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Nanosized palm bunch ash (NPBA) stabilisation of lateritic soil for construction purposes

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Nanosized palm bunch ash (NPBA) stabilisation of lateritic soil for construction purposes

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ABSTRACT

The stabilisation potential of Nanosized palm bunch ash (NPBA) was investigated. This investigation was aimed at assessing the effect of NPBA on the stabilisation of Umuntu Olokoro lateritic soil. The soil was studied under varying proportions of the NPBA mixed at 0% (control), 3, 6, 9, 12 and 15% by weight of the stabilised soil. The soil properties' tests; soil classification or grading test, specific gravity, compaction test, consistency limits tests, unconfined compressive strength (UCS) test, California bearing ration (CBR) test and UV/VIS spectrophotometric characterisation were conducted. The UV–VIS test was conducted on the ash and the lateritic soil to determine their absorbance, wavelength and average particle size. The results of the preliminary tests showed that the soil was classified as A-2-7 soil on AASHTO classification with group index of "0" a Matlab program run on the sample also predicted that the soil is made of silty or clayey gravel and sand and that the general rating as a sub-grade material was "GOOD". The average particle size of the ash by Debye Scherrer's method was 11.358 nm and the maximum absorbance was 1.120 nm at the wavelength of 650 nm. The optimum moisture content OMC increased at 12 and 15% by weight of NPBA compared to the 0% NPBA proportion, which gave 13%. The Maximum Dry Density (MDD) decreased from 1.84 to 1.72 kN/m^2 followed by a consistent increase in the value as higher percentages of admixtures were added. It was observed that the 6% NPBA gave the highest value of MDD of 1.93 g/cm^3 followed by 9% NPBA of 1.84 g/cm^3. The California Bearing Ratio (CBR) test results showed high and low values of CBR with 9% NPBA, which gave the highest (CBR) value of 30%. 12% addition of the admixture (Nanosized Palm Bunch Ash) by weight gave the highest unconfined compressive strength value of 399.46 kN/m^2 at 28 days curing time. The least percentage NPBA (3%) gave the lowest UCS value of 192.9746 kN/m^2. From the general results recorded, it is important to note that using lower percentages of NPBA as an admixture in treating lateritic soil will yield considerably, poor results. If NPBA should be used, it should be in higher percentages. However, 12% NPBA by weight of stabilised soil gave the best results and is preferred for use to stabilise lateritic soils for construction purposes.

KEYWORDS

Evaluation; nanosized palm bunch ash; stabilisation; engineering soil; construction purposes; southeastern Nigeria

Introduction

Soil Stabilisation can be explained as the alteration of the soil properties by chemical, non-chemical or physical means in order to enhance the engineering properties of the soil like the use of admixtures. Soil stabilisation increases the bearing capacity of the soil, its resistance to weathering process and soil permeability. The long-term performance of any construction project depends on the soundness of the underlying or foundation soils. Unstable soils can create significant problems for pavements or structures, therefore soil stabilisation techniques are necessary to ensure the stability of soil so that it can successfully sustain the load of the structure especially in cases of soil which is highly active. Equally, it saves a lot of time and millions of money when compared to the method of cutting out and replacing the unstable soil.

Nanomaterials are a set of substances where at least one dimension is less than approximately 999 nanometers. A nanometer is one millionth of a millimeter approximately 100,000 times smaller than the diameter of a human hair. Nanomaterials are of interest because at this scale, unique optical, magnetic, electrical and other properties emerge. These emergent properties have the potential for great impacts in electronics, medicine and other fields (Chang-Jun et al. 2010; Nazari, Rafieipour, and Riahi 2011; Ying et al. 2011; Mubayi et al. 2012; Ahmad, Yaser, and Ehsan 2013; Anitha and Pandya 2014).

Palm Bunch Ash (PBA) is the powdery residue that remains after palm bunch is burnt; it is reportedly a desirable component in artisan soap making, as well as possessing several present and potential industrial uses and has been used previously at the macro and micro scales used in soil stabilisation. Palm bunch ash is highly alkaline (pH = 12) and can be used to neutralise acidic soil. The volume of wastes generated in the world has increased over the years due to increase in population, socio-economic activities and social development and palm bunch is one of those wastes from palm oil production. These wastes come from agricultural, industrial, commercial as well as construction activities.

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One of the most attractive options of managing such wastes is to look into the possibility of waste minimisation and re-use. This research is aimed at assessing the impact of palm bunch ash (PBA) at the nanosized scale on the stabilisation of weak lateritic soils. In Nigeria, especially in the southern and western parts, lots of engineering projects founded on soil fail primarily as a result of foundation soil failure. Results of researches have shown that most of the lateritic soils, yield in terms of geophysical and Geotechnical properties which eventually render the material unfit to serve relevant engineering purposes. As a result, there is need to evaluate and to improve on the engineering properties of the soil using admixtures. Hence the use of nanosized palm bunch ash (NPBA) in soil stabilisation to control the quantity of waste coming out from some local oil mills in the Nigerian local communities and industrial areas. Specifically, the main objectives of this research work were; (i) to designing the use of Palm Bunch from biodegradability and evaluate its stabilisation potentials as an admixture, (ii) To compare the effect of Palm Bunch Ash at the nanoscale on stabilised Olokoro soil and (iii) To determine the improvement in the Olokoro lateritic soil Geotechnical properties with varying percentages; 3, 6, 9, 12 and 15% of NPBA.

Literature review

Over the years, engineers and researchers through scientific methods and theories have developed techniques to overcome these naturally occurring engineering difficulties. Soil stabilisation is one of the many techniques and was developed to accommodate the insufficiency in the natural soil materials which are already considered unstable for an intended engineering use. Soil stabilisation is the process of altering some soil properties by different methods; mechanical or chemical to produce an improved soil material which has all the desired engineering properties. Soils are generally stabilised to increase their strength and durability or to prevent erosion and dust formation in soils. The properties of soil vary a great deal from place to place or in certain cases even at one place; the success of soil stabilisation depends on soil testing to decide natural soil behaviour. Various methods are used to stabilise soil and the methods are verified in the lab with the soil material before applying it in the field. Soil stabilisation is a very important technique used to optimise the qualities of a sample of soil. Soil stabilisation was carried out when the required engineering properties needed for the soil used are not met by the soil sample or some more improvements required to achieve a desired purpose. It is the process of improving the engineering properties of a particular soil, thereby providing it with more stability.

Soil stabilisation is also used to cut the permeability and compressibility of the soil mass in earth structures, to make it more stable, increase the bearing capacity of foundation soils and to increase the shear strength. The principles of soil stabilisation are used for controlling the grading and particle size distribution of particles at the construction of bases and sub-bases of highways and airfields. Over the years, research has shown that various binders have been applied in this process and these binders are very expensive in Nigeria's today's market. For example, binders like cement, (Osinubi 1999), lime, (White 2005; Awasthi et al. 2009), fly ash, (White 2005), bitumen (Osinubi 2000), cement kiln dust (Osinubi, Bafyau, and Eberemu 2009, etc. have been used to improve the properties of weak engineering soil. At the same time, earlier research and research results have shown that non-traditional binders like silicates (Osinubi, Bafyau, and Eberemu 2009), chlorides, (White, Harrington, and Zach 2005), etc. have also been used in varying degrees with many positive results. Fiber reinforcements (Sherwood 1993) and polymers have also shown to be useful in the stabilisation of engineering soil. More importantly and relevantly, researches over the years have used admixtures like Rice Husk Ash, bagasse ash, egg-shell ash, palm kernel ash, palm bunch ash, etc. in various proportions in stabilising weak engineering soil and have achieved great results (Feynman 1960). It is said that a great number of studies have focused on stabilising soils using various additives. Traditional materials such as cement, lime and mineral additives such as fly ash, silica fume and rice husk ash were used for improving soils (Hussin et al. 2009; Hossain and Mol 2011) (Figure 1).

Nanotechnology and geo-nano-stabilisation

Nanotechnology revolves around the creation of a varied collection of nanomaterials (NM), which encompass nanoparticles (NP) along with Nanoobjects. NMs are known to be 100 nm lower in terms of dimensions, whereas nanoobjects fall two dimensions lower. An example of this phenomenon can be observed through carbon nanotubes. Nanoparticles are described as material three dimensions lower than 100 nm. According to (Feynman 1960), the idea of nanotechnology was first introduced in the year 1959 by Richard Feynman in his lecture entitled "There's Plenty of Room at the Bottom". At the time, the term "nanotechnology" had not yet been coined. This technology made a significant and rapid progress years later. Nanotechnological achievements provided a modern approach in Geotechnics. Each field of science had a specific definition for Nanotechnology and the National Nanotechnology Initiative (NNI) provided a comprehensive definition of nanotechnology (Wu et al. 2008; Awasthi et al. 2009; Chang-Jun et al. 2010; Ershadi et al. 2011; Yang and Li 2015). According to the NNI, "nanotechnology" is the control, comprehension and reformation of material based on the hierarchy of nanometers to develop matter with essentially new uses and a new constitution. Considering this definition, nanotechnology is a novel approach in all sciences. Such an approach can be applied in Geotechnical engineering in two ways:

- In studying the soil structure at the nanoscale to gain a better understanding of soil nature as well as in studying the performance of soils with different nanostructures and its interaction with admixture materials.
- In conducting soil manipulation at the atomic or molecular scale, which is facilitated by the addition of nanoparticles as an external factor to the soil.

According to (Norazlan et al. 2014), soil stabilisation is seen as a means of enhancing aspects of engineering and other elements, including the conductivity of hydraulics, compressibility, strength and the density. Methods relating to soil stabilisation can be categorised in numerous ways, including surcharge load, vibration, enhancing support for structures at hand with

Figure 1. Nigerpet laboratory unconfined compressive strength and CBR test set-up.

Waveleng	Absrbance	
0	1.154	
200	1.153	
250	1.149	
300	1.144	
350	1.146	
400	1.142	
450	1.143	
500	1.146	
550	1.151	
600	1.149	
650	1.15	
700	1.147	
750	1.146	
800	1.154	Exp details:
850	1.151	Re: mouau/chemlab/UV-VIS/lateritic soil/exp.001
900	1.15	Date Printed: 29:03:2017
950	1.152	Number of Replicate: 1
1000	1.154	Max. Absorbance: 1.154 nm at 800 cm wavelenght

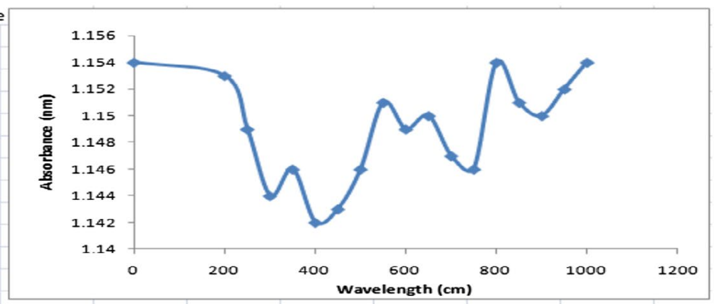
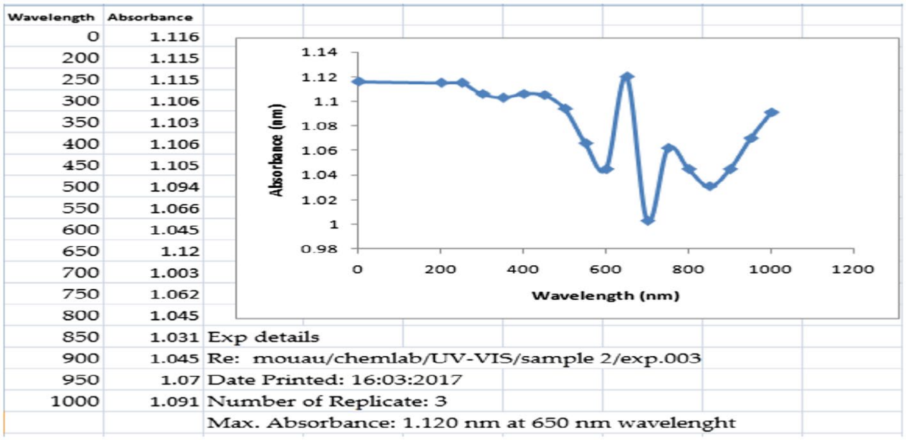


Figure 2. Variation of absorbance against wavelength for the lateritic soil using UV/VIS Spectrophotometer at 25 °C.

structure fill, grouting and other techniques. Many techniques can be used for different purposes by enhancing some aspects of soil behaviour as well as the basic makeup and texture of the soil (Ozawa and Ōsawa 2006). Ground treatment can enhance the bearing competence of the target soil, reduce the possibility of complete and disparity-based settlement, reduce the rate and extent to which the settlement occurs, reduce the possibility of liquefaction with hydraulic fills or saturated fine sand, and reduce the hydraulic conduciveness, water retention, and water release of the soil (Zhang et al. 2007; Majeed and Taha 2012). A researcher has presented the Laboratory experiments to study the fundamental Geotechnical properties of mixtures of natural soils and its product after ball milling operation. The product after the ball milling process was termed nanosoil. The effect of Nanoalumina material of the volume change and desiccation crack behaviours for different plasticity index soils was investigated by (Taha 2009).

Nanomaterials

Nanomaterials are cornerstones of Nanoscience and nanotechnology. Nanostructure science and technology is a broad and interdisciplinary area of research and development activity that has been growing explosively worldwide in the past few years. It has the potential for revolutionising the ways in which materials and products are created and the range and nature of functionalities that can be accessed. It is already having a significant commercial impact, which will assuredly increase in the future. Some nanomaterials occur naturally, but of particular interest are engineered nanomaterials, which are designed for and already being used in many commercial products and processes (Rogers and Glendinning 1993; Sumadi and Hussin 1995). They can be found in such things as sunscreens, cosmetics, sporting goods, stain-resistant clothing, tires, electronics, as well as many other everyday items and are used in medicine for purposes of diagnosis, imaging and drug delivery. Engineered nanomaterials are resources designed at the molecular (nanometre) level to take advantage of their small size and novel properties which are generally not seen in their conventional bulk counterparts (Karim et al. 2011; Jacob, Nair, and Isac 2014). The two main reasons why materials at the nanoscale can have different properties are increased relative surface area and new quantum effects. Nanomaterials have a much greater surface area to volume ratio than their conventional forms, which can lead to greater chemical reactivity and affect their strength. Also at the nanoscale, quantum effects can become much more important in determining the materials properties and characteristics leading to novel optical, electrical and magnetic behaviour (Tingle and Santoni 2003; Kannan 2010; Raki et al. 2010; Kavitha, Geetha, and Ramesh 2015). Novel discoveries have been made in the use of nanomaterials in the field of environmental geotechnics to improve the strength characteristics of lateritic soils (Osinubi, Bafyau, and Eberemu 2009). Nanomaterials are materials which are characterised by an ultra fine grain size (<999 nm) or by a dimensionality limited to 999 nm. Nanomaterials can be created



Wavelength	Absorbance	
0	1.116	
200	1.115	
250	1.115	
300	1.106	
350	1.103	
400	1.106	
450	1.105	
500	1.094	
550	1.066	
600	1.045	
650	1.12	
700	1.003	
750	1.062	
800	1.045	
850	1.031	Exp details
900	1.045	Re: mouau/chemlab/UV-VIS/sample 2/exp.003
950	1.07	Date Printed: 16:03:2017
1000	1.091	Number of Replicate: 3
		Max. Absorbance: 1.120 nm at 650 nm wavelenght

Figure 3. Variation of absorbance against wavelength for the NPBA particles using UV/VIS Spectrophotometer at 25 °C.

with various modulation dimensionalities as defined by Richard W. Siegel: zero dimension (atomic clusters, filaments and cluster assemblies), one dimension (multilayer), two dimensions (ultrafine-grained over-layers or buried layers) and three dimensions (nanophase materials consisting of equiaxed nanometer sized grains) as shown in Figure 2 (Xiao et al. 2005; Chang-Jun et al. 2010; Nazari, Rafieipour, and Riahi 2011; Ying et al. 2011; Mubayi et al. 2012; Ahmad, Yaser, and Ehsan 2013; Anitha and Pandya 2014; Jacob, Nair, and Isac 2014; Bykkam et al. 2015).

Nanosized palm bunch ash

The growing cost of conventional soil stabilisation materials, the need to increase bonding and reactive surface of soil/additive mixture, the need to rid the environment of solid waste that could be converted to usable engineering materials and the need for the economical utilisation of industrial and agricultural waste for beneficial engineering purposes have prompted an investigation into the stabilisation potentials of Palm Bunch Ash (PBA) as admixture at the nanoscale. As a result, there is a need to improve on the engineering properties of the soil using admixtures hence this previous research work that was targeted at improving the engineering properties of Engineering soil (lateritic soil) with PBA and presently, the research with the materials at the nanoscale; NPBA.

Materials and methods

Materials

Materials used for the research work include, Olokoro lateritic soil, Ordinary Portland Cement and NPBA. Lateritic soil sample was excavated from the burrow site at Umuntu, Olokoro, located on latitude 05°28′36.900″North and Longitude 07°32′23.170″East from a depth of 2.00 m at a distance of 5 km from Isicourt junction, Umuahia South, Abia State, Nigeria (www.google.com, 2015). Random sampling was used to obtain the lateritic soil sample. The sample was obtained in a semi-solid state and was reddish brown in colour. Dangote ordinary Portland cement was purchased from the Umuahia timber market, which satisfies (ASTM C150 2013). Dried palm bunch was obtained from dump site of Macay Oil Mill Ltd in Amakama-Olokoro Umuahia, Nigeria. The palm bunches were sun dried for two weeks and then burnt without gasoline. The ash was collected and sieved using the 0.75 μm BS test sieve to achieve a smooth, uniform and fine particle. The powder ash filtrate was found to be hygroscopic (absorbs atmospheric moisture) hence the ash was stored in an airtight container. To obtain the nanosized ash, the collected sample from the 0.75 μm sieve was finally passed through the 200 nm sieve; UV/VIS Spectrophotometer at 25 °C characterisation was conducted to determine the maximum absorbance, peak wavelength and the average particle size of the ash and stored for use. This sample was used in proportions of 0, 3, 6, 9, 12 and 15% by weight in the investigation of its effect on the properties of Umuntu, Olokoro soil in accordance with (BS 1377 1990; BS 1924 1990; ASTM D7762-11, 2013)

Methods

Experimental tests were conducted as follows;

(a) *Particle Size Distribution:* This was conducted at the Geotechnical and Materials Engineering laboratory, Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike.

Aim: To determine the grading and particle size distribution of the lateritic soil sample in accordance to (BS 1377-1 & 2 1990; Eurocode 7-2 1997; Nigeria General Specification 1997; ASTM D6913-04 2009; ASTM D2487-11 2015; ASTM D2488-09a 2015; BS 5930 2015).

Apparatus: Orderly arranged British Standard Sieves to BS410 (1976); 4.36 mm, 2.36 mm, 1.18 mm, 600 μm, 425 μm, 300 μm, 212 μm, 150 μm, 75 μm; Lid and receiver; balance readable and accurate to 0.1 g, drying oven, sieve brush and the mechanical shaker.

(b) *Consistency Limits Tests:* This was conducted at the Geotechnical and Materials Engineering laboratory, Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike.

Aim: To determine the liquid and plastic limits and hence the liquidity and the plasticity indices of the natural lateritic soil sample in accordance to (BS 1377-1 & 2 1990; BS 1924 1990; Eurocode 7-2 1997; NGS, 1997; ASTM D4318-10

2015; ASTM D2487-11 2015; ASTM D2488-09a 2015; BS 5930 2015).

Apparatus: A flat glass plate (10 mm thick and 500 mm square) two (2) palette knives (200 mm long and 30 mm wide) Casagrande liquid limit apparatus, a grooving tool and gauge, an evaporating dish or a damp cloth, a beaker containing distilled water and a non-corrodible air tight container large enough to take about 250 g of wet soil and the material soil sample.

(c) *Soil Compaction Test*: This was conducted at the Geotechnical and Materials Engineering laboratory, Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike.

Aim: To determine the bulk density and dry density/moisture content relationship (2.5 kg rammer method) in accordance to (BS 1377-1 & 2 1990; BS 1924 1990; Eurocode 7-2 1997; Nigeria General Specification 1997; ASTM D698-12 2015; ASTM D2487-11 2015; ASTM D2488-09a 2015; BS 5930 2015).

Apparatus: A cylindrical metal mould having an internal diameter of 105 mm, internal effective height of 115.5 mm and a volume of 1000 cm^3 (the mould was fitted with a detachable base plate and a removable extension 50 mm high), a metal rammer having a 50 mm diameter circular face and weighing 2.5 kg (the hammer was equipped with a suitable arrangement for controlling the height of drop to 300 mm) a balance readable and accurate to 1 g, a palette knife (100 mm long and 20 mm wide), a straight edge steel strip 300 mm long, 25 mm wide and 3 mm thick with one bevelled edge, 20 mm BS test sieve and a receiver, large metal tray (600 mm × 500 mm with sides 80 mm deep), apparatus for moisture content determination.

(d) *Specific Gravity Test:* This was conducted at the Geotechnical and Materials Engineering laboratory, Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike.

Aim: To determine the specific gravity of the lateritic soil sample in accordance to (BS 1377-1 & 2 1990; Eurocode 7-2 1997; Nigeria General Specification 1997; ASTM D854-14 2015; ASTM D2487-11 2015; ASTM D2488-09a 2015; ASTM D7262-09 2015; BS 5930 2015).

Apparatus: Two density bottles (pycnometers) of approximately 50 ml capacity with stoppers, water bath maintained at constant temperature of 20 °C within + 0.2 °C, vacuum desiccators, thermostatically controlled drying oven (105–110 °C) balance readable and accurate to 0.001 g, a vacuum pump, spatula (150 mm long, 3 mm wide), plastic wash bottle containing air-free distilled water; sample divider of the multiple slot type (riffle box) with 7 mm width of opening and a length of rubber tubing to fit the vacuum pump and the desiccators.

(e) *CBR Test:* This was conducted at the Niger Pet Geotechnical Engineering laboratory, Uyo, Akwa Ibom State, Nigeria.

Aim: Determination of CBR of the natural soil sample as well as the stabilised samples with 3, 6, 9, 12 and 15% percentage proportions of nanosized palm bunch ash in accordance to (BS 1377-1 & 2 1990; Eurocode 7-2 1997; Nigeria General Specification 1997; BS 1924 1990; ASTM D1883-99 2003; ASTM D2487-11 2015; ASTM D2488-09a 2015; BS 5930 2015).

Apparatus: Compressive machine, proving ring, dial gauge, stopwatch, sampling tube, split mould, vernier caliper, balance.

(f) *Unconfined Compressive Strength Test:* This was conducted at Niger Pet Geotechnical Engineering Laboratory, Uyo, Akwa Ibom State, Nigeria on the sample with admixture proportions of 3, 6, 9, 12 and 15% in accordance to (BS 1377-1 & 2 1990; BS 1924 1990; Eurocode 7-2 1997; Nigeria General Specification 1997; ASTM D2166/D2166M-13 2015; ASTM D2487-11 2015; ASTM D2488-09a 2015; ASTM D2166-65 2015; BS 5930 2015) as shown in Figure 3.

(g) *Chemical Composition Test*: This was conducted at the spectroscopic laboratory of the Root Crop Research Institute, Umudike on the nanosized ash of palm bunch to determine the constituent elements of the studied admixture and UV/VIS Spectrophotometer test at 25 °C in accordance with (BS 1377 1990) at the Chemistry lab of the Michael Okpara University of Agriculture, Umudike on both the soil and the admixture to determine their particle absorbance and average particle sizes.

Results and discussion

After the preceding laboratory studies, the following results were achieved; From Table 1, it can be deduced that the soil has the following properties in its natural state;

- A plasticity index of 21.85% > 17% and that condition satisfies that Umuntu Olokoro lateritic soil is a highly plastic soil. Also the plasticity index falls between 20 and 35% condition for high swelling potential and between 25 and 41% condition for a high degree of expansion (Gopal and Rao 2011)
- The soil relative consistency and liquidity index, which are 1.69% > 1 and 0.91% < 1, respectively, show that the soil is in a semi-solid or solid state, very stiff and plastic (Gopal and Rao 2011)
- Is classified as A-2-7 soil on AASHTO soil classification, poorly graded, GP on USCS, the group index of 0 and of silty, clayey gravel and sand material (Gopal and Rao 2011).
- An optimum moisture content of 13% and maximum dry density of 1.84 g/cm^3.
- An Unconfined Compressive Strength (UCS) of 230.77 kN/m^2 at 28 days curing time, which falls between 200 and 400 kN/m^2, a condition for soils of very stiff consistency with respect to UCS (Gopal and Rao 2011; NGS/FMWH 1997).
- A California bearing ratio of 14 which makes it good for the sub-grade material (NGS/FMWH 1997).

Figure 2 shows the UV–VIS Spectrophotometer at 25 °C characterisation of the lateritic soil. It can be deduced that the soil has an absorbance of 1.154 nm at wavelength of 800 cm.

Cohesive bonding between material mixtures is a very important factor in soil stabilisation because the soil and added

Table 1. Geotechnical properties of the lateritic soil.

Property/Unit		Quantity
% Passing BS No. 200 sieve		25.40
Natural Moisture Content, (%)		10
Liquid Limit, (%)		47.00
Plastic Limit, (%)		25.15
Plasticity Index, (%)		21.85
Coefficient of Curvature, $C_c = \frac{D_{30}^2}{D_{10} \times D_{60}}$		0.09
Coefficient of Uniformity, $C_u = \frac{D_{60}}{D_{10}}$		10
Specific Gravity		2.67
AASHTO classification		A-2-7
USCS		GW
Group Index		0
Material		Silty or Clayey Gravel, Sand
Condition/General Subgrade Rating		Good
Optimum Moisture Content, (%)		13
Maximum Dry Density (g/cm^3)		1.84
California bearing ratio, (%)		14
Unconfined Compressive Strength, (KN/m^2)	28 days	230.77
	14 days	219.11
	7 days	194.26
Colour		Reddish Brown

Table 2. Chemical properties of NPBA.

Constituents	CaO	MnO	MgO	ZnO	PbO	CuO	CdO	Fe_2O_2	Al_2O_2	SiO_2	Na_2O	P_2O_5	K_2O
% wt in NPBA	12.7	0.13	0.01	0.78	0.07	Trace	Trace	0.95	20.12	64.45	0.71	0.64	0.14

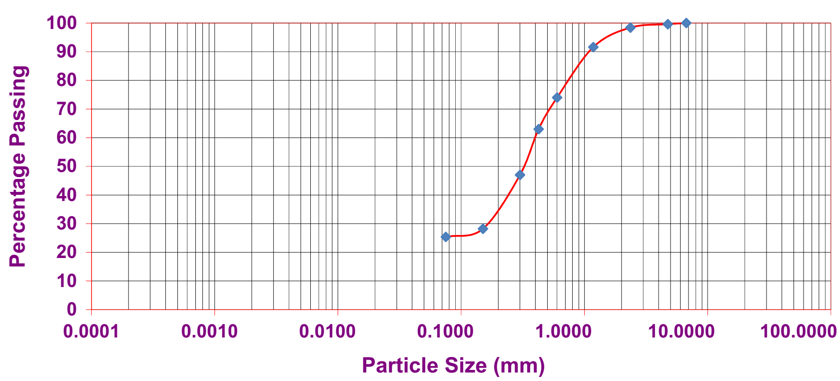


Figure 4. Particle size distribution curve of the lateritic soil.

admixture need to form a strong cohesive bond. The ASTM requirement for cementing materials is that the sum of SiO_2, Al_2O_3 and Fe_2O_3 should not be less than 70%. The result of the analysed NPBA shown in Table 2 shows that the percentage of $SiO_{2+}Fe_2O_{3+}Al_2O_3$ is 85.52% greater than 70%, which makes the admixture a highly pozzolanic material. This property is of great advantage because it brought about a high degree of interaction and bonding between the soil and the admixture. So also, the CaO present in NPBA is capable of reacting with the fine particles of soils to aid stabilisation. The P_2O_5 also has the potential to act as a binding agent to cement particles of soil together and increase its stability. Since the above oxides (CaO and P_2O_5) are also present in NPBA, it is clear that it has the potential of reacting with the fine particles of soil to aid stabilisation and act as a binding agent to cement particles in increasing its stability. Equally, the expected alkali compound in the nanosized ash, which may act as chemical stabilisers in reacting with the clays to form a cementitious matrix, is K_2O (ASTM D7762-11 2015).

Figure 3 shows the variation of absorbance against wavelength for the NPBA particles using UV/VIS Spectrophotometer at 25 °C. From the exercise, it can be deduced that the maximum absorbance was 1.120 nm at a wavelength of 650 nm, full width of half maximum of 150 m and exposure angle of 65°. The above data gave an average particle size of 9.223 nm by Debye Scherrer's expression. The particle absorbance enhances the mechanism whereby size can potentially promote cohesion between admixture and stabilised soil, characterisation of the molecular composition of organic matter in soil fundamental pool, lateral distribution of carbon forms in soil microaggregates, characterisation of the composition of dissolved organic carbon in the ash during stabilisation, etc. The nanopores of the ash material due to nanosization contribute 99% of the surface areas to the mixture homogeneity because it was less kinetically

Table 3. Effect of NPBA on compaction of the lateritic soil.

NPBA Proportion	0%	3%	6%	9%	12%	15%
MDD (g/cm^3)	1.84	1.72	1.93	1.84	1.76	1.77
OMC (%)	13.00	11.84	11.10	11.74	12.50	12.90

Table 4. Effect of NPBA on CBR of the lateritic soil.

NPBA Proportion by weight	0%	3%	6%	9%	12%	15%
CBR (%)	14	10	21	30	16	20

Table 5. Effect of NPBA on UCS of the lateritic soil.

NPBA Proportion (%)	0	3	6	9	12	15
At 7 days (kN/m^2)	194.26	175.32	203.89	258.03	383.45	292.07
At 14 days (kN/m^2)	219.11	217.03	217.03	285.94	350.04	300.94
At 28 days (kN/m^2)	230.77	192.97	274.06	347.85	399.46	335.26

restricted at the temperature when its isotherm constructed during the mixing and stabilisation mechanics.

From Figure 4, it can be deduced that the soil is a well graded soil with C_c equals 0.09 and C_u equals 10. It has a good distribution between particle sizes.

Effect of nanosized palm bunch ash on the compaction of the lateritic soil

The results from compaction tests were shown in Table 3. From the compaction test results, it can be observed that there was a decrease in Optimum Moisture Content (OMC) at 3 and 6% NPBA followed by an increase in the OMC at 9%. The increase in OMC was consistent at 12 and 15% NPBA compared to 0% NPBA which maintained the highest OMC value of 13%, followed by 15% NPBA which gave an OMC value of 12.90%. The Maximum Dry Density (MDD) decreased from 1.84 to 1.72 KN/m^2 followed by an increase in the value to 1.93 g/cm^3 at 6% by weight of NPBA. It is observed that the 6% NPBA gave the highest value of MDD of 1.93 g/cm^3 with the corresponding decrease in the value of OMC. The increase in MDD after a reduction at 3% NPBA by weight implies a gain of strength. This is as a result of the increased reactive surface and the pozzolanic property of the NPBA mixed with the lateritic soil thereby achieving higher density at lower moisture content. This behaviour may also be due to cation exchange reactions and the admixture occupying the void within the soil matrix and in addition, the flocculation and agglomeration of the clay particles due to exchange of ions (Osinubi 2000). The subsequent reduction in MDD may be due to the fact that for any soil/admixture, there is always water content to produce maximum strength. The trend is in conformity with the results reported by (Osinubi 2000). An explanation that was offered for this trend is that there was increasing desire for water, which commensurate with the higher amount of additives because more water was required for the dissociation of admixtures with Ca^{2+} and OH^- ions to supply more Ca^{2+} for the cation exchange reaction. The decrease in the OMC with increased proportions of admixture content might be due to cation exchange also that caused the flocculation of clay particles. Moreover, the NPBA is a highly pozzolanic material and requires water for hydration thereby improving the strength gain of the NPBA + Soil mixture.

Effect of nanosized palm bunch ash on the CBR of the lateritic soil

Table 4 shows the results of the effect of NPBA on the stabilised lateritic soil. The California Bearing Ratio (CBR) test results showed high and low values of CBR with 9% NPBA which gave the highest value of 30%. The satisfies clause 6201 of the General Specification for Roads and Bridges, Vol. II, which stipulates that a soil material will be suitable for use as subbase and base course material if its CBR is not greater than 30% and more than 10% (Nigeria General Specification 1997). The lowest value was recorded at 3% NPBA which recorded a CBR of 10%. It could be observed that there was a consistent increase in the CBR values from 3 to 9% NPBA. The values of CBR at 6 and 9% were observed to be 21 and 30%, respectively, as shown in Table 4 which satisfies the condition for use as a good sub-grade, subbase and base course materials according to the Nigeria General Specification for roads and bridges. The increase in the CBR with the addition of NPBA could be due to the presence of adequate amount of calcium required for the formation of Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate (CAH), which are the major compounds responsible for strength gain. The soil + 6% NPBA, soil + 9% NPBA and soil + 15% NPBA mixtures passed to meet the minimum CBR value of 20–30% specified by (BS 1924 1990) for materials suitable for use as base course materials when determined at MDD and OMC. This is close to the findings of Gidigasu and Dogbey (1980), which stated that the minimum CBR value of 20–30% is required for sub-bases when compacted at OMC. Increase in CBR, an implication of the increase observed in MDD is attributed to the compatibility of the grains of the soil by the increased reactive surface and the high pozzolanic properties of the NPBA such that greater densification was achieved. The observed decrease in CBR recorded at 3, and 12% by weight addition of NPBA could be attributed to the failure under load of the soil particle matrix as a result of the fineness of the nanosized admixture.

Effect of nanosized palm bunch ash on the UCS of the lateritic soil

Table 5 and Figure 5 show the results of the effect of NPBA on the UCS of the stabilised lateritic soil. The Unconfined Compressive Strength (UCS) at different percentages of the admixture was also studied and the results are shown in Table 5 and Figure 5. It could be deduced that 12% NPBA gave the highest unconfined compressive strength of 399.46 KN/m^2 at 28 days curing time, which satisfies the condition for very stiff consistency for use as a subbase and base course material (Nigeria General Specification 1997; Gopal and Rao 2011). The lowest percentage of admixture (3%) gave the lowest UCS value of 192.9746 KN/m^2 which satisfies the condition of stiff consistency for use as a subgrade and subbase material (NGS/FMWH 1997; Gopal and Rao 2011). The gain in strength is attributed to the spherical agglomeration

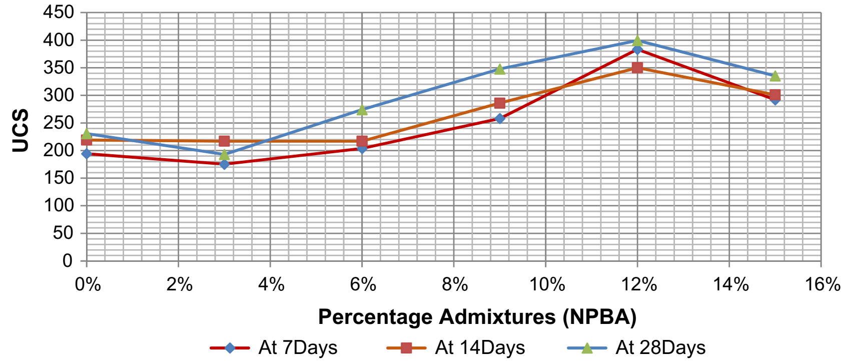


Figure 5. Effect of NPBA on the UCS of the studied lateritic soil.

of particles in the presence of the highly pozzolanic NPBA. A further observation was that the presence of the admixture in the soil increased the frictional angle of the stabilised mixture attributed to the physicochemical and pozzolanic properties of the admixture and to its ability to reduce adsorbed water thereby making soils with higher clay content to behave like granular soil.

Conclusion

From the foregoing, it will be concluded as follows;

(1) It is seen that at 9% by weight admixture the optimum value of the CBR was achieved, which met the specifications for materials to be used as sub-base and base course material in pavement construction.
(2) At 12% by weight addition of the NPBA, the UCS gained enough strength to meet the requirements for a material to be used as sub-base and base course also.
(3) Drawing conclusions from Construction standards, it could be observed that the natural soil is good for construction purposes as sub-grade material because it recorded a reasonable and acceptable MDD of 1.84 g/cm^{3}and CBR value of 14% but the addition of the right proportions of the NPBA achieved great strength properties.
(4) Finally, NPBA has proven beyond doubts its stabilisation abilities as it enhanced the engineering properties of stabilised soils from its lowest proportion of 3–15% as none fell short of the roads and bridges construction requirements for sub-grade, sub-base and base course. The primary concern was on the 14 days curing time, which decreased remarkably before an associated increase, but it is pertinent to point out the fact that it should be used in greater percentage particularly 9, 12 and 15% in order to attain reasonable and satisfactory engineering properties.

Disclosure statement

No potential conflict of interest was reported by the author.

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