Comparison Characterization of A-6(10) Laterite Soil Stabilized With Powermax Cement and Hydrated Lime Separately

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ABSTRACT

This work presents the comparison of A-6(10) laterite soil stabilized with Powermax cement and hydrated lime separately in percentages of 6%, 8%, 10%, 12% and 14%. It also considered the stabilized materials suitability in relationship to their strength and permeability qualities as subbase and basecourse materials in highway pavement design and construction based upon recommended practice of AASHTO classification system. Heuristic algorithms for reasoning and decision making carried out involved considerations for basic and physico-chemical properties of the laterite soil, Powermax cement and hydrated lime to optimally arrive at design objective functions and serviceability requirements of the stabilized pavement materials. Strength and permeability qualities of natural A-6(10) laterite soil and at its maximum of 14% admixture stabilization with Powermax cement and hydrated lime separately were different. The results respectively gave OMC of 19.3%, 16.5% and 18.1%; MDD of 1.548 Mg/m³, 1.68 Mg/m³ and 1.603 Mg/m³; unsoaked CBR of 27.87%, 138.5% and 53.75%; soaked CBR of 15.9%, 220% and 41.5%; uncurled shear strength of 64.947 kN/m², 279.624 kN/m² and 157.18 kN/m²; cured shear strength of 234.598 kN/m², 449.44 kN/m² and 310.591 kN/m² and k values are 10⁻⁵, 10⁻⁶ and 10⁻⁷. A-6(10) laterite soil, Powermax cement and hydrated lime are all alkaline in nature for having pH values of 12.7, 13.57 and 13.61 respectively. Also, A-6(10) laterite soil contain three major chemical constituents which are SiO₂, Al₂O₃ and AI at 61.58%, 33.91% and 17.95mg/k respectively whilst similarly for Powermax cement at 64.01%, 32.22% and 17.06mg/k. Whereas the only major constituent in hydrated lime is CaO which is of 52.98% of mineral Components whilst is respectively at 1.42% and 1.82% in A-6(10) laterite soil and Powermax cement. Despite the higher percentage of CaO in hydrated lime than that of Powermax Cement, the optimum value of its CBR occurred at 8% stabilization A-6(10) laterite soil resulted to 74% of soaked value that is less than 80% recommended as minimum value but that of Powermax stabilization CBR value is 178%.

Keywords: Optimum, Stabilizer, Premature, Strength, Permeability, Minimum

1. INTRODUCTION

In most highway pavement engineering design and construction processes that are formed on laterite soil do experience premature failure due to problems such as poor shear strength and good permeability whether in rural or urban environment (Akiije, 2015), (Akiije, 2014), (Marto et al., 2013).

Wright and Dixon (2004) claimed that there are four general classes of stabilization and described them as (1) soil-aggregate roads and granular stabilization, (2) bitumen- soil stabilization, (3) soil-cement roads, and (4) stabilization by the addition of salt, lime, and various other chemicals. However, due to these various alternatives highway engineers have to consider the most economical methodology of stabilization of the highway pavement at a given location. The most economical stabilization methodology the engineer is facing at a particular situation depends upon the challenges of choosing and using readily available admixtures at optimum time and strength developed for the design and construction of the highway pavement (Osinubi and Amadi, 2010), (Akinwumi, 2014), (Salahudeen and Akiije, 2014).

Schellmann (1981) considered laterites as products of intense subaerial weathering whose Fe and/or Al contents are higher and Si content is lower than in merely kaolinitised parent rocks. They predominantly consist of mineral assemblages of goethite, hematite, aluminium hydroxides, kaolinite minerals and quartz. Wikipedia (2015) claimed that nearly all laterites are rusty-red because of iron oxides and they are developed and formed in hot and wet tropical areas by intensive and long-lasting weathering of the underlying parent rock.

According to Chambers (2007), weathering is the process of disintegration and decomposition effected in minerals and rocks as a consequence of exposure to the atmosphere and to the action of frost, rain and insolation. These effects are partly mechanical, partly chemical, and partly organic and for their continuation depend upon the removal, by transportation, of the products of weathering. Kaolin’s main constituents are kaolinite, hydrated aluminium silicate, illite which is a mica-like alumino-silicate, potassium, magnesium and iron. Kaolinite is a finely crystalline form of hydrated aluminium silicate (OH), Al₂Si₃O₁₀, occurring as minute monoclinic flaky crystals with a perfect basal cleavage resulting chiefly from the alteration of feldspars under conditions of hydrothermal or pneumatolytic metamorphism, or by weathering. Goethite is orthorhombic hydrated oxide of iron with composition of FeO(OH). Hematite is oxide of iron Fe₂O₃, crystallizing in the trigonal system as in cement. Quartz is crystalline silica, SiO₂, that occurs either in prism capped by rhombohedra of low-temperature quartz, stable up to 573°C or in hexagonal bipyramidal crystals with high-temperature quartz, stable above 573°C. Quartz is widely distributed in rocks of all kinds;
igeneous, metamorphic and sedimentary; usually colourless and transparent (rock crystal), but often coloured by minute quantities of impurities as in citrine, cairngorm and also finely crystalline in the several forms of chalcedony and jasper. Igneous rocks are solidified magma injected into the Earth’s crust or extruded on its surface.

Chambers (2007) further claimed that Magma is molten rock, including dissolved water and other gases. It is formed by melting at depth and risen either to the surface, as lava, or to whatever level it can reach before crystallizing again, in which case it forms an igneous intrusion. Lava is molten rock material that issues from volcanic vent or fissure and consolidates on the surface of the ground (subaerial lava), or on the floor of the sea (submarine lava). Chemically, lava varies widely in composition; it may be in the condition of glass, or holocrystalline rock. Metamorphic rocks are formed due to the change in the mineralogical and structural characteristics and have reached chemical equilibrium under the consequence of heat and/or pressure. Sedimentary rocks result from the wastage of pre-existing rocks. They include the fragmental rocks deposited as sheets of sediment on floors of seas, lakes and rivers and on land; also deposits formed of the hard parts of organisms, and salts deposited from solution, in some cases by organic activity.

Bourman and Ollier (2002) criticized Schellmann definition and classification of laterite for being only based on the $\text{SiO}_2$, $\text{Al}_2\text{O}_3$ and $\text{Fe}_2\text{O}_3$ contents of weathered formations in comparison to the chemical composition of the underlying rocks, from which the weathered materials are assumed to be derived which does not also permit field identification. They claimed that understanding of geology; stratigraphy, geomorphic evolution, mineralogy and micromorphology are essential ingredients of regolith investigations of laterite.

According to Chambers (2007) geology is the study of the planet Earth. Stratigraphy is the definition and description of the stratified rocks of the Earth’s crust, their relationships and structure, their arrangement into chronological groups, their lithology and the conditions of their formation, and their fossil contents including igneous and metamorphic rocks. Stratification is the layering in sedimentary rocks due to chemical, physical or biological changes in the sediment. Fossil is the relic or trace of some plant or animal which has been preserved by natural processes in rocks of the past. Micromorphology, as a general term, comprises both the qualitative and the quantitative analysis of the soil. Mineralogy is the scientific study of minerals. Mineral is a naturally occurring substance of more or less definite chemical composition and physical properties with a characteristic of atomic structure that is frequently expressed in the crystalline form or other properties. Geomorphology is the study of landforms and their relationship to the underlying geological structure. Regolith is the mantle of rock material that overlies bedrock.

Henry (1991) claimed that laterite did not conform to any accepted specifications but performed equally well when compared with adjoining sections of road using stone or other stabilized material as a base. However, American Association State and Highway Transportation Officials (AASHTO) and American Society for Testing and Materials (ASTM) do have accepted standards among others to which laterite soils could easily conform while defining soils based on grain sizes. AASHTO described usual types of significant constituents of soil materials into (i) stone fragments, fine gravel, and sand, (ii) silty or clayey gravel and sand, (iii) silty soils and (iv) clayey soils. It is pertinent to note that laterite soils do cut across the four defined types with the presence of clayey soil in any type.

Mustapha et al., (2014), Apeh et al., (2011) and Akije (2014) have successful utilized AASHTO (2002) soil classification system and the Unified Soil classification system (USCS) of ASTM (2002) to classify and determine strength in addition to permeability of laterite soils successfully. Garber (2010) claimed that the most commonly used soils classification system for highway purposes is the American Association of State Highway and Transportation Officials (AASHTO) Classification System whilst the Unified Soil Classification System (USCS) also is used to a lesser extent and a slightly modified version of the USCS is being used fairly extensively in the United Kingdom.

The aim of this research is to compare and contrast the use of Powermax cement and hydrated lime separately for the stabilization of A-6(10) laterite soil sample from a burrow pit in use for highway pavement. Specifically the objectives are:

1. To identify at optimum the better admixture when each one of them is used to stabilize A-6(10) laterite soil that will yield long-lasting subbase or basecourse material for highway pavement regarding strength and permeability.
2. To establish between the two stabilizers the one that will provide a cheaper stabilized subbase/basecourse material during the design and construction of the highway pavement.

The main scope of work in this study therefore includes obtaining laterite soil material from a burrow pit meant for the preparation of stabilized subbase/basecourse and subjecting it to physical and chemical laboratory tests. The significance of this study is in ensuring the reliability at optimum that the chosen stabilizer between the two admixtures will not quickly subject highway pavement surface to premature failure.

2. MATERIALS AND METHODOLOGY

Laterite soil sample used for this research work was collected from a burrow pit at Agbara in Ogun State of Nigeria which is within South-West Nigeria. The laterite soil was found in use for subbase of highway pavement of roads near the place. The material was collected, bagged and transported to the University of Lagos, department of Civil and Environmental Engineering Road and Transport laboratory for engineering and physico-chemical composition analysis. At the laboratory, small sample of the laterite soil was taken and put inside the oven for 24 hours in order to determine the moisture content. The remaining soil sample was air dried in preparation for further laboratory tests.

Powermax cement was purchased in 50 kg normal bag while hydrated lime bought in 25 kg at retail of using scale measurement inside a material shop and they were transported to the laboratory. Powermax premium technical cement used was
produced by Lafarge Cement WAPCO Nigeria Plc. According to Lafarge (2012) Powermax cement is designed and produced for high performance based upon consistent quality, high workability, excellent strength at all ages, lower heat of hydration, smoother surface finish, environmental friendly and conforms to NIS 444-1(2014). Powermax cement is described as normal strength N of cement type II as CEM II 42.5N designed for high grade users desirous of top performance.

Hydrated lime used is quicklime combined with enough water to produce \( \text{Ca(OH)}_2 . \text{MgO} \) or \( \text{Ca(OH)}_2 . \text{Mg}_2 \text{O} \). Quick lime is calcium oxide containing magnesium oxide in an amount as high as 40% or as low as 0.5 \( \% \text{CaO} \). Marotta (2005) claimed that both quick lime and hydrated lime are produced from burnt limestone of which the latter is more stable and therefore easier to store than the former which hardens upon contact with air. He concluded that lime is usually mixed with materials in quantities of 2% to 4% of aggregate weight.

In the laboratory, the scope of work on natural laterite soil material was limited to tests for the determinations of natural moisture content, mineral components, grain-size distribution, weight-volume relationships, relative density, Atterberg limits and classification. Stabilization of the laterite soil using Powermax cement and hydrated lime individually paved way for laboratory tests that included hydraulic conductivity, moisture-density relationships, California Bearing Ratio together with the mineral components of the admixtures. The defined laboratory tests here were carried out in conformity to both AASHTO and ASTM relevant standards.

Basic soil properties and classification for highway purposes are coupled with equations. Related equations are with phrases and there symbols that include volume of air \( V_a \), volume of water \( V_w \), volume of dry solids \( V_s \) total volume \( V \), mass of air \( M_a = 0 \), mass of water \( M_w \), Mass of solids \( M_s \), total mass \( M \). To define properties of soil in mass-volume and moisture-density relations the following equations are relevant.

- **Water content** \( w \):
  \[ w = \frac{M_w}{M_s} \]  
  \( (1) \)

- **Mass of solids** \( M_s \):
  \[ M_s = \frac{M}{1+w} \]  
  \( (2) \)

- **Density of water** \( \rho_w \):
  \[ \rho_w = \frac{M_w}{V_w} \]  
  \( (3) \)

- **Density** \( \rho \):
  \[ \rho = \frac{M}{V} \]  
  \( (4) \)

- **Relative density RD**:
  \[ RD = \frac{M_s}{V_s \times \rho_w} \]  
  \( (5) \)

- **Dry density** \( \rho_d \):
  \[ \rho_d = \frac{\rho_w \times RD}{1+(w \times RD)} \]  
  \( (6) \)

- **Dry density** \( \rho_d \):
  \[ \rho_d = \frac{M_s}{V} \]  
  \( (7) \)

Dry density \( \rho_d \), \( \rho_d = \frac{\rho}{1+w} \)  
\( (8) \)

**Void ratio** \( e \):
\[ e = \frac{V_v}{V_s} \]  
\( (9) \)

**Degree of saturation** \( S \):
\[ S = \frac{V_w}{V_v} \]  
\( (10) \)

**Porosity** \( n \):
\[ n = \frac{V_v}{V} \]  
\( (11) \)

Part of AASHTO soil classification is by defining basic types based on the grain sizes as shown in the table below for the purpose for defining soil constituents as both granular materials of coarse grain and silt-clay of fine grained soils and as the methodology used in this study.

**Table 1: AASHTO Soil Types Based On Grain Size**

<table>
<thead>
<tr>
<th>S/N</th>
<th>BASIC TYPE</th>
<th>GRAIN SIZE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Boulders</td>
<td>&gt; 75</td>
<td>mm</td>
</tr>
<tr>
<td>2</td>
<td>Gravel (Coarse, Medium and Fine)</td>
<td>75 - 2.0</td>
<td>mm</td>
</tr>
<tr>
<td>3</td>
<td>Sand (Coarse and Fine)</td>
<td>2.0 - 0.08</td>
<td>mm</td>
</tr>
<tr>
<td>4</td>
<td>Silt</td>
<td>0.08 - 0.002</td>
<td>mm</td>
</tr>
<tr>
<td>5</td>
<td>Clay</td>
<td>&lt; 0.002</td>
<td>mm</td>
</tr>
</tbody>
</table>

Garber (2010) presented a table on AASHTO classification of soils and soil aggregate mixtures to define same for use satisfactorily as subgrade or subbase if properly drained and well compacted. Also, the table could be used to define and classify soils that will require a layer of subbase material when used as subgrade. The soil classification in the table made use of sieve analysis of percent passing 2.0 mm, 0.425 mm and 0.075 mm to be useful to define soil basic types based upon the significant material constituents and general rating of the natural soil. It is pertinent to note that textural classification of soils based on grain size is not enough and so has to be combined with plasticity. Specifically, the characteristics of fraction passing 0.425 mm paved way for the determination of liquid limit \( LL \), plasticity index \( PI \) and group index \( GI \).

The group index \( GI \) is calculated from the following formula.

\[ GI = (F - 35)(0.2 + 0.05(LL - 40)) + 0.01(F - 15)(PI - 10) \]  
\( (12) \)

\( F \) = Percentage passing 0.074 mm sieve expressed as a whole; this percentage is based only on the material passing the 75 mm sieve.

\( LL \) = Liquid limit

\( PI \) = Plasticity index

\( PI = LL - PL \)  
\( (13) \)

\( PL \) = Plastic limit

The unconfined compression test was performed on the natural laterite and also after stabilizing same using Powermax cement
and hydrated lime individually at varying percentages of 6%, 8%, 10%, 12% and 14% by weight of the soil. The unconfined compression test was carried out in the laboratory in order to determine unconfined compressive strength $q_c$ and shear strength $\tau$ or cohesion based upon maximum load at failure $M$, and the corrected area at failure $A_r$. Value $A_r$ is based upon original area $A$ and axial strain $\varepsilon$, in terms of deformation $\Delta$ and original sample length $L_o$.

$$\varepsilon = \frac{\Delta}{L_o}$$

$$A_r = \frac{A}{1-\varepsilon}$$

$$q_c = \frac{M}{A_r}$$

$$\tau = \frac{q_c}{2}$$

The optimum moisture and maximum density for the laterite soil were found under dynamic compaction test in the laboratory by a series of determinations of wet unit weight and the corresponding moisture content. Initially with the soil in a damp condition, at moisture content of a few percent below optimum, the soil sample was compacted and the wet unit weight determined. A small sample was selected from the interior of the compacted soil mass in the mould for the determination of the moisture content. The soil was then broken up and the moisture content was increased by 2 percent whilst the compaction process was repeated. Similar process was continued until a decrease was noted in the unit weight thereby showing an excess of moisture content. After the moisture content determinations were completed the dry unit weights were calculated and plotted. The relationship between the dry unit weight, wet unit weight, and moisture content is given in Equation 5. Similar optimum moisture and maximum density were carried out in the laboratory on samples stabilized with Powermax cement and hydrated lime separately in proportion of 6%, 8%, 10%, 12% and 14% by weight of the soil.

The California Bearing Ratio CBR tests were carried out for the strength determination of the natural laterite soil sample and when same was subject to stabilization using Powermax cement and hydrated lime individually at both soaked and unsoaked situations. The weight of wet prepared laterite soil sample $W$ at natural or stabilized state compacted in a mould of volume $V$ was based upon the maximum dry density $MDD$ and optimum moisture content $OMC$ obtained from the related moisture-density relationship under Proctor dynamic compaction test.

$$W = MDD \times V \times (1 + OMC)$$

In the experiment the mould containing the compacted natural or stabilized soil along with the baseplate and collar fitted was placed on the CBR testing machine with plunger then seated and the motor started to give a rate of penetration of the specimen of 1 mm/minute. Readings of the force were taken at intervals of penetration of 0.25 mm up to a total of 5.00 mm penetration for both top and bottom tests. Small sample of soil was removed from about centre below the penetrated part of the mould and checked for moisture content. The CBR value was calculated at plunger penetrations of 2.5 mm average of top and bottom readings and also same of 5 mm and the higher value taken. For the CBR machine used 13.2 kN and 20.0 kN are standard loads at 2.5 mm and 5.0 mm penetration respectively. However, considering $x$ and $y$ as the loads at 2.5 mm and 5 mm penetration respectively then CBR value at mm penetration of plunger is as following.

The load at 2.5 mm of plunger penetration of $x$ load is

$$CBR \ value \ at \ 2.5 \ mm = \frac{x}{13.2} \times 10$$

(19)

Also, the load at 5 mm of plunger penetration of $y$ load is

$$CBR \ value \ at \ 5 \ mm = \frac{y}{13.2} \times 10$$

(20)

The falling head permeability test was used for the natural laterite soil and when stabilized with Powermax cement and hydrated lime. The sample for a particular specimen was prepared in a mould and saturated for 24 hours. The falling-head permeameter used allowed for the flow of water through a tube with cross-sectional area $A$, together with the prepared specimen which has a larger cross-sectional area $A$. The coefficient of permeability $k$ was computed on the basis of the observed rate at which the water level descended in the tube while the prepared specimen remained saturated. The coefficient of permeability of each of the prepared laterite soil at natural or stabilized state of 6%, 8%, 10%, 12% and 16% were calculated using the following equation.

$$\frac{2.3 \times 10^a \times \log_{10} \frac{H_1}{H_2}}{A(t_2 - t_1)}$$

(21)

In the above equation a is area of standpipe, $A$ is area of specimen, $t_1$ and $t_2$ are respectively initial and final times, $i$ is the specimen length, $H_1$ and $H_2$ are initial and final heads.

### 3. RESULTS ANALYSIS AND DISCUSSION

Table 2 shows the basic and engineering properties on the A-6(10) laterite soil defined by the laboratory test based upon AASHTO classification system. A group index value of the laterite soil of 10 is an indication that is a weak material in the soil group A-6.

Based on AASHTO classification system, Figure 1 shows the grain size analysis of the A-6(10) laboratory tested laterite soil. Since silty-clay materials in the soil is 68% which is greater than 35% further laboratory tests by Atterberg limits shows that the laterite is of mixed-grain material containing coarse and fine fractions. The results show that A-6(10) laterite soil will require a layer of subbase material or a stabilized soil as basecourse for highway pavement.

Table 3 shows the strength and permeability results of A-6(10) laterite soil and at 14% stabilization using Powermax cement.
and hydrated lime individually. It could be seen that the higher the optimum moisture content the lower the maximum dry density. The value of the unsoaked CBR of the natural A-6(10) laterite soil is greater than that of the soaked one. Whereas the value of the soaked CBR for the A-6(10) laterite soil stabilized at maximum of 14% with Powermax cement and hydrated lime individually is greater than that of the unsoaked. At 14% optimum stabilization of A-6(10) laterite soil with Powermax cement and hydrated lime individually, the percent increase of shear strength to the natural laterite soil each is 192% and 132% respectively showing strength improvement for the road pavement. The permeability of the A-6(10) laterite soil decreased as the soil was stabilized individually with Powermax cement and hydrated lime individually as coefficient of permeability k changed from $1 \times 10^{-5}$ to $1 \times 10^{-6}$.

In Table 4, mineral components of the A-6(10) laterite soil, Powermax cement and hydrated lime are shown. The major principal components in A-6(10) laterite soil, Powermax cement are SiO$_2$ and Al$_2$O$_3$, while that of hydrated lime is CaO as shown in Figure 2. It is obvious in Table 4 that Powermax cement constituents are similarly like that of A-6(10) laterite soil while hydrated lime components are not similar to them.

Variations of uncured and cured UCS to strain of the A-6(10) laterite soil stabilized with Powermax cement at varying percentages of 0%, 6%, 8%, 10% 12% and 14% are in Figures 3 and 4. The maximum value at 14% for the uncured UCS is 112 kN/m$^2$ at the strain of 2.8. On the other hand, the maximum value at 14% for the cured UCS is 171 kN/m$^2$ at the strain of 3. Also, the variations of uncured and cured UCS to strain of the A-6(10) laterite soil stabilized with hydrated lime at varying percentages of 0%, 6%, 8%, 10% 12% and 14% are in Figures 5 and 6. The maximum value at 14% for the uncured UCS is 63 kN/m$^2$ at the strain of 2. On the other hand, the maximum value at 14% for the cured UCS is 124 kN/m$^2$ at the strain of 2.4. Figure 7 shows the variation of uncured and cured shear strength of the A-6(10) laterite soil stabilized with Powermax cement and hydrated lime at 14%. It is obvious in Figure 7 that at 14% A-6(10) cured laterite soil-hydrated lime stabilization the value of UCS is higher than that of 14% uncured A-6(10) laterite soil stabilized with Powermax cement. However, the use of hydrated lime could not be encouraged as an option compared to Powermax cement when basecourse will not be subjected wet environment. This is because the uncured 14% A-6(10) laterite soil-hydrated lime has a value of UCS as 62 kN/m$^2$ at the strain of 2, whereas the uncured 14% A-6(10) laterite soil-Powermax cement has a value of UCS as 112 kN/m$^2$ at the strain of 2.8.

In Figure 8 variation of uncured and cured shear strength of the A-6(10) laterite soil stabilized with Powermax cement and hydrated lime individually are shown. It is obvious that the difference in uncured shear strength of A-6(10) stabilized with Powermax cement and hydrated lime individually is wider than for cured of same.

The variations of optimum moisture content of the A-6(10) laterite soil stabilized with Powermax cement and hydrated lime individually at varying percentages of 0%, 6%, 8%, 10% 12% and 14% are shown in Figure 9. Also, Figure 10 depicts the variation of maximum dry density of the A-6(10) laterite soil stabilized with Powermax cement and hydrated lime separately at varying percentages of 0%, 6%, 8%, 10% 12% and 14%. It can be deduced from the two figures that as the admixture percentage of stabilization is increasing, the higher lower value of optimum moisture content the lower the maximum dry density.

Table 2: Basic and Engineering Properties of the selected laterite soil

<table>
<thead>
<tr>
<th>S/N</th>
<th>Properties</th>
<th>Laterite Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water Content, %</td>
<td>34.800</td>
</tr>
<tr>
<td>2</td>
<td>Bulk Density, Mg/m$^3$</td>
<td>1.945</td>
</tr>
<tr>
<td>3</td>
<td>Dry Density, Mg/m$^3$</td>
<td>1.556</td>
</tr>
<tr>
<td>4</td>
<td>Specific Gravity</td>
<td>2.700</td>
</tr>
<tr>
<td>5</td>
<td>Void Ratio</td>
<td>0.692</td>
</tr>
<tr>
<td>6</td>
<td>Porosity, %</td>
<td>0.409</td>
</tr>
<tr>
<td>7</td>
<td>Degree of Saturation, %</td>
<td>0.854</td>
</tr>
<tr>
<td>8</td>
<td>Liquid Limit (LL)</td>
<td>39.720</td>
</tr>
<tr>
<td>9</td>
<td>Plastic Limit (PL)</td>
<td>23.960</td>
</tr>
<tr>
<td>10</td>
<td>Plasticity Index (PI)</td>
<td>15.760</td>
</tr>
<tr>
<td>11</td>
<td>Sieve analysis, percent passing 0.075 mm</td>
<td>68.050</td>
</tr>
<tr>
<td>12</td>
<td>Group Index</td>
<td>10</td>
</tr>
<tr>
<td>13</td>
<td>AASHTO Soil Classification</td>
<td>A-6(10)</td>
</tr>
</tbody>
</table>
Figure 1: Grain size analysis of the A-6(10) natural laterite soil sample

Table 3: Strength and permeability results of A-6(10) laterite soil and at optimum 14% admixture stabilization

<table>
<thead>
<tr>
<th>S/N</th>
<th>Label</th>
<th>A-6(10) Laterite Soil</th>
<th>14% Laterite Soil- Powermax Cement</th>
<th>14% Laterite Soil-Hydrated Lime</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Optimum Moisture Content (OMC) %</td>
<td>19.3</td>
<td>16.5</td>
<td>18.1</td>
</tr>
<tr>
<td>2</td>
<td>Maximum Dry Density (MDD), Mg/m³</td>
<td>1.548</td>
<td>1.68</td>
<td>1.603</td>
</tr>
<tr>
<td>3</td>
<td>California Bearing Ratio (CBR) unsoaked, %</td>
<td>27.87</td>
<td>138.5</td>
<td>53.75</td>
</tr>
<tr>
<td>4</td>
<td>California Bearing Ratio (CBR) soaked, %</td>
<td>15.9</td>
<td>220</td>
<td>41.25</td>
</tr>
<tr>
<td>5</td>
<td>Uncured Unconfined Compressive Strength, kN/m²</td>
<td>129.89</td>
<td>559.246</td>
<td>314.359</td>
</tr>
<tr>
<td>6</td>
<td>Uncured Shear Strength, kN/m²</td>
<td>64.947</td>
<td>279.623</td>
<td>157.18</td>
</tr>
<tr>
<td>7</td>
<td>Cured Unconfined Compressive Strength, kN/m²</td>
<td>469.196</td>
<td>898.88</td>
<td>621.181</td>
</tr>
<tr>
<td>8</td>
<td>Cured Shear Strength, kN/m²</td>
<td>234.598</td>
<td>449.44</td>
<td>310.591</td>
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<tr>
<td>9</td>
<td>Coefficient of Permeability, k cm/s</td>
<td>1.00E-05</td>
<td>1.00E-06</td>
<td>1.00E-06</td>
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</tbody>
</table>

Table 4: Mineral components of the A-6(10) laterite soil, Powermax cement and hydrated lime

<table>
<thead>
<tr>
<th>S/N</th>
<th>Mineral (%)</th>
<th>Laterite Soil</th>
<th>Powermax Cement</th>
<th>Hydrated Lime</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>SiO₂</td>
<td>61.58</td>
<td>64.01</td>
<td>0.006</td>
</tr>
<tr>
<td>2</td>
<td>Al₂O₃</td>
<td>33.91</td>
<td>32.22</td>
<td>0.001</td>
</tr>
<tr>
<td>3</td>
<td>K₂O</td>
<td>0.18</td>
<td>0.049</td>
<td>0.003</td>
</tr>
<tr>
<td>4</td>
<td>Na₂O</td>
<td>0.21</td>
<td>0.053</td>
<td>0.004</td>
</tr>
<tr>
<td>5</td>
<td>CaO</td>
<td>1.42</td>
<td>1.82</td>
<td>5.298</td>
</tr>
<tr>
<td>6</td>
<td>FeO</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>7</td>
<td>Fe₂O₃</td>
<td>0.051</td>
<td>0.017</td>
<td>ND</td>
</tr>
<tr>
<td>8</td>
<td>MgO</td>
<td>0.74</td>
<td>0.7</td>
<td>0.15</td>
</tr>
<tr>
<td>9</td>
<td>TiO₂</td>
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<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>10</td>
<td>P₂O₅</td>
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<td>ND</td>
<td>ND</td>
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<tr>
<td>11</td>
<td>MnO</td>
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<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>12</td>
<td>Cadmium (Cd)</td>
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<td>ND</td>
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<tr>
<td>13</td>
<td>Copper (Cu)</td>
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<td>0.001</td>
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<tr>
<td>14</td>
<td>Manganese (Mn)</td>
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<td>0.002</td>
<td>0.002</td>
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<tr>
<td>15</td>
<td>Nickel (Ni)</td>
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<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>16</td>
<td>Lead (Pb)</td>
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<td>ND</td>
<td>ND</td>
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<tr>
<td>17</td>
<td>Iron (Fe)</td>
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<td>0.012</td>
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<tr>
<td>18</td>
<td>Zinc (Zn)</td>
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<td>ND</td>
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</tr>
<tr>
<td>19</td>
<td>Aluminum (Al)</td>
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<td>17.95</td>
<td>0.001</td>
</tr>
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<td>20</td>
<td>pH</td>
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<td>13.57</td>
<td>13.61</td>
</tr>
<tr>
<td>21</td>
<td>SO₄²⁻</td>
<td>40</td>
<td>570</td>
<td>140</td>
</tr>
<tr>
<td>22</td>
<td>Cl⁻</td>
<td>80</td>
<td>640</td>
<td>2380</td>
</tr>
</tbody>
</table>

Figure 2: Comparison of three major oxides of A-6(10) laterite soil, Powermax cement and hydrated lime
Figure 3: Variation of uncured UCS to strain of the A-6(10) laterite soil stabilized with Powermax cement at varying percentages

Figure 4: Variation of cured UCS of the A-6(10) laterite soil stabilized with Powermax cement at varying percentages

Figure 5: Variation of uncured UCS of the A-6(10) laterite soil stabilized with hydrated lime at varying percentages
Figure 6: Variation of cured UCS of the A-6(10) laterite soil stabilized with hydrated lime at varying percentages

Figure 7: Variation of uncured and cured UCS of the A-6(10) laterite soil stabilized with Powermax cement and hydrated lime at 14% percent

Figure 8: Variation of uncured and cured shear strength of the A-6(10) laterite soil stabilized with Powermax cement and hydrated lime

Figure 9: Variation of optimum moisture content of the A-6(10) laterite soil stabilized with Powermax cement and hydrated lime

Figure 10: Variation of maximum dry density of the A-6(10) laterite soil stabilized with Powermax cement and hydrated lime
4. CONCLUSIONS AND RECOMMENDATIONS

Basic soil properties, Atterberg limits tests, grain size analysis, Proctor compaction tests, California bearing ratio tests, permeability tests and physico-chemical composition tests were carried out on a natural laterite soil sample. The soil sample was further tested in the laboratory by chemical stabilization using Powermax cement and hydrated lime individually in percent of 6%, 8%, 10%, 12% and 14% for strength and permeability tests. The following are the conclusions and recommendations in relation to this study.

1. By American Association of State and Highway Transportation Officials (AASHTO) system of soil classification, the selected laterite soil sample has been classified in this study as A-6(10) based upon basic and engineering properties of the soil as shown in Table 2.

2. The soil sample classified as A-6(10) is clayey soil that is poor as subgrade material for highway pavement.

3. The laboratory determination of mineral components showed that A-6(10) laterite soil and Powermax cement constituents values are similar, having majorly $SiO_2$ and $Al_2O_3$ respectively at 61.5% and 33.91% for former and 64.01% and 32.22% for the latter. Hydrated lime major oxide material is $CaO$ with constituent value at 52.98%. Oyekan and Oyelade (2012) determined Burnham cement for having $CaO$ and $SiO_2$ as major oxide materials at 62.32% and 18.72% respectively.

4. Based upon compression strength tests, the shear strengths of cured and uncured stabilized A-6(10) laterite soil-Powermax cement test specimens as well as those of stabilized A-6(10) laterite soil-hydrated lime test specimens are all increasing with age as shown in Figure 8.

5. CBR value of soaked stabilized A-6(10) laterite soil-hydrated lime test specimens is 74% that is lower than 80% at its optimum of 8% of the stabilizer and hence failed to satisfy AASHTO standard recommendation. However, considering AASHTO standard recommendation of 7% maximum stabilization, the soaked and unsoaked stabilized A-6(10) laterite soil-Powermax cement test specimens CBR values are 173% and 85% respectively and therefore satisfactory.

6. Hydrated lime is not recommended for the stabilization of A-6(10) laterite soil as basecourse for sustainability of highway pavement. However, Powermax cement is recommended for the stabilization of A-6(10) laterite soil as for the improvement of the subbase or basecourse materials for sustainability and long term strength attainment of highway pavement.

REFERENCES


