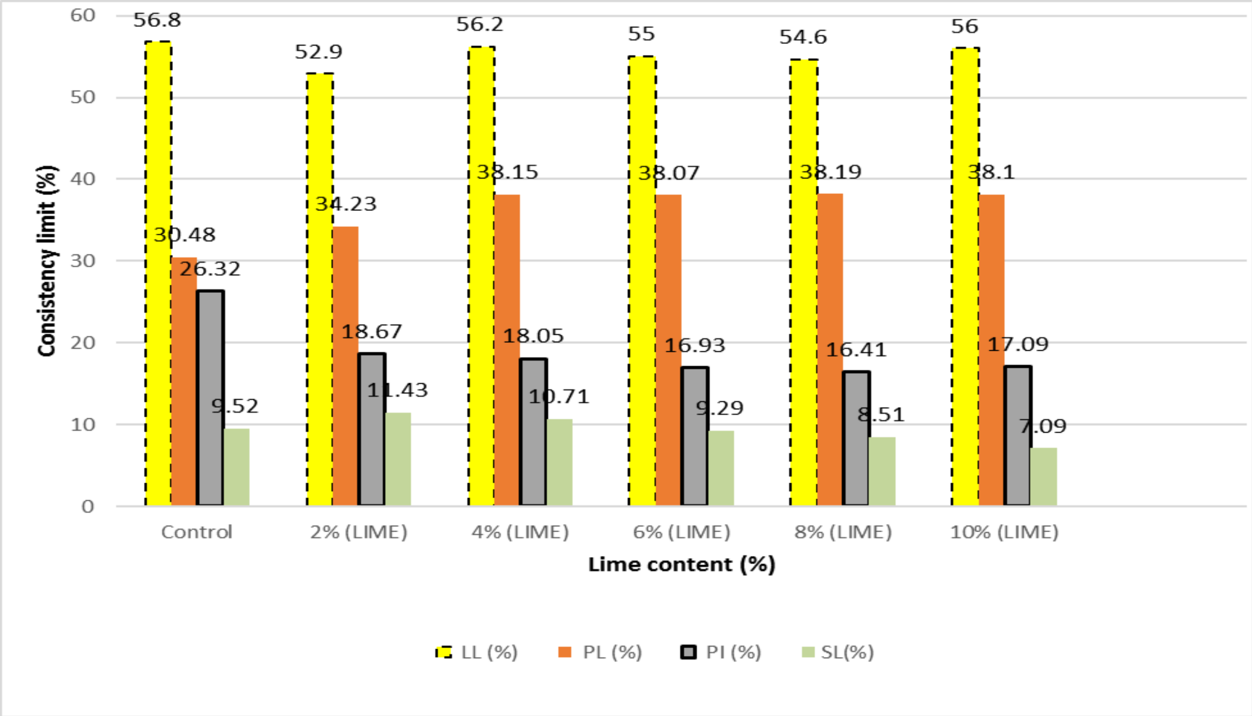

Figure 5: Effects of lime on the lateritic soil

Compaction

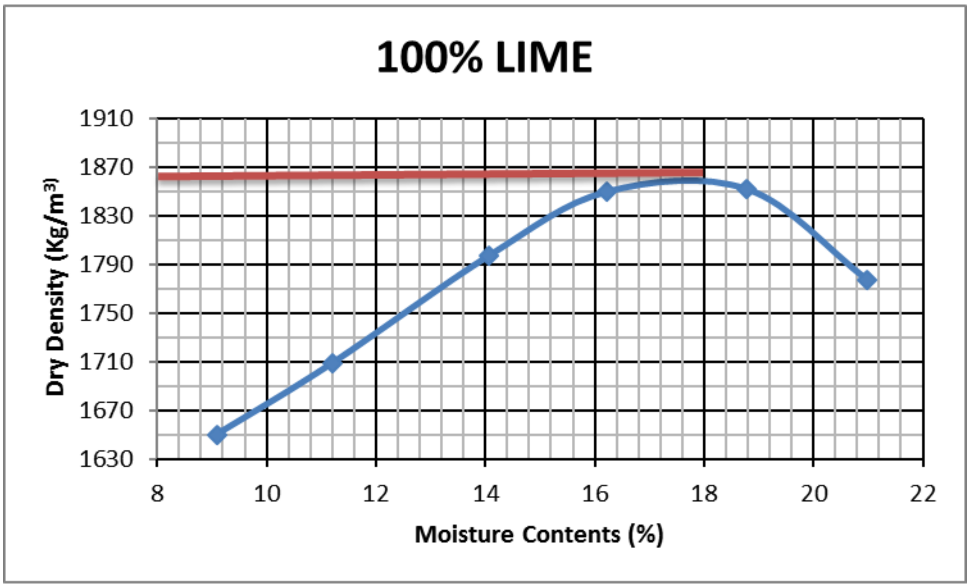

Figure 6: Chart showing lateritic soil stabilized with 100% Lime

California Bearing Ratio (CBR)

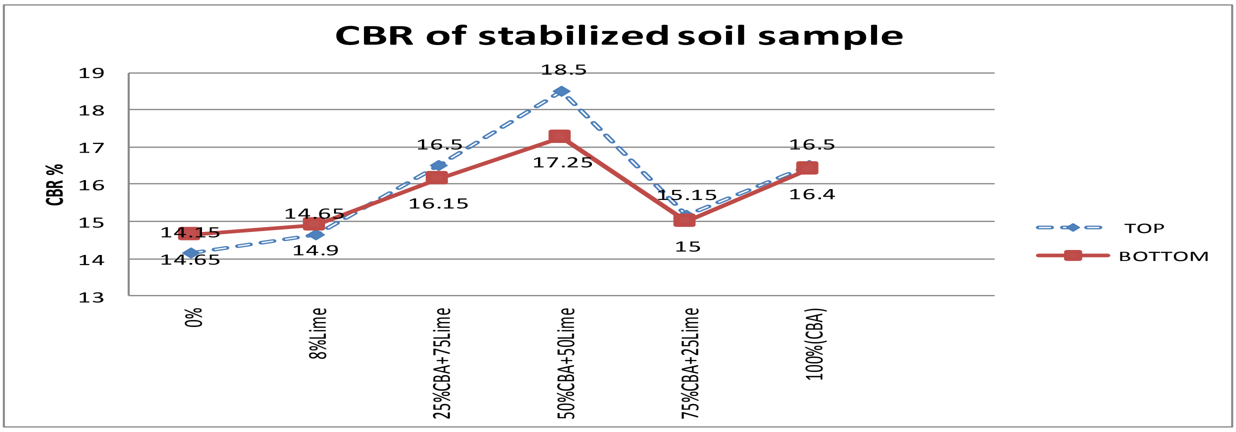

Figure 7: CBR Characteristics of the stabilized soil sample

X-Ray Fluorescence (XRF)

Table 3: Chemical composition (Oxides) of natural lateritic soil and cow bone ash (CBA) samples

Chemical constituents (Oxides)	**Chemical compounds (Oxides)**	**% of Natural Lateritic Soil**	**% of CBA**
Silicon Oxide	SiO_2	43.66	7.798
Aluminium Oxide	Al_2O_3	22.63	1.594
Ferric Oxide	Fe_2O_3	21.12	0.426
Calcium Oxide	CaO	0.13	60.263
Magnesium Oxide	MgO_2	0.39	0.000
Sulphate	SO_3	0.00	0.031
Phosphorous Oxide	P2O5	0.00	28.155
Potassium Oxide	K_2O	0.10	0.074
Loss on Ignition (LOI)		11.53	0.00

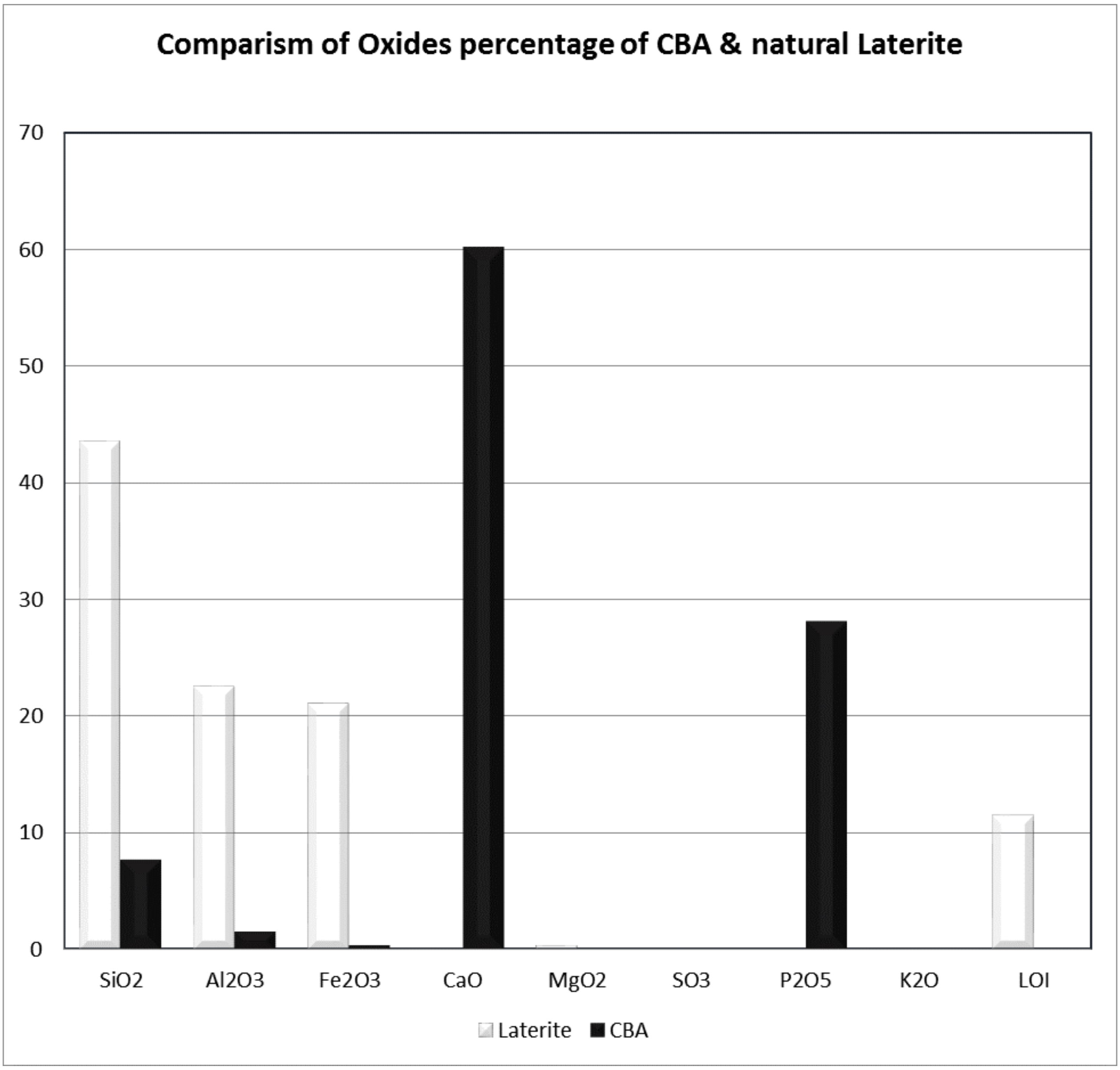

Figure 8: Chart showing the chemical (Oxides) composition of Natural Laterite and CBA

DISCUSSIONS

Specific gravity

Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at the same temperature. It indicates the density of the materials and helps in further classification of the soil. The specific gravity of cow bone ash and lime used in this study are relatively low compared to that of lateritic soil. The specific gravity of the soil is within the range of other result gotten for lateritic soil in Ado-Ekiti (Osuji & Akinwamide, 2018).

The average specific gravity value was 2.65g which shows that the lateritic soil sample has a good amount of clay mineral because clay has higher specific gravity than sand.

Sieve analysis

The soil sample was subjected to hydrometer test as the summary of the result shows. Percentage of soil passing was plotted against particle size in Figure 4. According to the American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS), the soil can be classified as fine-grain and also contains silt and sand with a little amount of clay. The percentage of fine grain passing sieve no 200 (0.075mm) is 69.58%. The soil sample contains 25.60% sand, 4.80% gravel, 48.60% silt and 20.70% clay.

Atterberg limits

The Atterberg limits helps to determine the Plasticity Index (PI) of the natural soil as well as that of the stabilized soil at different percentages of additives through determination of the liquid limit and the plastic limit. The addition of the ratio of lime and (or) cow bone ash has been observed to generally increase the liquid limit and plastic limit of the soil but decreases the plasticity index of the soil. The increase in liquid limit and plastic limit can be attributed more to the replacement of soil by CBA particles than to lime. The presented Atterberg limits revealed that the soil sample's liquid limit is 56.80%, plastic limit is 30.48%, shrinkage limit is 9.52%, and plasticity index is 26.32%. The difference between the liquid limit (LL) and plastic limit (PL) was recorded as plasticity index (PI), and FMWH (1997) stated that the liquid limit and plastic limit for materials suitable for subgrade, subbase, and base course respectively should be within 35% and 12%. The results of the Atterberg limit test shows that the sample did not meet the requirement of FMWH (1997), indicating that the soil sample needed to be improved. Figure 5 shows result of the effects of lime on the lateritic soil.

Compaction

Soil compaction tests were undertaken with the aim of determining the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). The compaction results show that the lateritic soil has a higher MDD compared to the stabilized soils. The MDD and OMC generated by the natural soil and 100% lime stabilized the soil. For the stabilization process, compaction with 100% lime resulted in a maximum dry unit weight of 18.52kN/m^3 and an optimum moisture content of 18.78% was later adopted for the stabilization process considering its strength.

CBR

Figure 7 shows the CBR values for lateritic soil stabilized with CBA and lime. The CBR value increased with addition of CBA and lime content. In the stabilization process, the CBR value increased up to 50% CBA plus 50% lime. It shows that Lime/CBA (50% / 50%) content at 8% lime stabilized soil is optimum for the improvement of the lateritic soil.

XRF

All the samples of laterite collected for this study are of rusty-red colouration because of the high iron oxide ($Fe_2O_{3)}$ content. They are referred to as a soil type as well as being a lateritic soil. It is a residual of rock decay that is reddish in colour and has almost equal amount of iron oxide (21.12%) and aluminium (22.63%) with high percentage of silicon oxides (43.66%) obtained from a local borrow pit along Ado-Ikere road, Ado Ekiti, Ekiti state. All the samples of CBA used for this study are of grey-whitish colouration because of the high calcium oxide (CaO) content. They are referred to as having a high chemical composition of oxides as well as being an ash, a residual of pulverised cow bone that is whitish grey in colour and has almost varying substance of iron oxide (0.425%) and of aluminium (1.594%) and also high percentage of calcium oxides (60.263%), phosphorous oxides (28.155%) and silicon oxides (7.798) acquired from a community abattoir in Ado-Ekiti, Ekiti state.

CONCLUSION

Recent research has identified that the appropriateness of any type of laterite soil deposit can usually be judged by a methodical study of the diverse engineering characteristics of the soil, relevant to a given structure. The performance of lateritic soil type for road application therefore depends on many factors.

The study of the engineering properties of lateritic soils as an important procedure of improving the performance of challenging soils makes lateritic soils perform better as a civil engineering material. This is based on the laboratory tests carried out to determine the effects of lime and cow bone ash as stabilization agents for the lateritic soils. In general, an additional amount of cow bone ash and lime caused the beneficial improvement in the results obtained from the CBR, Compaction and Atterberg limits tests on the lateritic soil samples. It was also observed that the mechanical properties of stabilized soil vary and depend on the percentage of stabilizers used. The result indicates that the CBR of the samples improved optimally at 50% CBA and 50% lime stabilization additives in lateritic soil sample.

The following conclusions are made from the results of using variable percentages of cow bone ash and lime:

- The soil from the study site, classified as laterite but unsuitable for use as subgrade, subbase, or base course materials in road construction, with constituents ranging from fair to poor. The soil can be categorised as clayey soil (i.e., A-7-5);
- The CBA can be classified as poor pozzolans (i.e., $Si0_2 + Al_20_3 + Fe_20_3 < 70\%$), as it possesses high calcium oxide (CaO) oxide and phosphorous oxide (P_20_5) content.

RECOMMENDATIONS

Laterite materials are economically available and its energy efficiency when combined with other local stabilization materials in developing countries helps in improving its strength. It is recommended from this research that the stabilization of lateritic soil samples with cow bone ash (CBA) and lime should be explored for use in road works. Consideration should be given to the following:

- Much effort should be placed on study means and materials for stabilizing laterite soil for road application along this region.
- Suitable test procedures that properly evaluate these stabilization materials should be proposed for the construction of roadways.
- Appropriate assessment should be made on the adequacy of lateritic soil for the construction of more roads.

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