



## Improvement of Strength Properties of Black Cotton Soil Using Corn Cob Ash and Cement Kiln Dust for use as Base Materials

Sani J. E., Moses G., Adoga E. J., Mustapha K. K.

Department of Civil Engineering,  
Nigeria Defence Academy, Kaduna Nigeria

### ABSTRACT

The preliminary investigation of the black cotton soil (BCS) collected from Deba Local Government Area of Gombe State, shows that it belongs to A-7-6 or CH in AASHTO and Unified Soil Classification System (USCS), respectively. Soils under these groups are usually very poor for engineering use. The soil was treated with cement kiln dust (CKD) – corn cob ash (CCA) blend in stepped concentration of 0, 2, 4, 6 and 8 as well as 0, 2, 4, 6, and 8, for CKD and CCA, respectively by dry weight of soil. Compaction was carried out using British Standard Heavy (BSH). The liquid limit decreased from 57.8% for the natural soil to 49.2%, while the plastic limit decreased from 19.16% for the natural soil to 14.65% at 6% CKD/6% CCA treatment. Unconfined compressive strength (UCS) values of 1037.18kN/m<sup>2</sup> recorded for the natural soil increased to 1807.55kN/m<sup>2</sup> at 6% CKD/6% CCA for specimens compacted and cured under 7 days. The California bearing ratio (CBR) values (unsoaked condition) of the compacted natural soil increased from 15% to 89% when treated with 6% CKD/6% CCA. For the 24-hour soaked condition the CBR values obtained increase from 10%-31%. The 6% CKD/8% CCA blend attained 66.85% resistance to loss in strength. Statistical analysis of the results showed that improvements in the soil characteristics can be attributed to the CKD/CCA treatment with more significant effects upon addition of CCA. The results recorded shows that stabilization with CKD/CCA blend significantly improved the strength properties of the Black Cotton Soil to be used as a base material in highway construction.

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### INTRODUCTION

Expansive soils are unreliable due to high volume change and moisture sensitivity. The well-known type of expansive soil is the Black Cotton Soil (BCS). Black cotton soil has colors ranging from light grey to dark grey and black Eberemu *et al.*, (2019). Black cotton soil are confined to semi-arid region of tropical and temperate climatic zones and are abundant where the annual evaporation exceeds the precipitation (Ikeagwuani, *et al.*, 2019). Black cotton soil are very hard in dry state and possessed high bearing capacity (Prasad and Ahalya 2023) Black cotton soil at dry state crack to the dept of about 1.5m deep and 0.9m width making it very difficult to

handle in construction work, but when black cotton soil come in contact with moisture it expand suddenly and start swelling due to this properties its strength and other engineering properties are very poor (Nigatha and Neduri (2022)). To improves on these properties the soil needs to undergoes stabilization, which will improve its shear strength and improves its shrink-swelling properties and other engineering properties. To overcome the adverse effect of expansive soil, many researchers are consistently searching for various alternatives via ground improvement techniques.

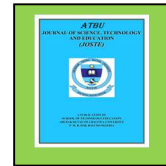
The main aim of the researcher is to stabilize the volume change behavior, improve

Corresponding author: Adoga E. J.

✉ [adogajasper@gmail.com](mailto:adogajasper@gmail.com)

Department of Civil Engineering, Nigeria Defense Academy Kaduna Nigeria.

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plasticity characteristics, and significantly enhance the strength characteristics. Several methods are adopted for improving the geotechnical properties of the expansive soil. They include methods such as mechanical, chemical, and bio- agro stabilization. However, many chemical substances have miffed the environment (Akinmade (2008)). To armor the environment, a lot of research is being carried out. As a result of these research studies, corn cob ash/cement kiln dust will be one among which are more effective in augmenting the geotechnical properties of the soil. It is an agro industrial method that is environmentally friendly and provides durability.

Cement kiln dust (CKD) is an industrial waste from cement production, the quantities and characteristics of CKD generated depend upon a number of operational factors and characteristics of the inputs to the manufacturing process (Oriola *et al.*, (2017)). Although the relative constituent's concentration in CKD can vary significantly, CKD has certain physical characteristics that are relatively consistent. When manage on a site in a waste pile, CKD can retain these characteristics within the pile when developing an externally weathered crust. Corn Cob Ash the corn cob was gathered after the harvest season and was dry by sun before taken to Yusuf Dan Shoho teaching hospital Tudun Wada for incineration and combustion, the corn cob was combusted at a temperature of 700°C into ash and was taken to a grinding machine at Bakin Dogo market for crushing into powder before sieves through sieves 75µm at lab for the test.

In recent years, agro industrial application for soil improvement is gaining popularity, for stabilize soil against erosion for runway, roadway, and helipad construction (Osinubi and Stephen, 2005); Later, research on the interaction between soil and agro industrial materials has transcended into engineering applications. Agro industrial materials are alternative to chemical methods because of their nontoxic nature and cost-saving benefit (Oriola *et al.*, (2017)). This has meant that in some cases, more effectives and economical method of

stabilizations were not considered because they are less well known.

Increasing emphasis on the use of suitable materials for constructions has led to the uses of varieties of stabilizing agents in soil. One of such materials is the uses of corn cob ash with cement kiln dust, given the availability of corn cob and the cheap cost of cement kiln dust, it is agreed that their uses for soil stabilizations is highly economical and accessible.

Primarily, the objectives of soil stabilization were to improve the soil strength, decrease permeability and moisture absorption, improve soil bearing capacity and the durability under adverse weather condition (Osinubi and Stephen, 2005); However, the behavior of untreated specimen and treated specimen has been shown to be different. This is so because untreated specimen develops maximum shear stress at maximum dry densities which occur at optimum moisture content. But for treated specimens, Researchers such as (Chijioke, 2016, Osinubi *et al.*, (2011), have observed that for every pozzolana there is molding water content required for achieving maximum shear strength which is completely independent of the maximum dry density and optimum moisture content. And this value could be on the dry or wet side of optimum moisture content depending on the compactify energy level and the type of pozzolana. Cement kiln dust (CKD) is an industrial waste from cement production. As with most large manufacturing industries, by-products are generated. Cement kiln dust is a fine-grained solid material generated as the primary inherent process residue at all cement plants.

## MATERIAL AND METHOD

### Materials

#### Black Cotton Soil

The disturb black cotton soil was obtained from dadin kowa axis of Yamaltu Deba local government area of Gombe state at a depth of 1.5m deep (Latitude 14°26'N and longitude 15°33'E) in terms of extern of deposit black cotton soil is not found only in Gombe state but all-over north-eastern Nigeria.

### **Cement kiln dust (CKD)**

The cement kiln dust used for this research was collected from Dangote- cement factory Obajana Kogi State.

### **Corn cob ash (CCA)**

The corn cob used for this research was gotten from a farm at Maraba-Rido Kujama Road Kaduna state, at (Latitude 21°19'N and longitude 08°13'E) the specific gravity of the CCA was 1.6

## **METHOD**

### **Index Property**

The index tests on both the natural and stabilized soils were performed following the guidelines established in BS 1377 (1990) and BS 1924 (1990) for the stabilized soil samples. For the treated soil specimens, varying percentages of corn cob ash (0, 2, 4, 6, and 8%) by dry weight of soil were incorporated. The soaked California bearing ratio test method was utilized in accordance with the Nigerian General Specification (1997), which requires that specimens be cured dry for six days and then soaked for 24 hours prior to testing. The assessments conducted on the natural and modified soils included compaction and strength tests (such as the unconfined compressive test, California bearing ratio, and durability test). Compaction was performed at the British Standard Energy level.

### **Compaction**

All compactions were performed using the BSH mould compactive effort. To establish the moisture-density relationships, energy was applied from a 4.5 kg hammer that fell from a height of 45 cm in a 2360 cm<sup>3</sup> mould. The soil was compacted in five distinct layers, with each layer subjected to 27 blows. The California bearing ratio (CBR) compaction utilized the same hammer weight and drop height, where each layer received 62 blows in a 2360 cm<sup>3</sup> mould.

### **Unconfined compressive strength**

The unconfined compressive strength (UCS) was conducted on black cotton soil and treated samples using the British Standard heavy

(BSH) energy level, as per B.S. 1377 (1990), with varying proportions of 0, 2, 4, 6, and 8% corn cob ash, and the addition of 0, 2, 4, 6, and 8 CKD based on dry weight of the soil. The soil samples were compacted into 1000 cm<sup>3</sup> molds at their corresponding optimum moisture content (OMC). After compaction, the samples were removed from the molds and trimmed to dimensions of 38.1 mm in diameter and 76.2 mm in length. Eight samples were prepared; two were cured for 7 days, the remaining six were continued to cure for 14 and 28 days, and another two were soaked in water for 7 days after being cured for 7 days. After the specified duration of curing and soaking, the specimens were positioned centrally on the lower platen of a compression testing apparatus, where a compressive force was applied with a strain control set at 0.10% mm. Measurements were recorded concurrently for the axial deformation and the axial force at regular intervals until the sample failed. The unconfined compressive strength (UCS) of the sample was identified at the point on the stress-strain curve corresponding to the failure. The UCS was computed using the following equation.:

$$UCS = \frac{\text{Failure load}}{\text{Surface Area of Specimen}} \times 100\%$$

### **Durability**

The evaluation of the soil sample's durability (in challenging field conditions) was conducted by measuring its strength loss when submerged in water. This was represented as the ratio of the unconfined compressive strength (UCS) of the specimen that was cured for 7 days and then soaked for an additional 7 days to the UCS of the specimen that was cured for 14 days.:

$$\text{Resistance to loss in strength (\%)} = \frac{UCS(7 \text{ day cured} + 7 \text{ day soaked})}{UCS(14 \text{ day cured})} \times 100\%$$

### **California bearing ratio**

California bearing ratio (CBR) tests were performed on the crudely contaminated and remediated soils in compliance with British Standards 1377 (1990). To assess the mechanical strength of the remediated soils as a subgrade material, the CBR measures the force applied by

Corresponding author: Adoga E. J.

✉ [adogajasper@gmail.com](mailto:adogajasper@gmail.com)

Department of Civil Engineering, Nigeria Defense Academy Kaduna Nigeria.

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the plunger and the depth of its penetration into the specimen. Its goal is to ascertain the relationship between force and penetration. Using BSH energy level, 6 kg soil samples were thoroughly mixed in a 2360 cm<sup>3</sup> mold at their optimal moisture contents. Three layers of compaction each received 62 blows from the 2.5 kg rammer.

In accordance with Nigerian General Specifications (2016), the base plates were taken out (after compaction), and the compacted specimens were put in a sealed plastic bag to cure for six days. Following the sixth day, the specimen was submerged in water for twenty-four hours prior to testing. After the base plates were changed, the specimen was moved to the CBR testing apparatus and placed on the lower plate. After that, the specimen was forced to write at a pace of 1.3 mm each minute until it failed. The process was then repeated for the specimen's base when the mold was turned upside down and the base plate was taken out.

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process was then repeated for the specimen's base when the mold was turned upside down and the base plate was taken out.

The CBR was calculate as:

$$CBR = \frac{\text{Measured Load}}{\text{Standard Load}} \times 100\%$$

Where standard load = 13.24 kN of 2.5mm penetration

= 19.96 kN of 5.0mm penetration

## RESULT AND DISCUSSION

### Index Properties

The findings of preliminary tests were carried out to identify the natural soil and ascertain its characteristics, which are compiled in Table 1. According to the American Association of State Highway and Transportation Officials, the soil falls under categories A – 6 (AASHTO) classification system, high swell potential soil based on the Nigerian Building and Road Research Institute (NBRI, 1983) classification, and low plasticity clay (CL) based on the Unified Soil Classification system (USCS) (ASTM, 1992). The outcomes of the tests indicated the soil's unsuitability as a base course, sub-grade, or sub-base material for building of pavement. Table 2 provides a summary of the oxide composition derived from the Chemical Analysis of Cement Kiln Dust (CKD) and Corn Cob Ash (CCA). However, Tables 3 and 4 reveal the black cotton soil's oxide content and categorization.

**Table 1:** Index Properties Results of Unstabilized Black Cotton Soil

Property	Quantity
Percentage passing BS No 200 sieve	68.5
Natural Moisture Content, %	18.4
Liquid Limit, %	52.8
Plastic Limit, %	19.2
Plasticity Index, %	33.6
Linear Shrinkage, %	22.1
Free Swell, %	85.0
Specific Gravity	2.40
AASHTO Classification	A-7-6 (13)
USCS	CH
NBRI Classification	High swell potential
Maximum Dry Density, Mg/m <sup>3</sup>	1.84

Corresponding author: Adoga E. J.

✉ [adogajasper@gmail.com](mailto:adogajasper@gmail.com)

Department of Civil Engineering, Nigeria Defense Academy Kaduna Nigeria.

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Property	Quantity
British Standard heavy Optimum Moisture Content, %	
British Standard heavy Unconfined Compressive Strength, kN/m <sup>2</sup>	14.6
British Standard heavy California Bearing Ratio, %	898.56
British Standard heavy Colour	6.22
Dominant clay mineral	Greyish black Montmorillonite

**Table 2 Oxide composition of CCA and CKD**

Oxide	CCA (%) <sup>*</sup>	CKD (%) <sup>**</sup>
CaO	3.50	59.84
SiO <sub>2</sub>	63.60	5.8
Al <sub>2</sub> O <sub>3</sub>	5.85	2.4
Fe <sub>2</sub> O <sub>3</sub>	2.95	3.76
MgO	2.11	-
MnO	0.06	0.68
Na <sub>2</sub> O	0.45	0.40
K <sub>2</sub> O	8.42	1.51
SO <sub>3</sub>	1.14	0.92
P <sub>2</sub> O <sub>5</sub>	2.42	-
TiO	0.60	-
Loss on Ignition	8.55	17.2

<sup>\*</sup>Worku *et al.*, 2022

<sup>\*\*</sup>Eberemu *et al.*, 2019

**Table 3 Oxide Composition of Black cotton soil**

Oxide	Concentration (%)
CaO	3.58
SiO <sub>2</sub>	49.00
Fe <sub>2</sub> O <sub>3</sub>	14.23
Al <sub>2</sub> O <sub>3</sub>	15.10
MnO	0.23
TiO <sub>2</sub>	2.09
K <sub>2</sub> O	2.25
V <sub>2</sub> O <sub>5</sub>	0.10
Cr <sub>2</sub> O <sub>3</sub>	0.022
CuO	0.022
Ag <sub>2</sub> O	2.17
Eu <sub>2</sub> O <sub>3</sub>	0.16
LOI	11.1

Eberemu *et al.*, 2019

Corresponding author: Adoga E. J.

✉ [adogajasper@gmail.com](mailto:adogajasper@gmail.com)

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**Table 4:** Categorization of Black Cotton Soil of North Eastern Nigeria

S/No	Plasticity (%)	Index	Free (%)	Swell	%Smaller 1 $\mu$ m	than	Swelling Potential
1	< 20		<50		<20		Low
2	15 – 30		50 – 80		15 – 30		Medium
3	> 30		> 80		> 30		

(Source NBRI, 1983)

### COMPACTION CHARACTERISTICS

#### Maximum Dry Density

MDD decreased from a maximum 1.84Mg/m<sup>3</sup> in the natural state to a minimum 1.74Mg/m<sup>3</sup> at 0% CKD/8% CCA and to a value of 1.76Mg/m<sup>3</sup> at 8% CKD/8%CCA (see Figure 1). The trend of decreasing MDD with admixture contents was reported by Worku *et al.*, (2022).

The same trend was also reported by Osinubi *et al.*, (2007). Other probable reasons for the drop in MDD may be due to the product of cation exchange reaction between CKD-CCA ash and the soil minerals which resulted in the flocculated and agglomerated clay particles.

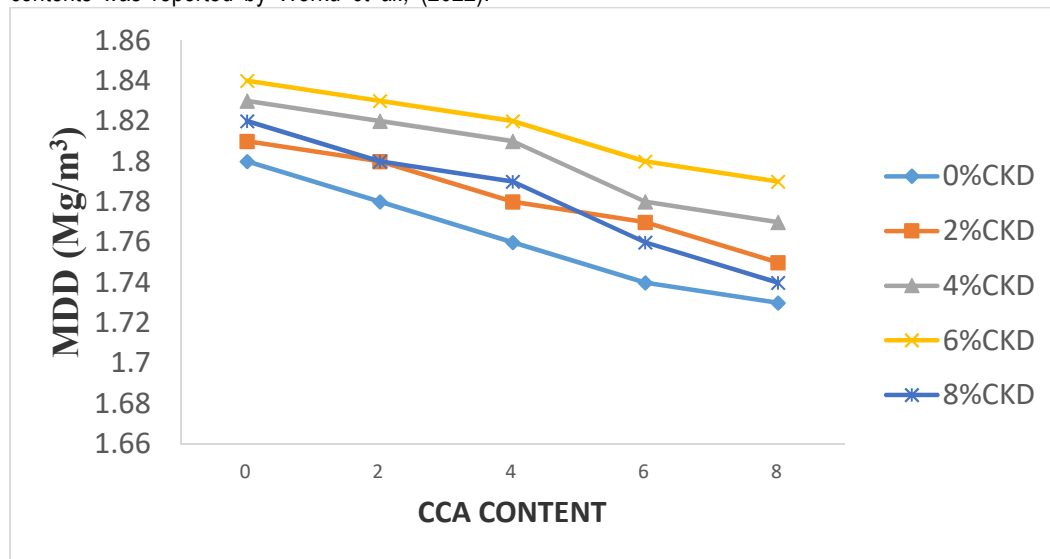


Fig. 1: Variation of maximum dry density of soil – cement kiln dust mixture with CCA content (BSH Compaction)

#### Optimum Moisture Content

The OMC increased from its natural state of 13.4% to 15.6% at 0% CKD/6% CCA (see Figure 2). At 4% and 6% CKD the OMC increases up to 8% CCA while at 0%, 2% and 8% CKD the OMC increases to peak value at 6% CCA before it decreases as CCA increases to 8%. Research findings of Osinubi *et al.*, (2007), Akinmade (2008), Eberemu *et al.*, (2019) and Worku *et al.*, (2022) agree with the trend of increasing OMC with admixture contents. An explanation that was

offered for these trends is that there was increasing desire for water which commensurate with the higher amount of the additives because more water was required for the dissociation of admixtures with Ca<sup>2+</sup> and OH<sup>-</sup> ions to supply more Ca<sup>2+</sup> for the cation exchange reaction. Another reason could be due to the increasing surface area caused by the higher amount of the additives, that required more water for the lubrication of the entire matrix.

Corresponding author: Adoga E. J.

✉ [adogajasper@gmail.com](mailto:adogajasper@gmail.com)

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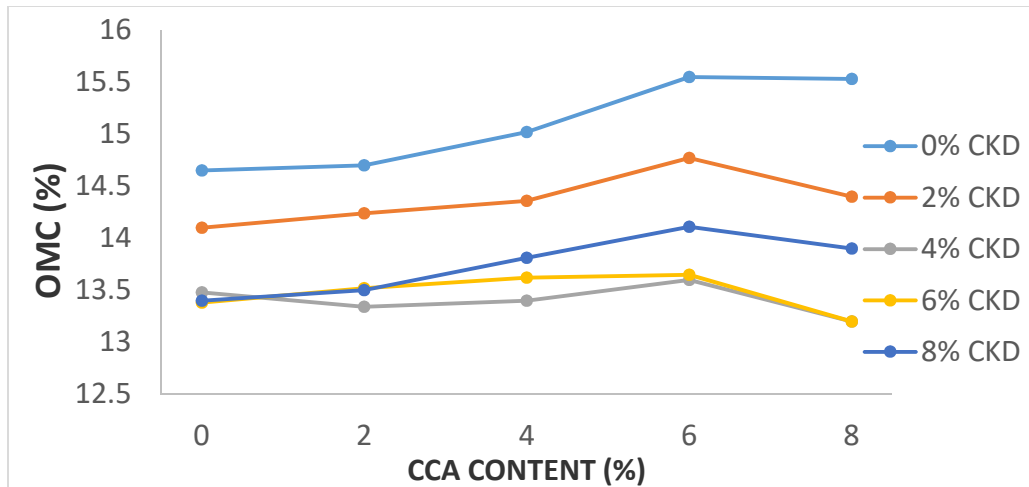


Fig. 2: Variation of optimum moisture content of soil – cement kiln dust mixture with CCA content (BSH Compaction)

### Strength Characteristic

#### Unconfined compressive strength

The general test recommended for use in the determination of the additive to be used in the stabilization of soil is the unconfined compressive strength (UCS) test (Singh, 1991). It is an important factor in the evaluation of the design criteria for the use soil as a pavement material.

#### 7days curing period

The figure 3 shows the different value of UCS with different percentage of CKD and CCA for 7 days curing. The UCS values for the BSH

compaction showed a sharp increase from 898.56kN/m<sup>2</sup> for the natural soil to 1620.47kN/m<sup>2</sup> at 6% CKD/6% CCA. Subsequent addition of CCA content did not increase the UCS, rather, it recorded a slight decrease to a value of 1373.19kN/m<sup>2</sup> at 6% CKD/8% CCA also the UCS increases to a value of 1637.39kN/m<sup>2</sup> at 8% CKD/6% CCA and subsequently decreased to a value of 1569.3919kN/m<sup>2</sup> as the CCA increased to 8%. This is as a result of the CCA occupying greater fraction of the soil matrix which leads to decrease in strength. The finding is in agreement with the finding of Eberemu *et al.*, (2019).

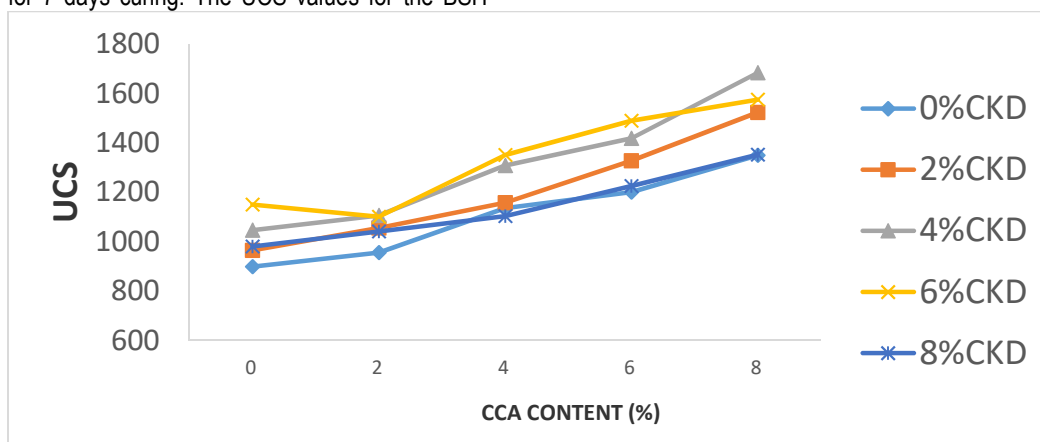


Fig. 4: Variation of UCS (14-day curing) of soil – cement kiln dust mixture with CCA content (BSH Compaction).

Corresponding author: Adoga E. J.

✉ [adogajasper@gmail.com](mailto:adogajasper@gmail.com)

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### 28 days curing period

The figure 5 shows the different value of UCS with different percentage of CKD and CCA for 28 days curing. The same trend of increase in UCS values recorded for specimens cured for 7 and 14 days was also observed for 28 days curing period except that the UCS values increased with the curing periods. The finding is in agreement

with the finding of Eberemu *et al.*, (2019). The UCS for 28 days curing period increased from 1652.06 kN/m<sup>2</sup> for the natural soil to 2980.77kN/m<sup>2</sup> at 6% CKD/6% CCA for BSH compactive efforts which met the 1720 kN/m<sup>2</sup> requirement for base material recommended by TRRL 1977.

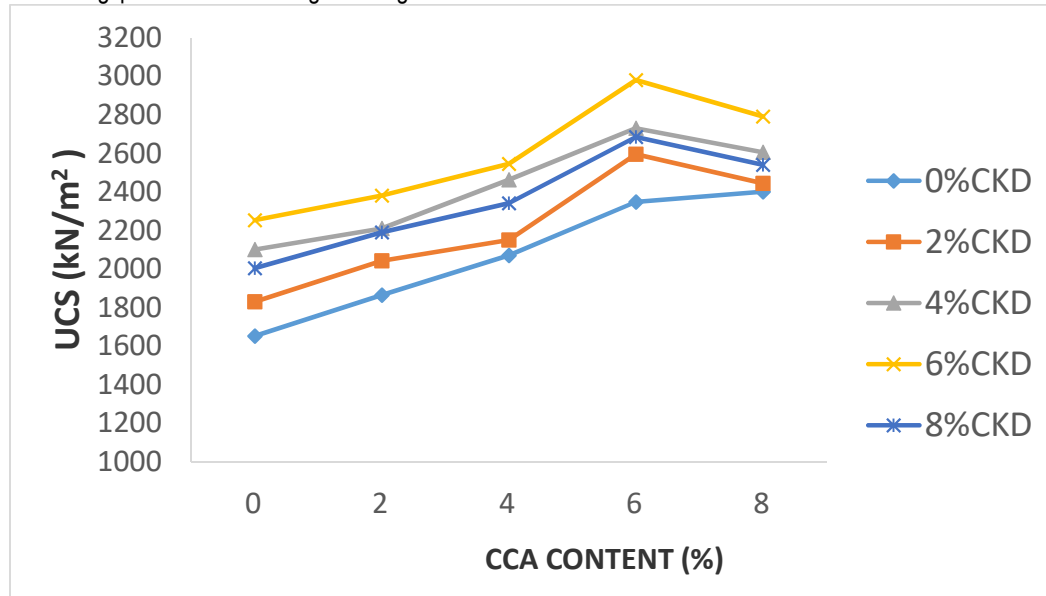


Fig. 5: Variation of UCS (28 day curing) of soil – cement kiln dust mixture with CCA content (BSH Compaction)

### California Bearing Ratio

The California bearing ratio (CBR) value of a soil/stabilized soil is an important parameter in gauging the suitability of the soil/stabilized soil for engineering use. It gives the indication of the strength and bearing ability of the soil. The Nigerian General Specification (1997) recommends a CBR of 80% to be attained in the laboratory for cement stabilized materials to be used as base materials by the mix-in-place method.

For the unsoaked CBR (see Figure 6) shows an increase in CBR value with increase in

the CCA and CKD value to a peak value at 8% CKD. The treatment at 8% CKD/6% CCA gave the best CBR value of 105%, which meet the requirement for base courses recommended for Nigerian General Specification (2016). There were increases in the values of CBR for soaked CBR for BSH compactive efforts but peak at 32% at 4%CKD/ 8%CCA (see Figure 7) which met the requirement of 30% of the Nigerian General Specification (1997) requirement for sub base materials.



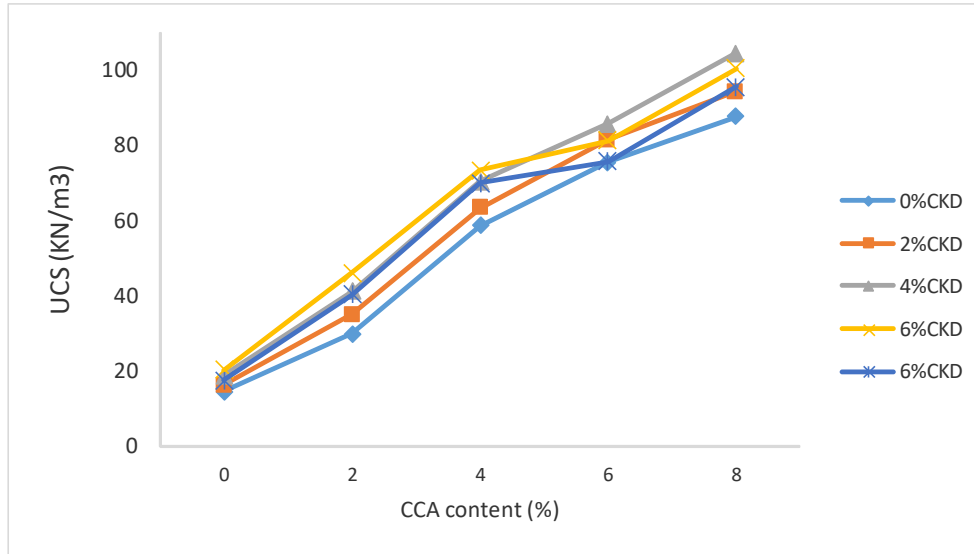


Fig. 6: Variation of CBR (unsoaked) of soil – cement kiln dust mixture with CCA content (BSH Compaction)

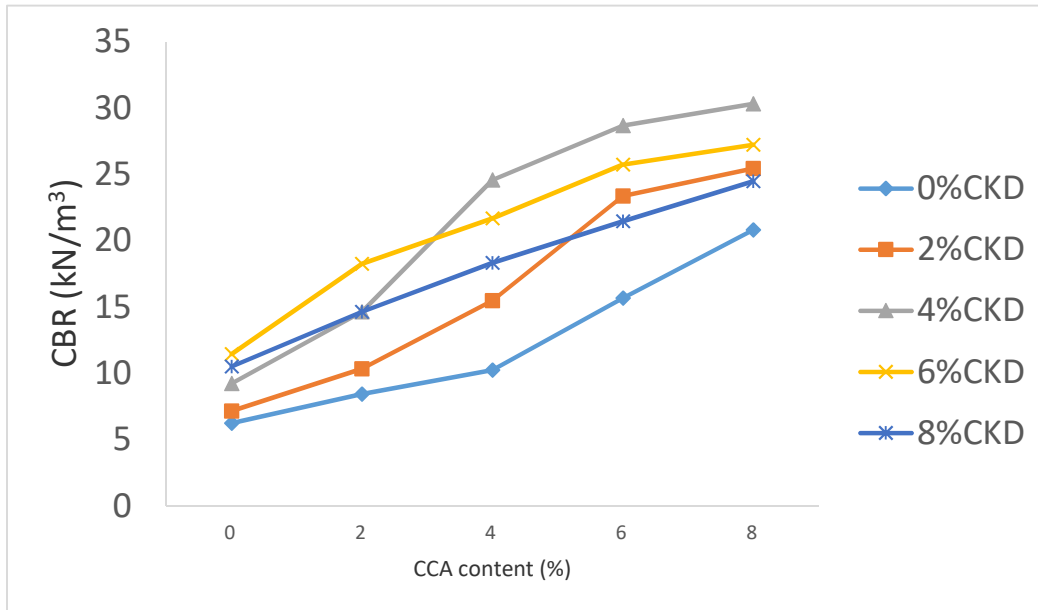


Fig. 7: Variation of CBR (soaked) of soil – cement kiln dust mixture with CCA content (BSH Compaction)

### Durability

Durability assessment of soil samples involves the simulation of some of the worst conditions that could be obtained in the field. It was evaluated by the immersion of specimens in water to determine resistance to loss in strength

which is more acceptable for tropical regions like Nigeria (Moses, 2009). The resistance to loss in strength determined as the ratio of the unconfirmed compressive strength of specimen wax-cured for 7 days de-waxed top and bottom to allow absorption of water and later immersed in

Corresponding author: Adoga E. J.

✉ [adogajasper@gmail.com](mailto:adogajasper@gmail.com)

Department of Civil Engineering, Nigeria Defense Academy Kaduna Nigeria.

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water for 7 days, to those cured for 14 days. Conventionally, an allowable 20% loss in strength is recommended for a specimen cured for 7 day and immersed in water for 14 days (Ola, 1974; Osinubi, 1998; 1999 and Eberemu *et al.*, (2019)). The resistance to loss in strength of soil-cement kiln dust mixtures with CCA contents for BSH (see

Figure 8) show the resistance to loss in strength peak at 63.41% at 6%CKD/8%CCA. The peak resistance to loss in strength values falls short of the acceptable 80% stipulated by Ola, 1974.

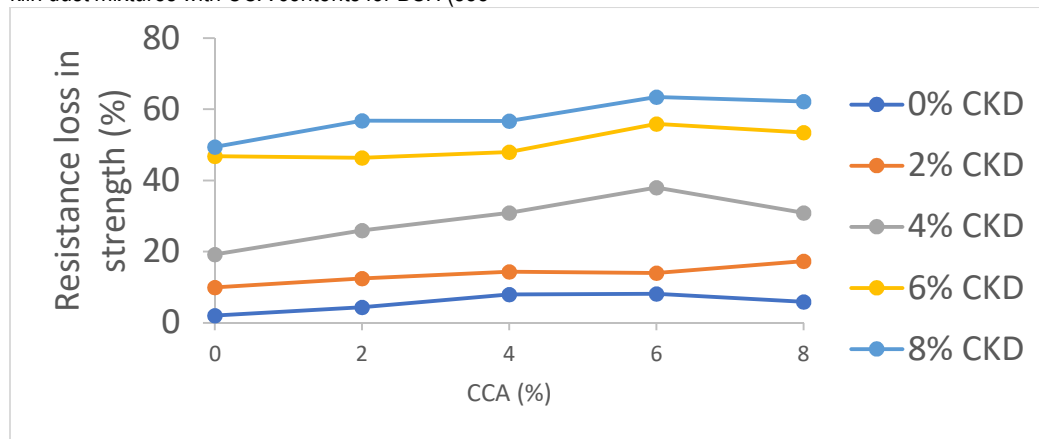


Fig. 8: Variation of resistance to loss in strength of soil – cement kiln dust mixture with CCA content (BSH Compaction)

## CONCLUSION

Based on the results of the study on black cotton soil stabilized with corn cob ash and Cement kiln dust the following conclusion can be drawn:

1. The black cotton soil falls under A-7-6 classification for AASHTO (1986) and CH according to Unified Soil Classification System (USCS, 1992).
2. The MDD decreased with higher additive blends, The minimum MDD values recorded for BSH compactive efforts is  $1.73\text{Mg/m}^3$  at 0%CKD/8%CCA treatment. The OMC, on the other hand, increased with higher CCA contents. The optimum moisture content values at the natural states increased from 13.2% to 15.55% when compacted using BSH energies at 4% CKD/6% CCA.
3. The unconfined compressive strength (UCS) values for natural soil compacted with BSH energies at 7 days curing period is  $898.56\text{kN/m}^2$ , increased to  $1683.59\text{kN/m}^2$  at 0% CKD/6% CCA treatment. The 28 days curing period UCS recorded a peak value of

approximately  $3000\text{kN/m}^2$  at 6% CKD/6% CCA for BSH compaction, showing that the soil treated with this blend can be used (at BSH compaction) as base course of pavement material.

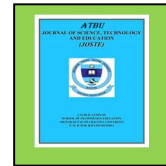
4. The unsoaked CBR values of 14.38% (for the natural soil) compacted with BSH energies efforts, increased to 104.5% at 8% CKD/6% CCA which meet the requirement for base courses. The soaked CBR for BSH compactive efforts peak at 32% at 4%CKD/8%CCA which met the requirement of 30% of the Nigerian General Specification (1997) for sub base materials.
5. The resistance to loss in strength peak at 63.41% at 6%CKD/8%CCA. The peak resistance to loss in strength values falls short of the acceptable 80% stipulated by Ola, 1974

Corresponding author: Adoga E. J.

✉ [adogajasper@gmail.com](mailto:adogajasper@gmail.com)

Department of Civil Engineering, Nigeria Defense Academy Kaduna Nigeria.

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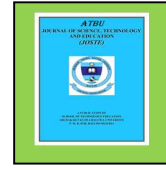
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Corresponding author: Adoga E. J.

✉ [adogajasper@gmail.com](mailto:adogajasper@gmail.com)

Department of Civil Engineering, Nigeria Defense Academy Kaduna Nigeria.

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