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A comparative study of the stabilization of two lateritic soils from South-western Nigeria for highway pavement using Palm Bunch Ash (PBA)

Apata AC[1], Etuke JO[2], Imoh UU[3], Busari UB[4]

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Author Affiliation:
[1]Department of Civil Engineering, University of Lagos, Nigeria
[2]Department of Civil Engineering, Delta State University, Nigeria
[3]Department of Civil Engineering, Akwa Ibom State University, Nigeria
[4]Department of Civil Engineering, University of Lagos, Nigeria

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ABSTRACT

The failure of Nigerian roads can be attributed to poor geotechnical properties of the underlying soils which constitute the entire road pavement. Road accidents which are a consequence of road failure continuously lead to the loss of lives and properties are increasingly becoming a major concern due to bad roads. The performance of highway pavement, particularly flexible pavement, is determined by the roles of the pavement layers, particularly the subgrade and subbase, which offer support to the pavement. One of the major reasons for continual road failures in Nigeria is the lack of investigation of the underlying geology during design and construction. The insufficient comprehension of the properties and behaviour of residual soils alongside wear from road usage, use of substandard construction materials, lack of maintenance, and non-conformity to design specifications contribute to the failure of Nigerian highways. Expansive clay minerals present in the subgrade are one of the components of the soil that cause highway failure. This menace can be solved by stabilizing the soil either using cement, lime, or other stabilizing agents. Researchers are motivated to look for other viable materials to serve as replacements or additives for conventional stabilizing agents owing to high costs in the use of stabilizer like cement and lime. The production of cement which gives of CO_2 that adversely effects on the environment. Agricultural waste products and others are been examined as additives for soil stabilization. Examples are sawdust ash (SDA), pulverized rice husk (PRH), pulverized beans husk (PBH), crushed bone ash (CBA), rice husk ash (RHA), rice straw ash (RSA), bagasse ash (BA), corn cob ash (CCA), cassava waste ash (CWA), plantain leaf ash (PLA), coconut husk, banana fibres, coconut fibres etc. This paper studies the use of Palm Bunch ash (PBA) as a stabilizer. Two soil samples were collected at a depth of 750mm from two different locations, a sample each from each state namely; Ogun, and Osun in South-western Nigeria. They were examined for their geotechnical properties, and then stabilized in the proportion of 3, 6, 9, and 12perxcentages by weight of the soil samples.

Keywords: California Bearing Ratio, Index property, Lateritic Soil, Highway pavement, palm punch ash.

1. INTRODUCTION

The construction of buildings, bridges, dams, railways or highways need a foundation to stand upon, this foundation serves as the base through which the structure transmits its load to the earth. Therefore, it is very important that the soil is suitable and suffices for whatever purpose it is to serve else failure could occur and this could cause damages (Ameta et al., 2007).

Expansive soils cause damages every year to the tune of $1 billion in the USA, £150 million in the UK, and billions of pounds worldwide. (Firoozi et al., 2017). Ademila in 2018, attributed the failure of Nigerian roads to poor geotechnical properties of the underlying soils which constitute the entire road pavement. Road accidents which are a consequence of road failure continuously lead to the loss of lives and properties are increasingly becoming a major concern due to bad roads.

Whether the soil is suitable or not, it hinges on the following geotechnical criteria: the design load of the structure, the type of soil, and the bearing capacity of the soil. The type of soil and bearing capacity of the soil is dependent on the soil properties. In the past, if the soil was found to be insufficient in its ability due to its properties, one of the following would happen:

- The design of the structure would be altered so as not to exceed the bearing capacity of the soil.
- The in-situ soil would be removed and be replaced with new better material
- The site would be abandoned.

Abandoning the site at times was pragmatic if the construction was a building and another site could be selected. However, for highway construction which spanned several miles and passed through different places, such an option was impractical. Removing and replacing the in-situ soil was more realistic however very expensive, thus engineers had to make do with the materials available. So, to make the soil suitable for use, it had to be stabilized.

Soil stabilization is the process of engineering base soils to alter geotechnical properties such as strength, stiffness, compressibility, permeability, swelling potential, water sensitivity, and volume change by various methods with the aim of increasing the soil's capacity to carry load and resistance to physical and chemical environmental stress with or without the use of admixtures. It is the improvement of soil as a construction material through a combination of physical and chemical methods for mass densification, cementation, and control of volume stability (Winterkorn and Pamukcu, 1991). It is the Geo-technical process of using stabilizing agents or binders (cementitious materials) to improve the engineering properties of soil such as density, shear strength while compressibility, settlement, and permeability are greatly reduced making it more stable and durable (Makusa, 2012).

Soil stabilization as a technique for improving soil properties predates recorded history. Soil stabilization has been around for about 5000 years. Research has shown that the use of lime-stabilised soil precedes ancient Egyptian and Mesopotamian civilizations. These civilizations along with the Roman and Greek empires also used lime-stabilized foundations for their roads. China and India have also employed the use of soil stabilization through the course of their history in constructing bridge footings and underground chambers, and masonry dams (McDowell, 1959).

Soil stabilization came to be of prominence in the US in the 1960s. Engineers were compelled to contemplate alternatives to the orthodox solution of replacing unsuitable soils with imported aggregates that had more suitable properties. The use of cement as a binder to aggregate soil particles to increase their strength and resistance to water then became more common and other methods of soil stabilization like lime and fly-ash followed. (Onyelowe and Ubachukwu, 2015)

Southwestern Nigeria is situated above the Pre-Cambrian complex, and when it is weathered, it results in lateritic soil (Rahaman; 1976 and 1988). Hence, the prevalent soil in southwestern Nigeria is lateritic. They are typically of high quality mechanically stable particle-size distribution, allowing them to function well as materials used in road building such as sub-base and base course (Thagesen, 1996). In general, they have an excellent reputation due to their strong strength, low compressibility, and availability. As far as road building materials are concerned, they are of high quality. Most of the time, in many parts of the world, the most dominant clay mineral in laterite is Kaolinite, a clay mineral with low swell-shrink properties. Laterite also contains lesser amounts of montmorillonite and illite. Montmorillonite is an expansive clay and using a lateritic soil containing it as sub-grade material for a pavement without proper stabilization can cause the failure of the highway pavement. (Adeyemi, 2002).

Soil stabilization refers to the use of various additives to modify soft soils having low strength and stiffness to make them suitable for use as an engineering material.

Soil stabilization is a standard technique that has been in widespread use in countries like the United States since 1960 with cement being used as a stabilizer. If an underlying soil meant for an engineering project was determined to be unstable and unsuitable for construction, it had to be removed and replaced with soil material of better geotechnical properties (Higgins, 2005). This solved the problem but was prohibitively expensive and it pushed engineers is to find less costly solutions to dealing with weak soil.

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Since the use of cement as a stabilizer took off in the 1960s, many other methods of stabilization have been developed. Substances like lime, fly-ash, blast furnace slags have also become conventional stabilizers. However, soil stabilization with cement and lime still carries significant costs, especially for highway constructions that span over long distances and require stabilization of subgrade, base course/sub-base.

Also, these stabilization methods had drawbacks, for instance, cement stabilization was good for increasing compressive strength and was favourable for cohesionless soil and soil with moderate cohesiveness but is not really effective on clay soils with high plasticity. Lime stabilization was most suitable for plastic clay but it was also lacking in stabilizing clay soils rich in sulphate. In addition, the effect of the production of cement on the environment was also a cause for concern (James and Pandian, 2016).

All these led to the investigation of waste products and agro-waste as viable alternatives or partial replacement to already established stabilizing agents or as additives that improve the performances of these agents. Materials like sawdust ash (SDA), pulverized rice husk (PRH), pulverized beans husk (PBH), crushed bone ash (CBA), rice husk ash (RHA), rice straw ash (RSA), bagasse ash (BA), corn cob ash (CCA), cassava waste ash (CWA), plantain leaf ash (PLA), coconut husk, banana fibres, coconut fibres, and broken glass have been extensively studied for this purpose. This study will be focusing on the effectiveness of palm bunch ash (PBA) as a stabilizer for lateritic soils for highway subgrade and sub-base/ base course.

(a)

(b)

Collecting Ogun soil sample

(a)

(b)

Collecting Osun soil sample

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2. MATERIAL

Lateritic soil

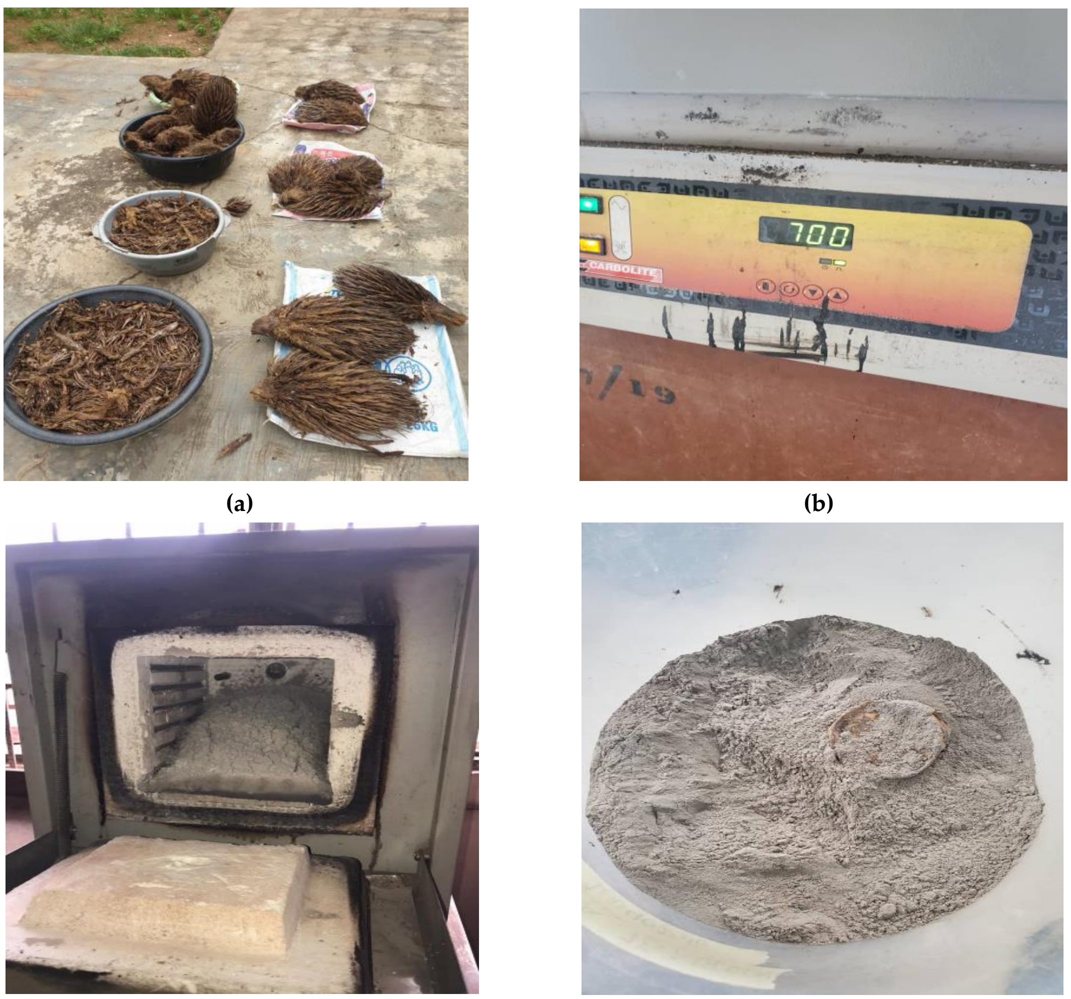
This study was conducted on two different disturbed bulk lateritic soil samples collected from two different locations from the residual soil deposit from two different states. The samples were obtained at sampling depths of 750mm to obtain true representative samples of the subgrade which is the placement level of flexible highway pavement. The sample collection was done systematically to ensure the proper collection of the samples. Global Positioning System (GPS) was used to measure the coordinates of each sample location. The sample locations were:

Ogun State – 115m inwards from the Abeokuta-Igboora-Iseyin highway pavement, 85.5m from the KM 13 + 200m mark, Ibara Orile/Onisasa. Coordinates: 7°08'37.6"N 3°15'23.2"E. Osun state – Asalu (Mogimogi) 18m inwards from the street, 10.7m from the corner piece, Apomu. Coordinates: 7°21'14.5"N 4°11'57.8"

All the laterite soil samples were carefully labelled in sample bags and then taken to the laboratory and stored properly.

Palm Bunch Ash (PBA)

Bulk samples of empty palm fruit bunch were collected from different farms and oil palm mills across different states including Ondo, Osun, Oyo, and Ekiti. The palm bunch was thoroughly sundried to remove as much moisture as possible. It was then incinerated to a temperature of 700°C using an electrically powered furnace. The ashes were then collected and pulverized. It was then sieved passing through a BS No. 200 sieve mesh, with a 0.075 mm aperture. BS 1377 (1990) and BS 1924 (1990) were used for this study.



(a) (b)

(c) (d)

Processing of Palm Bunch into palm Bunch ash

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3. METHODS

PROPORTION OF PBA ADDITIVE

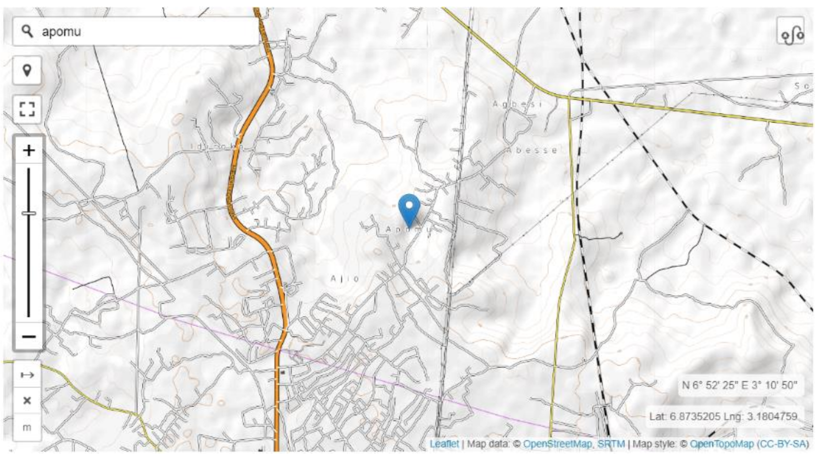
The quantity of PBA additive used in this study was measured in proportion of percentage of the weight of the dry lateritic soils. Namely; 0%, 3%, 6%, 9%, and 12%. The following laboratory tests were carried out on the natural state of the lateritic soil samples in accordance to BS 1377 (1990):

Particle Size Distribution, Specific gravity, Atterberg limits (Liquid limit, Plastic limit, Linear shrinkage), Standard Proctor Compaction test, California Bearing Ratio (CBR) and Unconfined Compressive Strength test (UCS). While compaction, CBR and UCS tests were also conducted on both natural samples stabilized with PBA. These tests conformed to BS 1377 (1990).

Location and geology of the study area

The areas of study in this research from which the soils were collected belongs to the Southwestern region of Nigeria and they are all located in three different states in the region. The locations are situated along the Eruwa-Ibadan highway, Eruwa, Oyo state; Abeokuta-Igboora-Iseyin Rd, Ibara Orile/Onisasa, Ogun State; and Apomu, Osun State. The locations were chosen semi-randomly to collect soil samples with as different properties as possible.

Apomu, Osun State



Map Location of Apomu

Apomu is a town located in Isokan local government area, Osun West senatorial district, off Ibadan-Ife highway. It lies between latitudes 7° 20' N and 7° 22' N and longitudes 4° 09' E and 4° 11' E. It covers an area of 179 km^2. It is 30 km east of Ibadan, 67km, and shares a border with Ikire which lies to its north. The topography is relatively flat. The average elevation is 204m above sea level. The area has a tropical wet and dry climate, with a lengthy wet season and relatively constant temperatures throughout the year with a mean annual rainfall of over 1,300 mm. The area is also characterized by a fairly uniform temperature and high relative humidity. According to the 2006 Nigerian census, the town has a population of about 103,117. The dominant occupation of the town is farming and sawmilling.

The area falls within the Pre-Cambrian basement complex rocks of southwestern Nigeria (Rahaman, 1976 and 1989). The underlying rock is weathered metamorphic bedrock comprising of banded gneiss, granite gneiss, some schist (Watanabe, 2015). The dominant mineral in the soil is kaolinite clay (Abe et al., 2006).

Ibara Orile/Onisasa, Ogun State

Ibara Orile/Onisasa is a town located on the fringes of the state capital, Abeokuta in Abeokuta North local government area, Ogun central senatorial district, along the Joga-Orile highway. It lies between latitudes 7° 04' N and 7° 15' N and longitudes 3° 11' E and 3° 18' E. It covers an area of 179 km^2. It is 37 km northeast of Ibese and 8 km west of Abeokuta. The topography is undulating and is drained by the Rori and Ayinbo rivers. The elevation above sea level ranges between 90m -120m with an average elevation of 108m. The area has a sub-humid tropical climate with a mean annual rainfall of over 1,909 mm. The area is also characterized by a fairly uniform temperature and high relative humidity.

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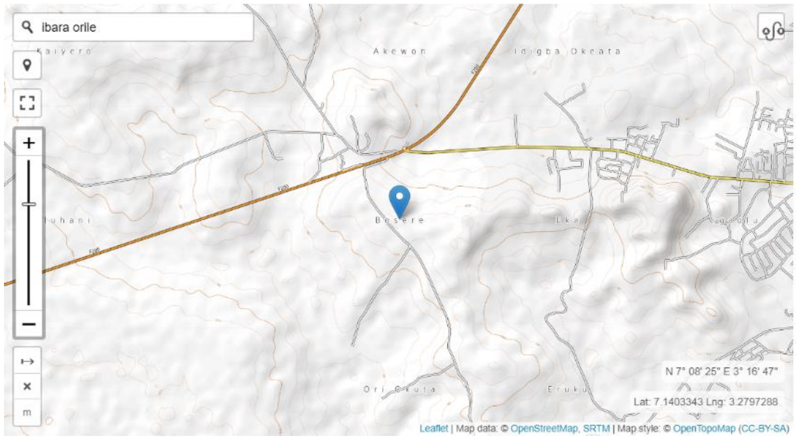


Map Location of Ibara Orile/Onisasa

The landform is a pedimented plain with well-incised valleys producing a trellis pattern. The soils form on top of a heavily worn layer of sedimentary rocks composed of false bedded sandstones that lie under the region. Lower cretaceous rocks, or the Abeokuta formation (Smyth and Montgomery, 1962), constitute the sediments, which extend monotonously in northwest and southwest directions.

4. RESULTS AND DISCUSSION

The discussion of results obtained from the tests carried out in the laboratory were given below. These tests include Particle size distribution, Specific gravity, and Atterberg limits for the natural soil. The Standard proctor compaction test, CBR (Soaked and Unsoaked) and unconfined compressive strength (UCS) tests for the natural and stabilized soil.

Properties of natural soil

The geotechnical properties of the Ogun and Osun soil in their natural states are tabulated below

Table 4.1: Index properties of lateritic soil samples from Ogun and Osun

Properties	Ogun soil sample	Osun soil sample
Percentage passing BS No 200 sieve	42.63	42.86
Natural moisture content, (%)	6.81	4.23
Liquid limit, (%)	29.50	31.50
Plastic limit, (%)	15.91	17.73
Plasticity index, (%)	13.69	13.77
Shrinkage limit, (%)	6.15	5.51
Coefficient of curvature	0.98	2.52
Coefficient of uniformity	2.16	8.52
Specific gravity	2.65	2.66
AASHTO classification	A-6 (2)	A-6 (2)
USCS	SC	SC
Optimum Moisture content, (%)	13.50	16.23
Maximum Dry Density, (g/cm^3)	1.76	1.68
California Bearing Ratio, (%) (unsoaked)	12.18	15.58
California Bearing Ratio, (%) (soaked)	5.35	7.33
Unconfined Compressive Strength (KN/m2) at 28 days	268.48	247.17
Colour	Reddish Brown	Reddish Brown

Table 4.3: Chemical composition of PBA

COMPONENTS	SIO_2	AL_2O_3	FE_2O_3	CAO	MGO	NA2O	MNO	ZNO	LOI
CONC. (%)	60.78	14.86	0.57	15.70	0.92	0.77	0.86	0.93	5.20

4.1. Soil classification

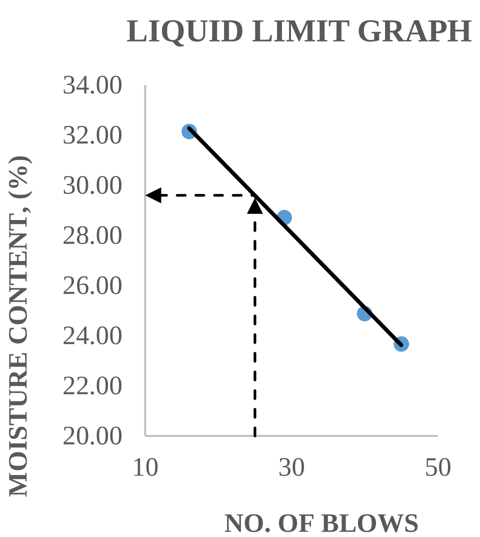
The Ogun soil sample was classified as A-6 (2) soil according to the AASHTO classification system. The percentage retained on the No. 200 sieve was 57.06% and the percentage passing was 42.63% and it was later used for hydrometer test to determine the silt content. While the Osun soil sample was classified as A-6 (2) soil according to the AASH TO classification system. The percentage retained on the No. 200 sieve was 57.07% and the percentage passing was 42.86% and it was later used for hydrometer test to determine the silt content.

4.2. Specific gravity

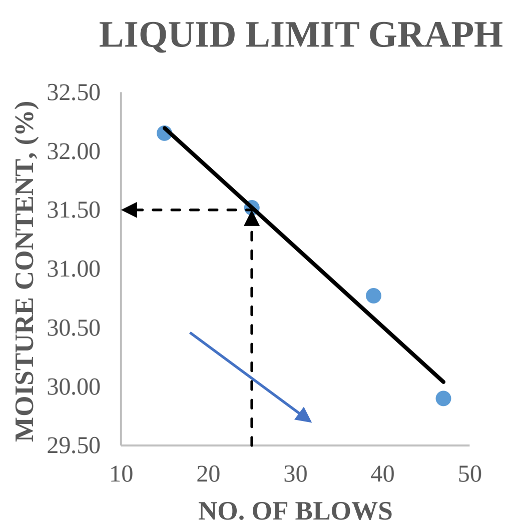
The soil samples had a specific gravity value of 2.65 and 2.66 for Ogun and Osun respectively.

4.3. Atterberg limits

Atterberg limit tests carried out on the Ogun soil sample revealed that the soil had a liquid limit of 29.5% as shown in figure (a) and a plastic limit of 15.91%. The plasticity index of the soil was calculated to be 13.69%. The shrinkage limit was 6.15%.



(a) Ogun soil sample liquid limit graph



(b) Osun soil sample liquid limit graph

Atterberg limit tests carried out on the Osun soil sample revealed that the soil had a liquid limit of 31.5% as shown in figure (b) and a plastic limit of 17.73%. The plasticity index of the soil was calculated to be 13.77%. The shrinkage limit was 5.51%.

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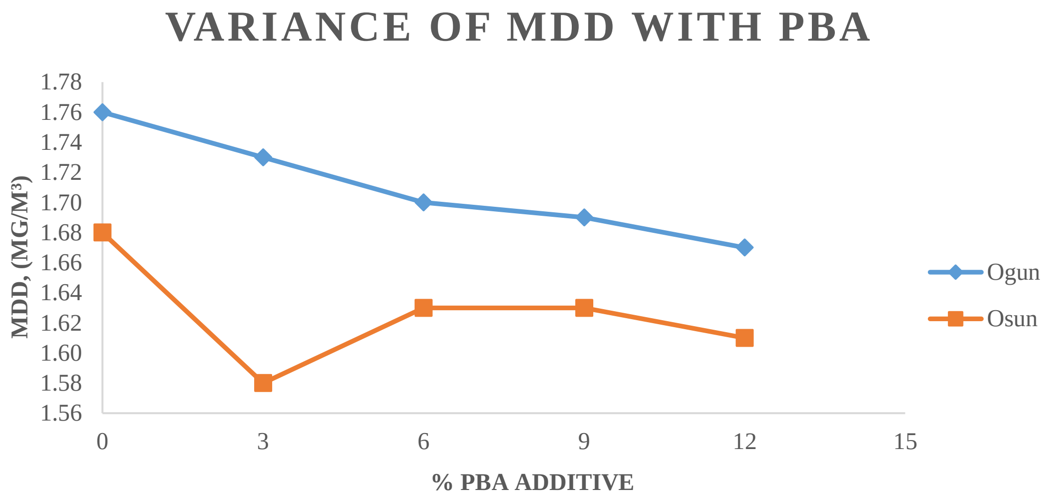
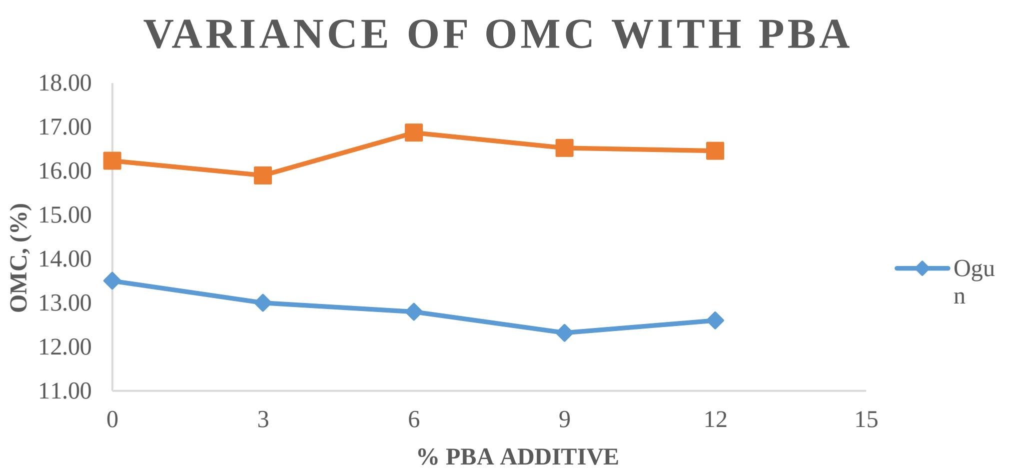
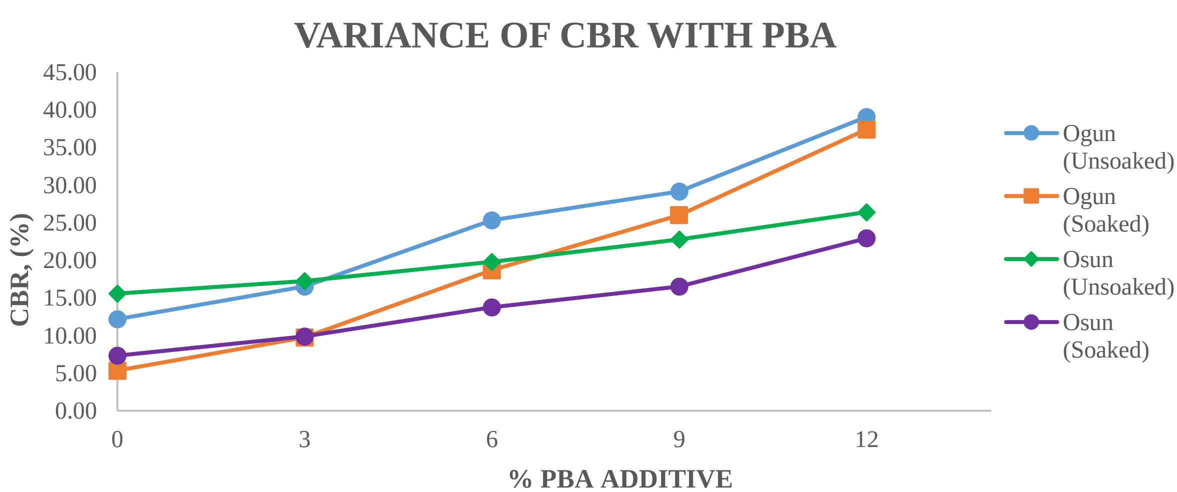


Variation of MDD of Ogun soil sample with Palm Bunch Ash additive



Variation of MDD of Osun soil sample with Palm Bunch Ash additive



Variation of CBR of Ogun and Osun soil sample with Palm Bunch Ash additive

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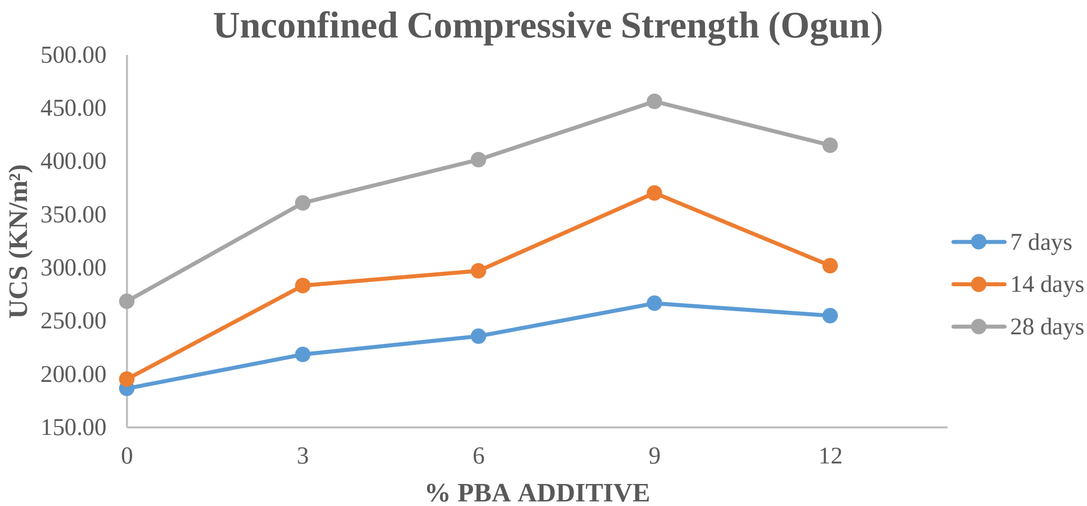
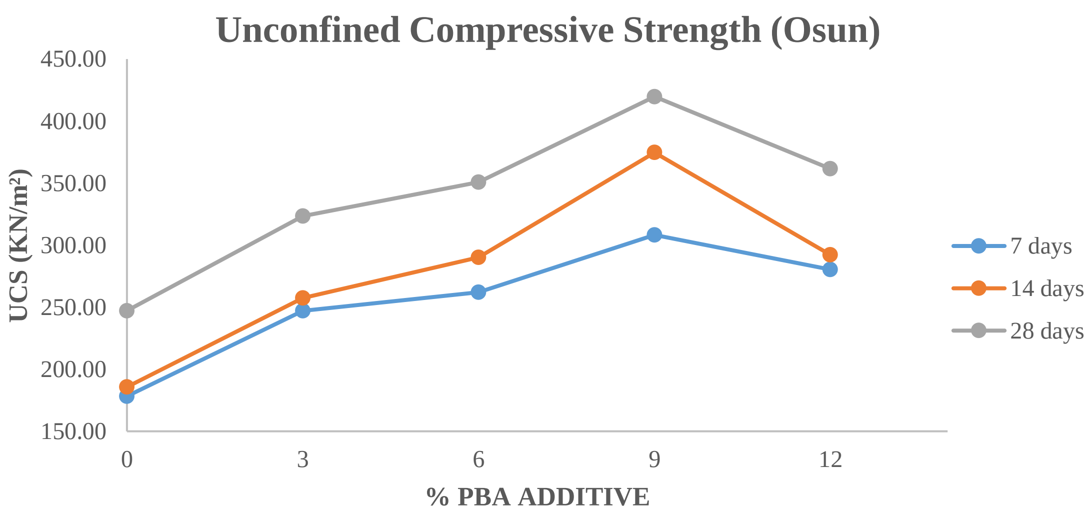


Variation of UCS of Ogun soil sample with Palm Bunch Ash additive



Variation of UCS of Osun soil sample with Palm Bunch Ash additive

5. CONCLUSION

The result from the chemical analysis showed that PBA contained substantial amounts of calcium oxide. It was observed that the stabilization of both Ogun and Osun lateritic soil samples for CBR using PBA was suitable for subgrade having met the requirement for 15% minimum CBR value (37.40 & 22.92) for standard proctor compactive energy level under soaked conditions.

For sub-base application, the use of PBA for stabilization was only successful for the Ogun soil sample as it exceeded the 30% CBR value required for sub-base under soaked conditions. However, the stabilization of the Osun soil sample for sub-base was unsuccessful under both soaked and unsoaked conditions as the CBR values were below 30%.

For the UCS test, both the stabilized Osun and Ogun soil samples 28 days respective values of 361.55 and 415.18 failed to meet the required standards of 750 KN/m2 and the cement and lime stabilization values of 1710 KN/m2 and 1034.25 KN/m2.

The cost of stabilizing the soil wasn't cost-effective when compared to cement in terms of one cubic meter of roadwork. This research work found Palm Bunch Ash (PBA) as a viable and promising stabilizing material and can be used at 12% PBA content to stabilize laterite for subgrade and in some cases, sub-base.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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