

Improvement of the Index and Compaction Characteristics of Black Cotton Soil with Palm Kernel Shell Ash

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ABSTRACT

The expansive soil obtained from Baure in Yamaltu Deba Local Government Area was rich in clay mineral (montmorillonite), unstable and difficult to use for construction purposes. The soil treated with up to 12% palm kernel shell ash (PKSA an agro – waste) by weight of dry soil to improve index properties and compaction characteristics of the soil using PKSA. Index tests were carried out to classify the natural soil, while the moisture-density relationships were determined by compaction tests on the natural and treated soils using three energy levels viz, British Standard light (BSL), West African Standard (WAS) and British Standard heavy (BSH). BCS used in the study was classified as A-7-5 (20) using the American Association of State Highway and Transportation Officials (AASHTO) and CH group in the Unified Soil Classification System (USCS). Tests results show that specific gravity of the soil increased from 2.29 for the natural to 2.34 at 12% treatment. Liquid limit decreased from 76.2% for natural to 73.4% at 10% PKSA content. Plastic limit increased from 40% for the natural soil to 47.1% at 12% PKSA content treatment. Maximum dry density (MDD) values decreased from 1.44Mg/m³, 1.5Mg/m³ and 1.65Mg/m³ for the natural soil to 1.38Mg/m³ at 10%, 1.45Mg/m³ at 10% and 1.56Mg/m³ at 6% PKSA content for BSL, WAS and BSH compaction energy levels respectively. On the other hand, optimum moisture content (OMC) value decreased from 28.5% and 22.4% for the natural soil to 22.4% and 21.0% at 12% PKSA content for BSL and WAS energies respectively while the value for BSH energy increased from 18.2% to 19.0% at 8% PKSA content. Results show that PKSA is suitable for the improvement of the index properties and compaction characteristics of BCS; and its beneficial use will reduce the attendant disposal problem on the environment.

Keyword-- Black Cotton Soil, Palm Kernel Shell Ash, Index Properties, Compaction Characteristics and Improvement

road and air field construction because of their swelling characteristics due to the presence of high percentages of expansive clay minerals (i.e. montmorillonite). Many roads and foundations of buildings have been reported distressed due to the seasonal volume change (i.e. swell and shrinkage) of these soils (Chen, 1988). These soils swell when in contact with water and shrink on drying. The soil deposits are usually extensive making it impossible to avoid or by pass during construction of engineering projects.

Expansive soils were reported to inflict damages on earth structures and facilities worth billions of dollars to repair annually (Gidigas and Gawu, 2013). Black cotton soils possess low strength and undergo excessive volume changes, making their use in constructions very difficult. The properties of the black cotton soils can be altered in many ways viz, mechanical, thermal, chemical and other means. Improvement of black cotton soils by chemical additives is a common stabilization method (Bell, 1993). Among various additives available, lime, fly ash and cement are the most widely and commonly used for the stabilization of the black cotton soils.

In Nigeria, black cotton soils are found predominantly in the North - Eastern region of the country, lying within the Chad Basin and partly within the Benue trough, which occur over an area of 4 million hectares between latitudes 8° 30' and 12° 30' N and longitudes 10° and 14° E within the Savannah ecological zone of the country (Klinkenberg and Higgins, 1968). It is believed that these soils derive their origin in Nigeria, from Basalts of the upper Benue Trough which cover several hundred square kilometers, extending North and East of the Jos Plateau, and from quarter-nary sediments of lacustrine origin, from the Chad Basin consisting mainly of shale, clays and sandy sediments. (Klinkenberg and Higgins, 1968)

The use of industrially manufactured soil improving admixtures such as cement, lime and bitumen made the cost of construction of stabilized road high whereby the under developed and poor nations are unable to provide accessible roads to meet the need of the rural dwellers (which form larger percentage of their population)

I. INTRODUCTION

Expansive soils (also known as black cotton soils because the cotton plant thrives well on them) are major problematic soils of some countries, especially in Africa and India. They are poor materials and difficult to use for

of the regions covered by black cotton soil. Again, the World Bank has been expended huge amount of money on research aimed at harnessing industrial waste products for further usage (Oriola and Moses, 2010), however, cheaper alternatives could be source such as agro waste.

The Palm kernel shells (see Plate 1) are a waste product from the processing of oil fruits in palm oil mills. Edible oils are extracted from both the oil palm fruit mesocarp fibre and the core (palm kernel oil which is used in the food and soap industry).



Plate 1: Typical sheared palm kernel shells from oil palm fruit

Palm kernel wastes produced from small and medium-scale industries pose a serious environmental problem in Nigeria. A portion of these wastes is used as feed supplements for livestock but most are disposed of by burning in the industry for heating purposes. This practice is an environmental concern and the by-product ash is also a problem which needs to be addressed (Kolade *et al* 2006). Alternative economic disposal methods are necessary and one potential method is to use the wastes as additives to improve soil properties. This research will evaluate the effect of palm kernel shell ash waste as an additive to improve black cotton soil.

Palm kernel shell ash and shell have the potential to be used as a partial replacement for cement and aggregate, leading to reduction in the cost of construction, and a convenient means of waste disposal and resource preservation (Oti *et al.*, 2015). Thus, the possible use of agricultural wastes (such as Palm Kernel Shell Ash - PKSA) will considerably reduce the cost of construction and as well as reduce or eliminate the environmental hazards caused by such a waste.

The study evaluates suitability of palm kernel shell ash (PKSA) for the improvement of the index and compaction characteristics of black cotton soil when used in road construction with the following objectives:

- a) Determination of the physical properties of the natural and stabilized black cotton soil with their oxide composition.

The palm kernel shell ash (i.e. the burnt sheared shell) has pozzolanic properties that enables it as a partial replacement for cement and also plays an important role in the strength and durability of soil, (Oti *et al* 2015 and Ogbodo, 2017). Its use in the stabilization of soils will lessen the increasing challenges of scarcity and high cost of cement. The focus of this study is to evaluate the potency of palm kernel shell ash when used as an additive for stabilizing black cotton soil in road construction.

- b) Determination of the moisture-density relationship of the natural and treated soil using three compactive efforts (i.e., British Standard light, BSL, West African Standard, WAS and British Standard heavy, BSH).
- c) Statistical analysis of test results using analysis of variance (ANOVA) and regression analysis

II. MATERIALS AND METHODS

2.1 Materials

2.1.1 Black cotton soil

The soil sample used in this study was black cotton soil, which is locally called “Kasan Kalar” was obtained from Baure in Yamaltu - Deba Local Government Area (Latitude 10° 14’N and longitude 11° 24’E) of Gombe state using the method of disturbed sampling, the soil collected was in depths range of 1.0 – 2.0 m. The moisture content of the samples was determined. Then sample was air-dried. All the clods and lumps in the sample were broken and classification test was carried out on the sample collected according to Unified Soil Classification System (USCS) and Association of America State Highway and Transport Officials (AASHTO). Test were carried out to determine the optimum quantity of palm kernel shell ash required for desired quality of the soil treated with palm kernel shell ash (PKSA) in stepped concentration of 2 %

(i.e., 0, 2, 4, 6, 8, 10, and 12 %) to improve the engineering properties of the soil. All tests were carried out in accordance with BS 1377(1990) and BS 1924 (1990) for the natural and treated soils, respectively.

2.1.2 Palm kernel shell ash

The ash was obtained from burnt palm kernel shells collected from waste dump of an oil palm fruit processing mill in Abeokuta, Ogun state. The dirt was removed and the shells were sun-dried for 4 days to facilitate proper combustion during burning. It ash was allowed to cool and sieved through No. 200 sieve (75 μ m aperture). The ash was stored in an airtight container to prevent gain or loss of moisture and any form of contamination.

2.1.3 Water

The portable water available in the laboratory was used for the study.

2.2 Methods

The following tests were carried out on the natural soil in accordance with BS 1377(1990) and the measured pksa was added to the determined soil mass and hydrated by 70% water for 24hours (treated) soil in accordance with and BS 1924 (1990), respectively.

The following tests would be performed moisture content, sieve analysis, Atterberg limits, compaction and specific gravity

2.2.1 Procedures

Preliminary tests such as moisture content, specific gravity, particle size distribution, Atterberg limits tests, and specific gravity were carried out to classify the soil. The moisture-density relationships to determine optimum

moisture content (OMC) and maximum dry density (MDD) by compaction tests on the natural and treated soils using the three compaction energy levels viz, British Standard light (BSL), West African Standard (WAS) and British Standard heavy (BSH) were carried out in accordance with procedure stated in BS 1377 (1990) and BS 1924 (1990).

The cation exchange capacity (CEC) test was carried out in accordance with the procedures given by ISRIC (1998) and the chemical composition of the soil and the ash was determined using XRD in accordance with ASTM C618 – 78(1978).

III. RESULTS AND DISCUSSION

3.1 Properties of the Material Used in the Study

3.1.1 The Natural Black Cotton Soil

The results of the tests conducted for the identification /determination of the properties of the natural soil before treatment are presented in Table 1, the soil is greyish black in colour and has a liquid limit of 76.2 %, plastic limit of 40.0 %, plasticity index of 36.2 % and free swell of about 81.7 % while the particle size distribution curve for the natural soil is shown in Figure.1. The percentage passing sieve No 200 or 75 μ m sieve in wet sieving analysis was 89.7 %, and the soil is classified as an A-7-5 (20) subgroup soil based on the American Association of State Highway and Transportation Officials Soil Classification System (AASHTO, 1986) and CH based on the Unified Soil Classification System, USCS (ASTM, 1992).

Table 1: Properties of the natural black cotton soil

Property	Value
Moisture Content (%)	26.75
Percentage Passing BS No 200 Sieve (%)	89.7
Atterberg Limit	
Liquid Limit (%)	76.2
Plastic Limit (%)	40
Plasticity Index (%)	36.2
Linear Shrinkage (%)	21.3
AASHTO Classification	A – 7 – 5 (20)
Unified Soil Classification System (%)	CH
Specific Gravity	2.29
Free Swell (%)	81.7
Cation Exchange Capacity	53.5
Maximum Dry Density (Mg/m ³)	
British Standard Light	1.45
West African Standard	1.50
British Standard Heavy	1.65
Optimum Moisture Content (%)	
British Standard Light	28.5
West African Standard	22.4
British Standard Heavy	18.2

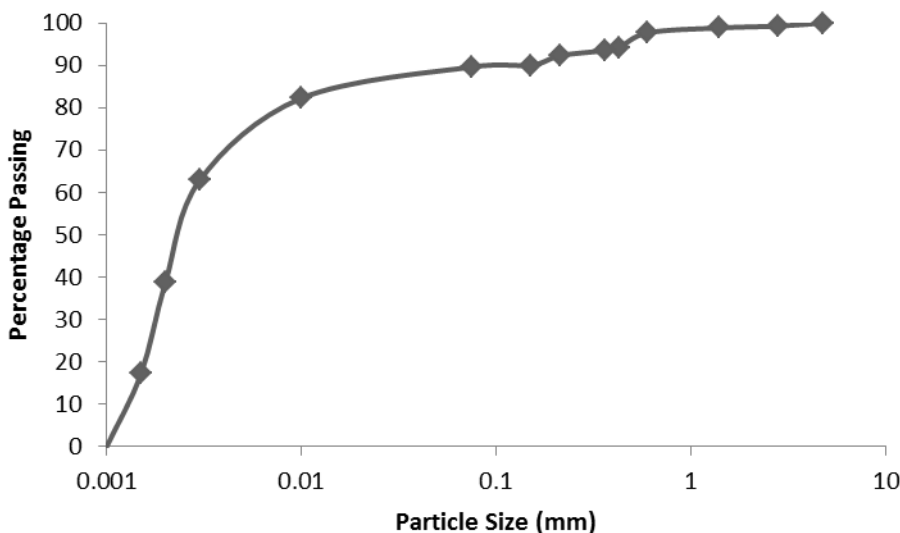


Figure 1: Particle size distribution curve of the natural black cotton soil

The Highway Research Board (1943) and Nigerian General Specifications (1997) specify that the limits of 50 % passing No. 200 sieve, 40 % liquid limit and 18 % plasticity index is required for base and sub base materials. Based on the results summarized in Table 1 the natural soil is not suitable for use as a base or sub base material in road construction.

3.2 Oxide Compositions of the Materials Used in the Study

The oxide compositions of black cotton soil and palm kernel shell ash were determined by X – Ray Diffraction (XRD) as shown in Table 2. Both BCS and PKSA contain aluminium oxide (Al₂O₃), calcium oxide or free lime (CaO), ferric oxide (Fe₂O₃), silicon dioxide or silica (SiO₂) and other compounds in different proportions.

It was also observed that the ash has higher percentage in other oxide compounds, hence will increase the percentages of the compounds in the soil when mix together. The CaO is responsible for hydration reaction (a chemical addition reaction where a hydroxyl group and proton are added to a compound) between the materials.

ASTM C618 –78(1978) specify the combined weight of silica, alumina and ferrous oxides greater than 70% for classes of N, C and F pozzolana. The addition of the combined weight of silica, alumina and ferrous oxides is 75.2 % and based on other tests recommended by ASTM C618 which includes Sulphite (SO₃), Moisture Content and loss on ignition, then, the PKSA used in the research may be classified as F Pozzolans.

Table 2: Chemical compositions of black cotton soil and palm kernel shell ash

Chemical Composition	Concentration (Wt. %)		
	*Black Cotton Soil	**Black Cotton Soil	Palm Kernel Shell Ash
Na ₂ O		0.814	4.928
MgO		0.807	8.529
Al ₂ O ₃	16.19	16.700	18.991
SiO ₂	31.01	45.188	49.884
P ₂ O ₅		0.911	4.561
K ₂ O		1.304	15.049
CaO		2.214	3.332
TiO ₂	1.34	0.892	0.688
Fe ₂ O ₃	4.74	5.295	6.341
pH		7.86	8.60

* Osinubi and Ijimdiya (2008).

3.3 Effect of Palm Kernel Shell Ash on the Properties of Black Cotton Soil

3.3.1 Specific gravity

The variation of specific gravity of black cotton soil-palm kernel shell ash mixture at various PKSA contents is shown in Figure 2. Generally, it was observed that specific gravity of the mixtures considered increases with higher palm kernel shell ash content. The value of specific Gravity of the soil decreased from 2.29 for the natural soil to a value of 2.16 at 4% treatment soil and thereafter progressively increased to 2.34 at 12% treatment.

The initial decrease may due to partial replacement of the soil particles by the palm kernel shell ash which was of lesser density compare with that of soil.

The increase may be due to: (i) fine particles of the palm kernel shell ash that fill the void spaces between the larger particles of black cotton soil, leading to higher density of the soil -pksa mixture (Edeh *et al*, 2012) and (ii) rearrangement of soil/palm kernel shell ash mixture particles in phase-to-phase structures resulting from cation exchange reactions of the mixture.

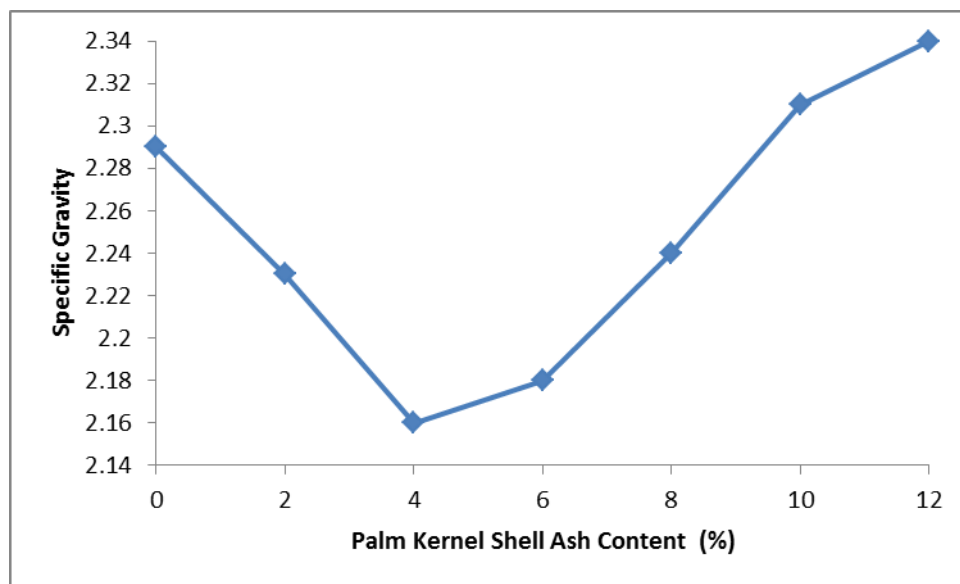


Figure 2: Variation of specific gravity for black cotton soil with palm kernel shell ash mixtures

From one – way analysis of variance (ANOVA) test on specific gravity results shown in Table 3 shows that

the effects of palm kernel shell ash on black cotton soil is statistically significant because F_{Cal} is greater than F_{Crit} .

Table 3: One-way analysis of variance result for specific gravity of BCS-PKSA mixtures

Property	Source of Variation	Degree of Freedom	F calculated	P-value	F critical	Remarks
Specific Gravity	Palm Kernel Shell Ash	1	6.385	0.0241	4.600	Significant Effect

3.3.2 Dry sieving using optimum moisture content from British Standard light compaction:

The particle size distribution curves of BCS-PKSA mixtures using optimum moisture content from BSL compaction are shown in Figure 3. An increase in the percentage of fines with increasing palm kernel shell ash contents was noticed. A change was also observed in the coarse sizes especially at 600 μm. This was in agreement with the findings reported by Sani (2009).

The increase in fine particles was due to the addition of palm kernel shell ash, which acted as a nucleus to which the soil particles adhered. With increase in the ash contents the quantity of free silt and clay progressively reduced and coarser materials were formed, this is in agreement with the findings reported by Mu'azu (2007).

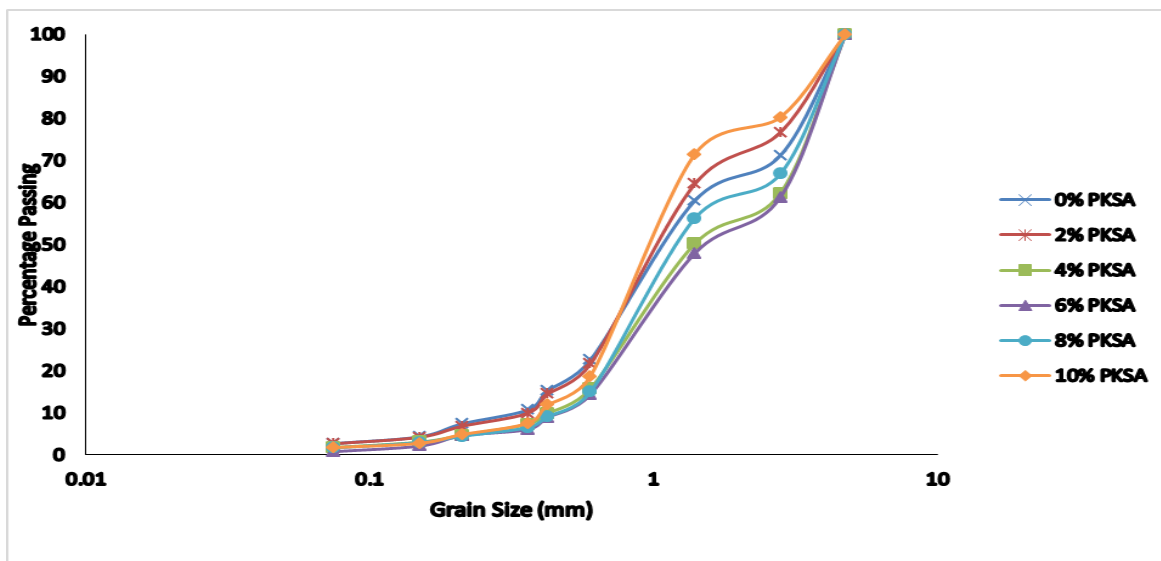


Figure 3: Particle size distribution curves of BCS-PKSA mixtures (BSL compaction)

Similar effects as observed in BSL was also observed for WAS and BSH compaction energy levels. The PKSA content on particle size distribution caused the BCS-PKSA mixtures to flocculate and agglomerate more and hence the BCS-PKSA mixture became coarser enabling the clay particle to form pseudo silt sizes.

There was a reduction in the percentage of fines with increase in PKSA content as shown by the curves in Figure 3. A little change was noticed in the coarser sizes which is due to agglomeration and flocculation of the particles (Sani, 2009).

3.3.3 Wet sieving

The particle size distribution from hydrometer test for the natural and treated soil samples are shown in Figure

4. It was observed in sand fraction that there was an increase in the percentage of sand fraction from 6.7 % at 0 % PKSA to 10.9 % at 6 % PKSA. There is a slight decrease in the silt and clay fraction of the natural soil, which decrease from 39.7% and 53.6 % to 39.2 % and 48.6 % at 8 % and 6 % PKSA content, respectively.

This reduction was due to the cation exchange capacity of the stabilizer and the soil particles. This reduction also may be as result of the agglomeration and flocculation of the clay particles and as a result of ion exchange at the surface of the clay particles; as the excess Ca²⁺ in the palm kernel shell Ash reacts with the lower valence metallic ions in the clay structure (Sani, 2009).

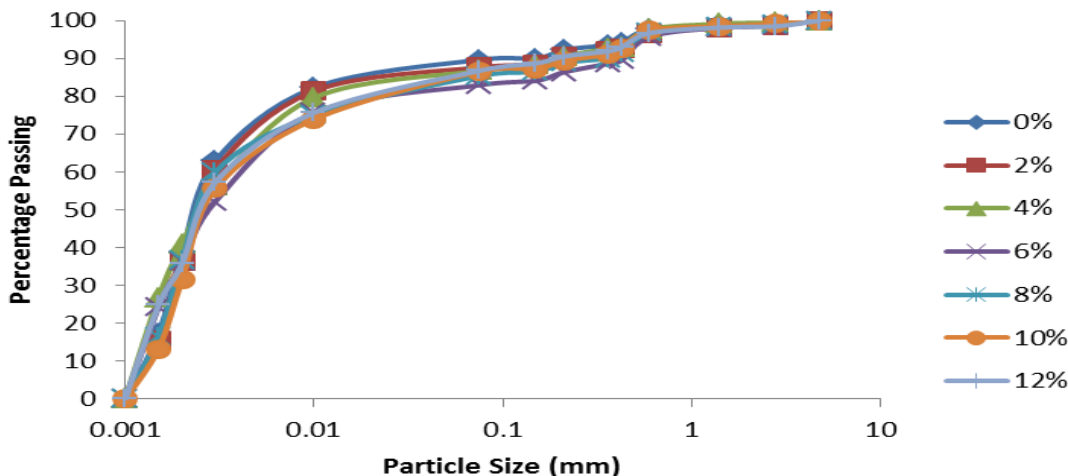


Figure 4: Particle size distribution curves of black cotton BCS-PKSA mixtures (Wet sieving)

4.3.4 Atterberg limits

The effect of PKSA content on the Atterberg limits are shown in Figure 5, The liquid limit and the plasticity index values decreases with increasing PKSA contents while the plastic limit increases. This trend is similar to the findings reported by Mu’azu (2007) for black cotton soils.

The reduction in liquid limit with PKSA content may be as a result of the exchange reaction which flocculates the soil particles together and reduces the clay size fraction and hence increase the surface area (Muhammad and Yamusa, 2013)

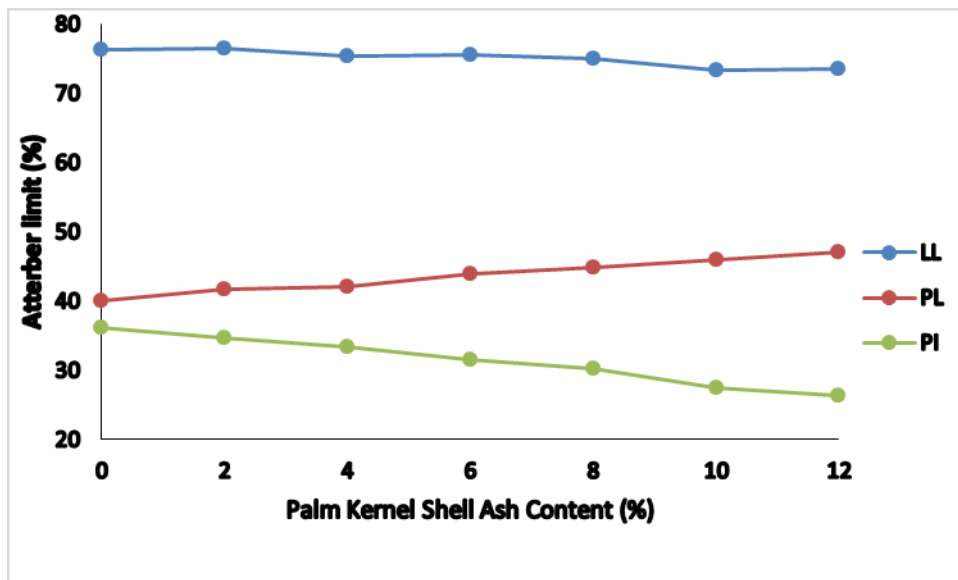


Figure 5: Variation of Atterberg limits of black cotton soil with palm kernel shell ash content

From the one-way analysis of variance (ANOVA) test on Atterberg limit results shown in Table 4 show that

the effects of palm kernel shell ash is statistically significant because F_{Cal} is greater than F_{Crit} .

Table 4: One-way analysis of variance result for Atterberg Limit of BCS-PKSA mixtures

Property	Source	Degree of Freedom	Fcal	P-value	F crit	Remarks
Moisture Content	Liquid Limit	1	1792.793	1.3E-12	5.0	Significant effect
	Plastic Limit	1	450.5317	1.2E-09	5.0	Significant effect
	Plasticity Index	1	136.5818	3.74E-07	5.0	Significant effect

3.4 Compaction characteristics

3.4.1 Maximum dry density

The variation of maximum dry density (MDD) of black cotton soil with palm kernel shell ash content for the compactive efforts used in this study are shown in Figure 6.

Generally, MDD values decreases with higher PKSA content and compactive effort. For BSL compactive effort, the MDD value initially decreased from 1.44Mg/m³ for the natural to 1.34Mg/m³ at 2% PKSA treatment and increased to 1.38Mg/m³ at 12% PKSA. The trend shows that MDD generally decreased with PKSA content.

For the WAS compactive effort, the MDD initially decreased from a value of 1.50Mg/m³ for the natural soil to a 1.47Mg/m³ at 2% PKSA treatment and at 12% PKSA

treatment the MDD increased to 1.56Mg/m³ which higher than that of the natural Soil.

For the BSH compactive effort, MDD decreased from an initial value of 1.65Mg/m³ for the natural soil to a value of 1.57Mg/m³ at 12% PKSA content.

This behaviour could partly be attributed to the flocculated and agglomerated clay particles occupying larger spaces leading to corresponding decrease in MDD (O’Flaherty 1988; Osinubi *et al.*, 2016). Furthermore, the reduction in MDD with increases in palm kernel shell ash could also be due to the partial replacement of soil particles that are of higher specific gravity (2.44) in a given volume, by particles of Palm kernel shell ash of comparatively lower specific gravity (1.57).

The increase in MDD at higher PKSA contents in all the compactive efforts could be because PKSA occupies most voids thereby increasing the density of soil.

The one-way analysis of variance (ANOVA) test on the MDD result for BSL, WAS and BSH

For the three compactive shown in Table 4 showed that the effects of PKSA on black cotton soil were statistically significant ($F_{CAL} = 5.36 > F_{CRIT} = 3.10$)

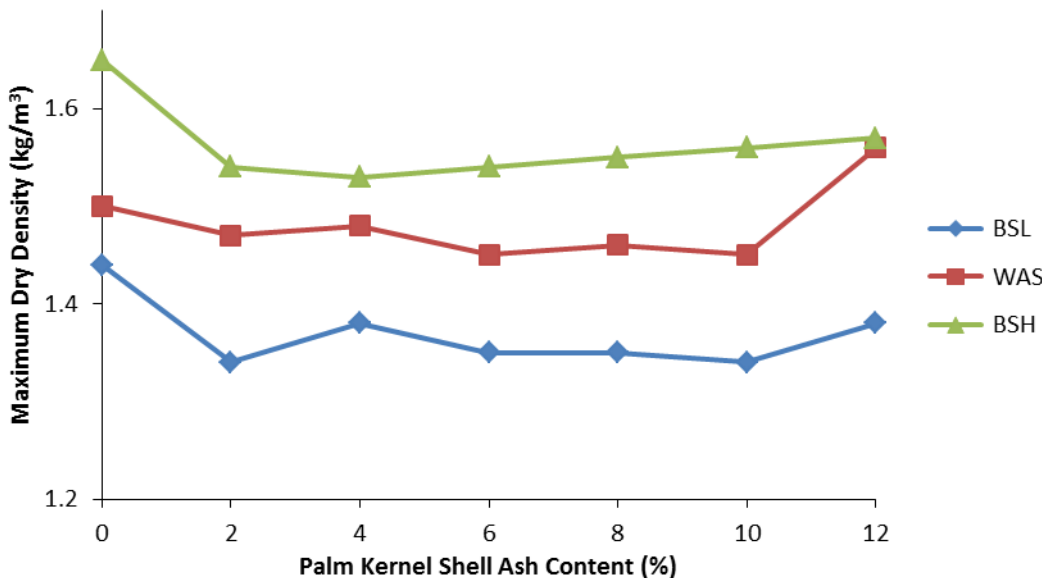


Figure 6: Variation of maximum dry density of black cotton soil with palm kernel shell ash content

Table 5: One-way ANOVA on the effect of PKSA on Max. Dry Densities of BSL, WAS and BSH

Property	Source	Degree of Freedom	Fcal	P-value	F crit	Remarks
Maximum Dry Density	BSL	1	13.6	0.004147	5.0	Significant effect
	WAS	1	13.1	0.004732	5.0	Significant effect
	BSH	1	12.7	0.005105	5.0	Significant effect

3.4.2 Optimum moisture content

The effect of palm kernel Shell ash content on optimum moisture content (OMC) of the Black Cotton Soil for BSL WAS and BSH compactive efforts are shown in figure 7

Generally, OMC decreased with higher PKSA treatment but reduced with higher compactive effort. The decrease in OMC for the various compactive efforts used was solely due to the desiccation induced by the introduction of PKSA into the voids of the natural soil. These voids were originally occupied by both moisture and air.

With the introduction of PKSA into the soil all the available water molecules were used up in the initial

hydration reaction which consequently lowered the OMC values with increased in PKSA content, the demand for water by various cations and the clay minerals particles undergo hydration reaction, thus decreasing the OMC (Majularani et al 2015). Another reason could be attributed to the increasing surface area caused by the higher amount of the PKSA (finer particles), which required more water for the lubrication of the entire material (Oyelakin, 2011)

The one – way analysis of variance (ANOVA) test on the OMC result in Table 5; showed that the effects of PKSA on black cotton soil is statistically significant ($F_{CAL} = 115.215 > F_{CRIT} = 3.098$).

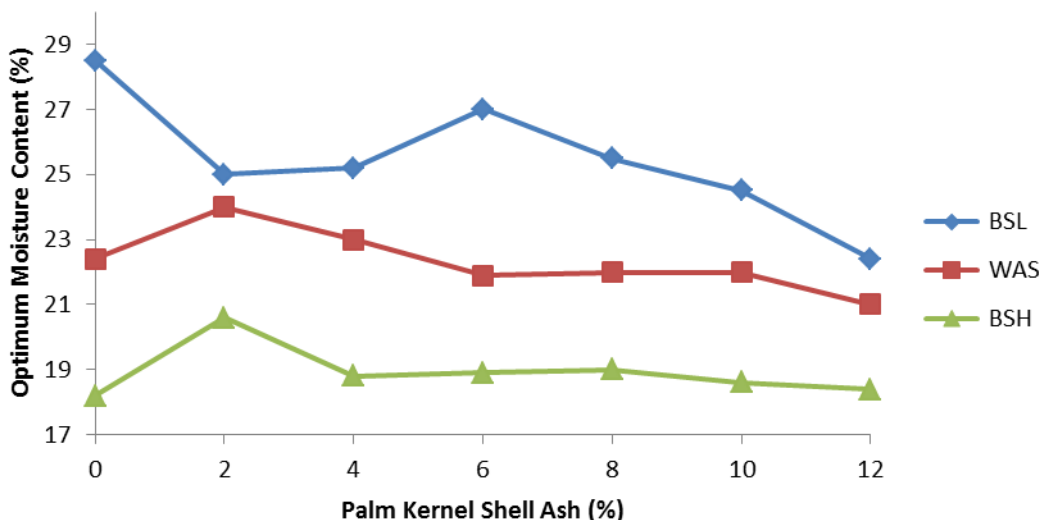


Figure 7: Variation of OMC of black cotton soil with palm kernel shell ash content

Table 6: One-way ANOVA on the effect of PKSA on OMC of BSL, WAS and BSH

Property	Source	Degree of Freedom	Fcal	P-value	F crit	Remark
Optimum Moisture Content	BSL	1	118.7	7.2E-07	4.7	Significant Effect
	WAS	1	126.9	3.47E-06	5.3	Significant Effect
	BSH	1	59.6	1.61E-05	5.0	Significant Effect

IV. CONCLUSION

Based on the results of tests conducted on the natural BCS, PKSA and PKSA – BCS mixture the following conclusions can be made:

- The grayish black soil is fine-grained with about 89.7% of the particles passing No. 200 sieve (0.075µm aperture). It belongs to the CH group in the Unified Soil Classification System or A-7-5 (20) soil group of the AASHTO soil classification system. Furthermore, the soil is of high swell potential with high plasticity based on NBRI classification.
- Atterberg limits improved based on decreased liquid limit and increased plastic limit while plasticity index decreased with higher PKSA content
- The compaction characteristics (MDD and OMC) recorded decrease values with higher PKSA content. However, the values increased with higher compactive efforts.
- The one-way analysis variance test carried out confirmed the suitability of Palm Kernel Shell Ash as an admixture for stabilizing the engineering properties of black cotton soil.

4.1 Recommendation

Based on the test results obtained from the natural and treated black cotton soil, palm kernel shell ash can be used for the improvement of the properties of black cotton soil when compacted with BSH energy for use in light traffic road.

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