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**Research Paper**

# Effect of *Prosopis Africana* Pod Ash on Cement-Stabilized Laterite

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***ABSTRACT:*** *Lateritic soil (LS) sample collected from Naka area of Benue State, classified as A-2-7 (9) soil according to AASHTO classification, was stabilized with 2%, 4%, and 6% cement by weight of the soil. Using British Standard Heavy (BSH) compaction energy, the effect of Prosopis Africana pod ash (PAPA) on the soil was investigated with 20% and 40% by weight addition of the PAPA on each of the cement percentage additions with respect to compaction characteristics. The test results reveal that, the addition of Prosopis Africana pod ash on cement stabilized laterite reduces liquid limit, plastic limit, linear shrinkage and plasticity index. In terms of the compaction and strength properties, it decreases maximum dry density (MDD), increases optimum moisture content (OMC) and increases California bearing ratio (CBR) respectively, with optimum improvement recorded at 14% Prosopis Africana pod ash and 6% cement and hence recommended for use in stabilization of marginal lateritic soils.*

***KEYWORDS:*** *Prosopis Africana Pod Ash (PAPA), Stabilization, optimum moisture content (OMC), California bearing ratio (CBR), Maximum Dry Density (MDD), Atterberg Limits.*

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## I. INTRODUCTION

Materials and highway engineers are confronted with the challenges of providing suitable materials for highway and other foundations construction. Efforts have been made to overcome the problem through importation of suitable materials from other locations but has led to another problem of high cost of road construction [1] with laterite used as one of the materials for road construction, which is readily available in tropical countries and sub-tropical regions of the world such a Nigeria [2],[3]. In most cases, these laterites found in Nigeria contain clay which stabilizing it to meet the required objective for use in construction makes it cheaper than sourcing for another material [4]. Stabilization is one of the feasible ways through which the engineering properties of soils could be improved for it to withstand the expected loads. Soil stabilization is a means of soil treatment by adding modifiers like cement, lime etc, to improve the strength and durability of the soil so as to make it suitable for construction [5].

Researchers like Ford [5], confirmed that lateritic soil is mainly, but not exclusively, available as a residual weathering product on wholly or partially decomposed basalts and other basic to intermediate igneous rocks. The particle-size characteristics, the nature and strength of the gravel particles, the degree to which the soils have been compacted, as well as the traffic and environmental conditions, has been found to be the main factors that determine how lateritic soil perform in pavement structure. However, what limits their usefulness as pavement materials on roads with heavy traffic is their tendency to be gap graded with depleted sand-fraction, to contain variable quantities of fines, and to have coarse particles of variable strength, which may break down. Such lateritic materials normally require treatment with additives in order to overcome the deficiencies associated with them [1, 6, 7].

Conventional materials that have been traditionally used for stabilization of deficient or marginal soils includes stabilizers like Lime, cement, bitumen or other combinations, due to an increasing cost of these stabilizers with an ever-increasing construction work in the tropical regions, it has become imperative to substitute the stabilizers with local additives [8]. The conventional materials have been used effectively in lateritic soil stabilization to alter the microstructure of the lateritic soils and thereby improve their engineering properties [9]. Recently, industrial and agricultural waste such as rice husk and other pozzolanic materials have been found useful in lateritic soil improvement or stabilization [6]. The use of industrial or agricultural waste for soil stabilization evolved out of the need to economically utilize by-products of agricultural processes which are often of undesirable environmental effects. Such full spectrum of biomass materials that are produced as by-products from agro-allied activities include; *Prosopis Africana* pod, rice and wheat husks, maize cobs, cassava stems, coconut shells, etc.

Today, supplementary cementing materials are widely used as pozzolanic materials in stabilized laterites to improve strength, reduce permeability and improve the durability of the soil. A pozzolan comprises siliceous materials and when combined with Calcium Hydroxide ($Ca(OH)_2$), exhibits cementitious properties depending on the constituents of the pozzolan. The basis of pozzolanic reaction is a simple acid base reaction between Calcium Hydroxide, ($Ca(OH)_2$) and Silicon Hydroxide ($Si(OH)_4$). The chemistry is shown in the equation below.

$$(Ca(OH)_2) + (Si(OH)_4) \rightarrow Ca_2^{2+} + H_2SiO_4^{2-} + 2H_2O \rightarrow CaH_2SiO_4.2H_2O \quad (1)$$

Where $CaH_2SiO_4.2H_2O$ is the gel that is cementitious in nature [10].

Many researchers have examined the possibility of improving the engineering properties of marginal soils with use of agricultural wastes ash in combination with the conventional stabilizing agents. Akinloye and others [11], assessed the effect of lime-guinea Corn Husk Ash (GHA) on engineering properties of lateritic soil and found that, the lateritic engineering properties were greatly improved with a general decrease in Maximum Dry Density (MDD) and increase in Optimum Moisture Content (OMC) at increasing percentages of the Lime-GHA. Alhassan [6], reported a decrease in coefficient of permeability and an increase in UCS with corresponding increase in Rice Husk Ash (RHA) content at specified lime content. Adama and others, [12] found that, the use of locust bean pod ash and cement as a stabilizing agent on weak subgrade soil reduces maximum density and increases optimum moisture content and hence improves compaction properties of the soil. Basha and others [13], investigated the effect of the Rice Husk Ash (RHA) content on cement stabilized residual granite soil and recorded a decrease in plasticity of the soil and increase in Optimum Moisture Content with increased RHA content at specified cement with optimum values at 6-8% cement and 10-15% RHA

Cement and lime has been considered as the major materials used for stabilizing weak soils over the years, however, there has been a rapid increase in the cost of the stabilizing material due to increase in the number of construction works and significant increase in cost of energy since 1970s, which call for substitution of the stabilizers with additives. Disposal of various agricultural wastes has also been a problem over time [14]; [1]. Therefore, investigating the suitability of using *Prosopis Africana* Pod Ash (PAPA) as a substitute in stabilization increases the number of possible agricultural wastes that can be used as substitutes to reduce the cost of stabilized roads and also addresses the disposal problems associated with *Prosopis Africana* pod wastes. The primary aim of this study is to investigate the stabilization effects of *Prosopis Africana* pod ash (PAPA) and cement on marginal lateritic soil.

## II. MATERIALS AND METHODS

### 2.1 Materials

The materials used in this study were locally sourced from Benue State of Nigeria.

#### 2.1.1 Lateritic Soil

The lateritic soil was obtained from Naka (Latitude 7°37'55.6''N, Longitude 8°12'59.6''E), a distance of 42 km from Makurdi, the capital of Benue State of Nigeria along Makurdi-Ankpa road.

The identified soil is reddish brown and its classification was done using AASHTO soilclassification. The particle size distribution curve of the natural lateritic soil (LS) is shown in Figure1 which contains 37.2% gravel, 61.4% sand and 1.4% silt/clay particles, while Table 1 presents the properties of the soil.

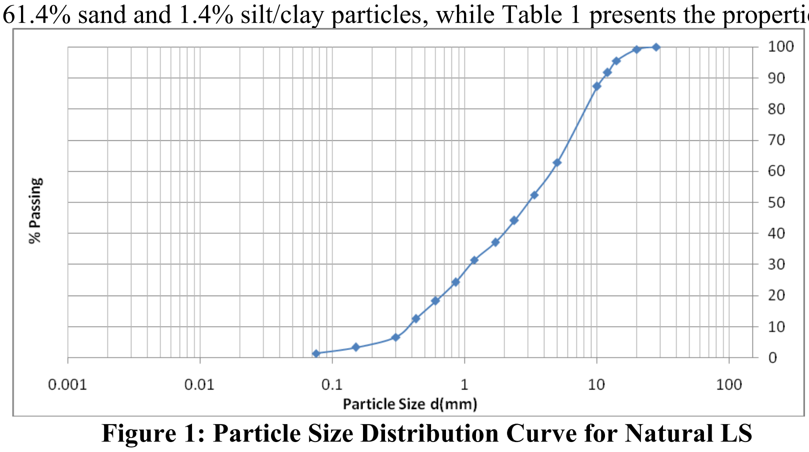


**Figure 1: Particle Size Distribution Curve for Natural LS**

**Table 1: Properties of the Natural laterite**

| Property | Description |
|---|---|
| ***Physical properties*** | |
| Colour | Reddish Brown |
| Natural Moisture Content | 6.52% |
| Plastic Limit | 28 % |
| Liquid Limit | 47% |
| Plastic Index | 19% |
| Linear Shrinkage | 10.47% |
| Specific gravity | 1.67 |
| AASHTO classification | A-2-7 (9) |
| % Passing BS Sieve 200 | 1.41% |
| ***Particles*** | |
| gravel | 37.2% |
| sand | 61.4% |
| Silt and clay | 1.4% |
| ***Compaction properties*** | |
| OMC (%) | 12.5% |
| MDD | 2.22 $Mg/m^3$ |
| ***Strength property*** | |
| CBR | 22% |

### 2.1.2 *Prosopis Africana* Pod Ash (PAPA)

*Prosopis africana* (Iron tree) is a popular tree in Sub-Saharan Africa with all the parts used for food and medicinal purposes. *Prosopis Africana* pod (Iron tree pod) which is shown in plate 1 is the fruit pod of the tree that houses its seeds. Once the seeds are removed from the pod, it becomes an agricultural waste *Prosopis Africana* tree (see plate 2) [15]. The Ash of the *Prosopis Africana* pod (Iron tree pod) was obtained by incineration of *Prosopis Africana* pod at temperature above 500°C, which was then sieved through sieve 75µm to have particle size in close range with cement before usage. The chemical properties of the *Prosopis Africana* pod ash (PAPA) are shown in Table 2.

**Plate 1: *Prosopis african*a pods [16]**

**Plate 2: Prosopis africana waste pod [16]**

**Table 2: Chemical properties of *Prosopis Africana* Pod Ash**

| Compound | Concentration Unit (%) |
|---|---|
| $SiO_2$ | 36.27 |
| $Al_2O_3$ | 3.73 |
| $P_2O_5$ | 2.77 |
| $SO_3$ | 5.59 |
| CaO | 28.27 |
| MgO | 3.88 |
| $Na_2O$ | 0.30 |
| $K_2O$ | 55.58 |
| $TiO_2$ | 0.32 |
| MnO | 0.45 |
| $Fe_2O_3$ | 1.95 |
| SrO | 0.05 |
| Cl | 0.59 |

#### 2.1.3 Cement

Ordinary Portland Cement obtained from the general market in Makurdi which is produce by Dangote cement was used for the work.

### 2.2 Laboratory tests

#### 2.2.1 Atterberg Limits test

Determination of the Atterberg consistency limits was done in accordance with the British Standard methods – BS 1377: part 2 [17]. The lateritic soil was sieved through 425 mm and the materials that passed through the pores were used for the test, those retained were rejected. The soil was oven dried for at least 2 hours before the test. Different proportions of cement and *Prosopis Africana* pod ash (PAPA) were used on the soil to carry out the test.

#### 2.2.2 Compaction Test

Proctor compaction test was carried out in line with BS 1377 part 4 [17] to determine the optimum moisture content (OMC) and maximum dry density (MDD) of the soil. The first series of compaction was carried out on the natural soil to determine its compaction properties. The compaction was further carried out with different percentages of *Prosopis Africana* pod ash (PAPA) and cement admixtures on the soil. The compaction process was carried using the British standard heavy (BSH) compacting effort specified for road construction works.

#### 2.2.3 California bearing ratio test

The California Bearing Ratio (CBR) test is an empirical test which indicates the shear strength of a soil sample [18]. The tests were carried out on samples prepared at optimum moisture content (OMC) and compacted with 4.5 kg mechanical rammer into 5 layers, giving 62 blows on each layer. The compacted samples were tested after 7days of moist curing for un-soaked CBR and then tested again after being soaked in water for 7 days for the soaked CBR. From the test result, an arbitrary coefficient CBR was calculated by expressing the forces on the plunger for a given penetration of 2.5 mm and 5 mm as a percentage of the standard force according to BS 1377 part 4 [17].

## III. RESULTS AND DISCUSSION

### 3.1 Specific Gravity

The specific gravity of the soil is the ratio of the unit weight of a given material to the weight of water [10]. From the result, the specific gravities of lateritic soil (LS), PAPA and cement alone are 2.665, 2.00 and 3.145 respectively. The specific gravity of the stabilized material increased as the quantity of cement increased in the mix from 2% to 6% and decreases as the quantity of ash increases in the mix with a peak value of 2.530 at LS + 14% PAPA + 6% C mix.This might be as a result of the high margin between the specific gravity of cement and that ofash. The stabilization generally lowered the specific gravity of the parent lateritic soil material. The trend of the changes in the specific gravity of the natural soil due to the various percentagesof the admixture is shown in Figure 2.

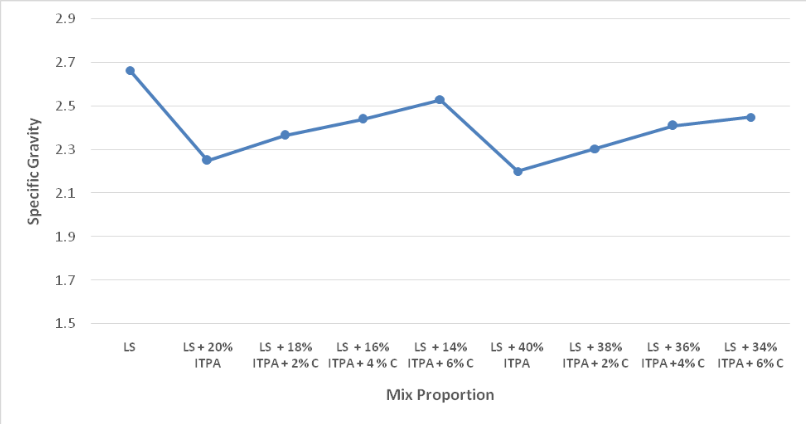


Figure 2: Trend of Specific Gravity Variations of various PAPA-Cement Mixes on LS

### 3.2 Atterberg limits test

The trends of the results of the consistency limits of the lateritic soil (LS) blended with different percentages of PAPA and cement is shown in Figure 3. The results of the treated soil showed that the liquid limit and plastic limit decreases as the PAPA and cement content increases from 2% to 6%. Thenatural soil has liquid and plastic limits of 47% and 28% respectively. These decreased to about 25% and 17% with addition of 14% PAPA + 6% cement respectively. Decrease in the liquid and plastic limits are indication of improvement on the engineering properties of the soil. This is consistent with the views of Uche and Ahmed [8] on changes of the liquid and plastic limitsof engineering soil. The reduction in plastic and liquid limits is accompanied with corresponding decrease in the plasticity index and linear shrinkage of the soil.

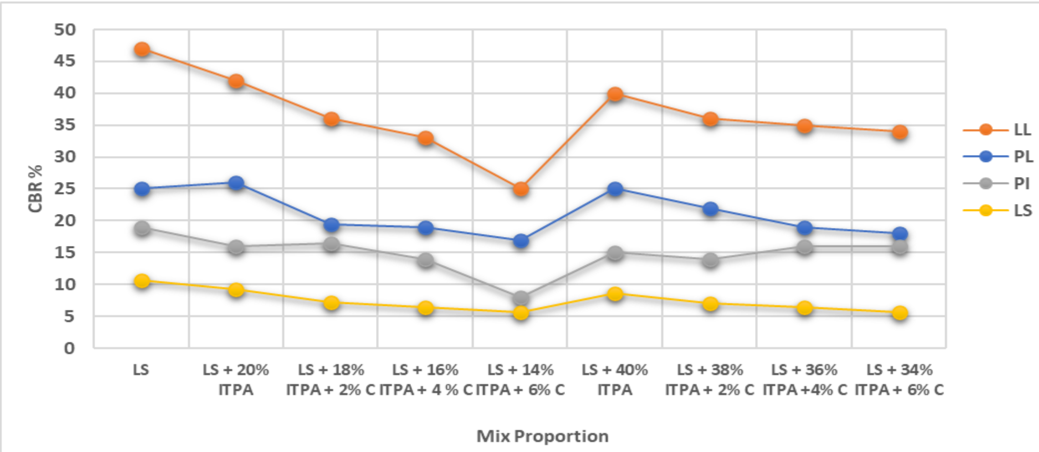


Figure 3: Trends of variations in consistency limits of various PAPA-Cement mixes on LS

### 3.3 Compaction Characteristics

The compaction test result shows a decrease in Maximum Dry Density (MDD) of the *Prosopis Africana* pod ash – cement stabilized laterite with a corresponding increase in the Optimum Moisture Content (OMC) as the cement content increases from 2-6% for the various mixes. The MDD decreased from 2.22 mg/m$^3$ to 1.64 mg/m$^3$ while the OMC increased from 12.5% to 24%. The increase in moisture content can be attributed to moisture content required for hydration of cement and pozzolanic reaction of the ash [1]. It may also be attributed to increased surface area due to increase in ash and cement content [8]. The probable reason for the decrease in MDD may be due to the production of cation exchangereaction between PAPA and the soil minerals which resulted in the flocculated and agglomerated clay particles. The particles occupied larger spaces that led to a corresponding decrease in dry density [8]. The trend of the changes in OMC and MDD against the various percentages of PAPA and cement mixes on lateritic soil (LS) is shown in Figure 4 and Figure 5 respectively while the combined compaction curves of the various mixes are shown in Figure 6

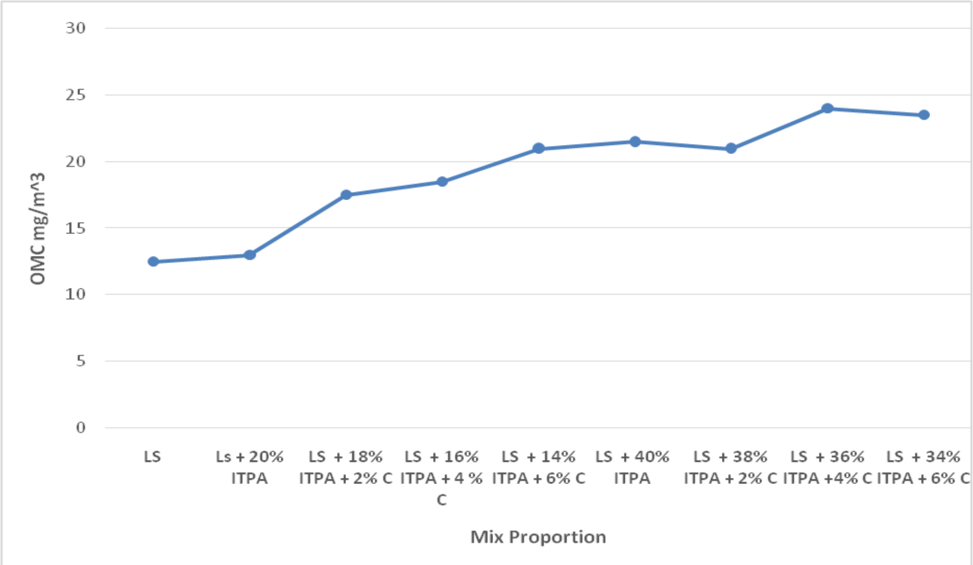

Figure 4: Trend of variations in OMC of various PAPA-Cement mixes on LS

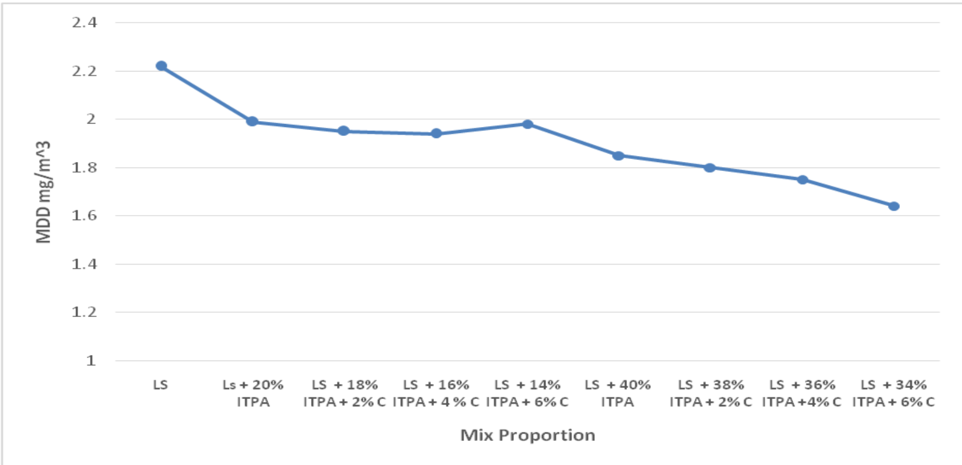


Figure 5: Trend of variations in MDD of various PAPA-Cement mixes on LS

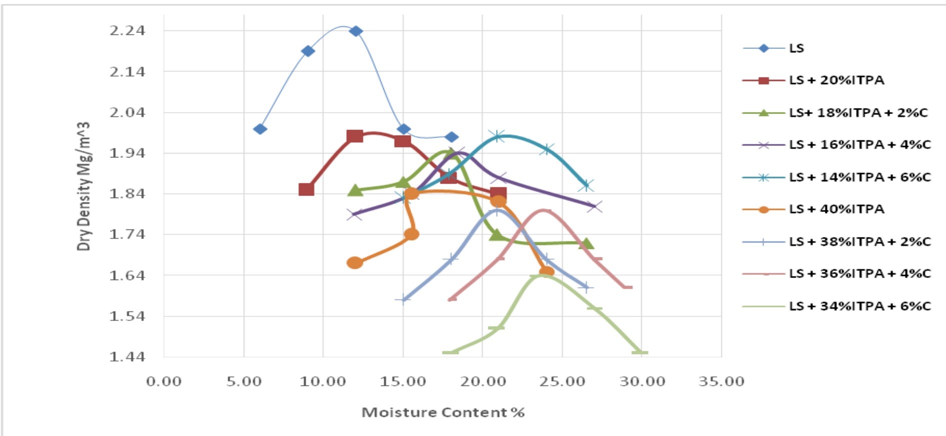


Figure 6: Compaction curves for the various PAPA – cement mixes on LS

### 3.4 California Bearing Ratio (CBR)

The trend of the various changes in CBR against different PAPA-cement proportions is shown in Figure 7. For un-soaked samples, CBR values of the natural soil increases from 22% to a peak of 60.9% at

14% PAPA + 6% C additive and drastically reduces to 38.5% at 40% PAPA additive and then increases gradually on replacement with cement from 2-6%. The soaked CBR also follows the same trend but with reduced values at 20.2% of the natural soil to 60.1% at 14% PAPA + 6% C and down to 36.7% at 40% PAPA additive. The increment in the CBR withthe addition of the additive can be attributed to the gradual formation of cementitious compounds between the PAPA and $Ca(OH)_2$ produced by hydration of cement. The sudden decrease in the CBR from the peak due to addition of 40% PAPA may be due to excess PAPA that was not mobilized in the reaction, which consequently occupies spaces within the sample and therefore reduces bond in the soil-PAPA mixtures. This conforms with the work of Basha *and others*, [13].

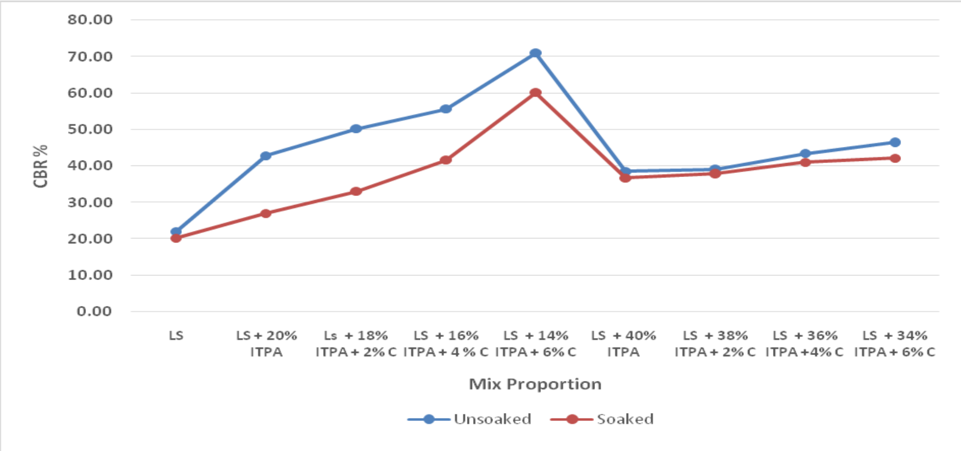


Figure 7: Trend of variations in soaked and un-soaked CBR values of various PAPA-cement mixes on LS

## IV. CONCLUSIONS

The result of the experimental investigation into the stabilization effects of *Prosopis Africana* pod ash (PAPA) and cement on natural lateritic soil have been presented and the following conclusions are drawn;

i. The natural soil is classified as A-2-7 (9) based on AASHTO classification, and hence identified with good properties for use as subgrade material but weak properties for use as subbase or base material for flexible pavement and hence require stabilization.

ii. The addition of PAPA (20% to 40%) with 2% to 6% replacement with cement in lateritic soil improves the index (Atterberg Limits) properties of the soil with optimum improvement at 14% PAPA + 6% cement where the liquid limit decreases from 47% to 25%, plastic limit decreases from 28% to 17%, plastic index decreases from 19% to 8% and linear shrinkage decreased from 10.7% to 5.7%.

iii. The addition of PAPA (20 - 40%) with 2-6% replacement with cement caused general increase in Optimum Moisture Content (OMC) along with a general decrease in Maximum Dry Density (MDD) of compaction with BSH compacting effort. The OMC increased from 12% to 21% while MDD decreased from 2.22 mg/$m^3$ to 1.98 mg/$m^3$ at addition of 14% PAPA and 6% cement to the soil.

iv. The un-soaked and the soaked CBR of the natural soil improved from 22% to 71% and 20 to 60% respectively, which is about 70% improvement in strength of the soil at the addition of 14% PAPA + 6% Cement and makes it suitable for use as sub base material according to the Nigerian General Specification for Pavement Materials [19], which specifies minimum CBR of 35% and 80% for sub base and base material respectively.

v. The PAPA underwent a pozzolanic reaction due to the presence of $SiO_2$.$Fe_2O_3$ and $Al_2O_3$ that induced cementitious properties which led to the improvement in the engineering properties of the soil.

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