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Assessment of Volumentric Shrinkage and Hydraulic Conductivity of Lateritic Soil – Corn Cob Ash Admixure as Liner Materials

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Abstract A lateritic soil was treated with an agro-industrial waste—Corn Cob Ash (CCA)—using the West African Standard (WAS) compaction energy, with CCA content varied up to 12% in 3% increments. The test specimens were prepared at -4, -2, 0, 2, and 4% of optimum moisture content (OMC), extruded from the compaction mould, air-dried in the laboratory until no significant volume change was observed, and then tested for permeability using a falling head permeameter. The effects of CCA on the soil-CCA mixtures were assessed in terms of volumetric shrinkage and hydraulic conductivity. Results show that volumetric shrinkage decreased with increasing CCA content, reaching a minimum at 6% CCA, while hydraulic conductivity was lowest at 9% CCA, after which permeability slightly increased. Additionally, moulding water content significantly influenced volumetric shrinkage and hydraulic conductivity, as specimens compacted below OMC exhibited higher shrinkage and permeability, while those compacted above OMC initially showed lower shrinkage but increased void ratios, leading to higher permeability upon drying. These results indicate that not more than 6% and 9% CCA are optimal for reducing volumetric shrinkage and hydraulic conductivity, respectively. The findings suggest that CCA can be used as a sustainable stabilizer in soil modification for waste containment barrier materials.

Keywords: Corn Cob Ash, Lateritic soil, Volumetric Shrinkage, Hydraulic Conductivity, Liner material

I. Introduction

Nigeria and some developing countries are still battling the long-term problem of efficient management and disposal of waste. In Nigeria, the commonest means of waste disposal has been landfill. Subsurface pollution from these wastes occurs when water that has leached potentially harmful chemical species migrate through these wastes ultimately reaches the environment beneath the waste. The amount and quality of the contaminated water generated by the waste depends primarily on the conditions, the physical and chemical properties of the waste involved. Hence, materials are needed as liners or covers in waste confinement structures such as landfills. Material for liner construction should contain reasonable amounts of clay minerals and have very low hydraulic conductivity ($< 1 \times 10^{-7}$ cm/s) to prevent infiltration of water and less than four percent volumetric shrinkage [1]. Due to the increase in construction of landfills because of bursting population of urban communities, more materials with aforementioned properties are required for construction of landfills liner. To solve this problem, much research has been instigated on clay and lateritic soil with or without additives [2][3][4].

For expansive soils which have undesirable engineering properties, their properties need to be improved by stabilization. For sustainable development use of locally available materials, waste materials which are renewable should be encouraged for stabilization to save the natural resources for future generations. There are many natural waste materials found in our community.

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Examples include rice husk ash, bagasse ash, spent coffee grounds, wood ash, and agricultural waste fibers.

Corn cob ash (CCA) had been used as partial replacement of cement and other concrete components [5][6]. It has also been used to stabilize lateritic soil and its adequacy for use as a pavement layer material [7]. However, its usage in construction of landfill liners has been sparsely reported in published literature. The use of corn cob ash to stabilize soil for lining materials is an innovative way of reducing the cost of construction of liner and getting our environment free of waste material that is damaging and dangerous to humans.

II. Materials and Method

A. Materials

i. Laterite

The disturbed soil samples used for this study were collected at opposite Osogbo city stadium, Osogbo, Osun State. The top soil was removed to a depth of 1.2 m before the soil samples were taken. The soil samples were collected in large-to-medium-sized bags and thereafter transported to the Soil Mechanics Research Laboratory of the Department of Civil Engineering, Osun State University, Osogbo, Osun State. The soil samples were spread and allowed to air-dry under laboratory conditions.

ii. Corn cob ash

The Corn cobs used for this study were sourced and gathered in large quantities in the metropolis of Osogbo, Osun State. The cobs were washed, dried in the sun, burnt in an open atmosphere and then heated up in a furnace at 700^0C for 2 hours to obtain the ash. This was done for the decomposition of organic matter, formation of reactive silica (SiO_2), a standard practice in pozzolanic material production [8][9]. The ash was allowed to cool, sieved using 75µm sieve size to get a fine ash and was kept in a sealed polythene bag to prevent moisture absorption, as CCA possesses hygroscopic properties.

iii. Water

The water used in this study was fresh portable water obtained from the water tap in Osun State University, Osogbo, Osun State.

B. Methods

i. Index properties

Laboratory tests were conducted to determine the index properties of the samples in accordance with British Standard [10].

ii. Compaction

The compactive energy level used is the West African Standard (WAS). Air dried soil samples passing through BS sieve with 4.76 mm aperture mixed with 0%, 3%, 6%, 9% and 12% CCA by weight of dry soil were used. The WAS compactive effort is the conventional energy level which consists of energy level derived from a 4.5 kg rammer falling through 450 mm height onto five layers and each receiving10 uniformly distributed blows in a 1000 cm^3 mold [11][12].

iii. Volumetric shrinkage

The volumetric shrinkage upon drying was measured by extruding cylindrical specimens compacted using the WAS energy. The extruded cylindrical specimens were placed on a laboratory bench at a uniform temperature of 25 ± 2ºC for 30 days to dry naturally. This method is considered better than the method in which compacted cylindrical specimens were made to dry in an air-conditioned building [13]. This is because natural drying in the laboratory is considered to duplicate field conditions. Measurements of diameter and height for each compacted specimen at different CCA contents (0%, 3%, 6%, 9% and 12%) using the WAS compactive effort were taken with the aid of a vernier caliper accurate to 0.05 mm every 5 days. The average diameters and heights were used to compute the volumetric shrinkage strain.

$$\text{Volumetric shrinkage strain } = \frac{\Delta V}{V} \text{ x } 100 \quad (1)$$

Where: ΔV = reduction/change in volume
V = original volume of the soil.

iv. Hydraulic conductivity

This was measured using the rigid wall permeameter under falling head condition [9]. A relatively short sample was connected to a standpipe which provided the head of water flowing through the sample. The compacted soil – CCA samples at the different CCA contents (0%, 3%, 6%, 9% and 12%) using the WAS compactive effort were used. The height, h_1 in the stand-pipe was measured and the valve was then opened as a stop clock is started. After a measured time, t, the height to which the water level has fallen, h_2 was determined.

$$\text{Hydraulic conductivity, K } = 2.3 \frac{al}{At} \log 10 \frac{h_1}{h_2} \quad (2)$$

Where: A = cross-sectional area of sample
a = cross-sectional area of stand-pipe
l = length of sample
h_1 = head at time, t_1
h_2 = head at time, t_2.

III. Results and Discussion

A. Properties of Materials Used In The Study

i. Natural soil

Preliminary tests conducted to determine the natural properties of the soil revealed that the soil has a natural moisture content of 7.49% and which shows the amount of open spaces (void) present in the soil mass. The index properties are summarized in Table 1. and the oxides composition of the lateritic soil used in this study is as shown in Table 2. The soil belongs to the CL group in the Unified Soil Classification System [14], or A–7–5 (7) soil group of the AASHTO soil classification system [15]. The soil has a specific gravity value of 2.27 with Halloysite being the dominant clay mineral present in it. The soil is reddish-brown in colour with a liquid limit of 50.7%, plastic limit of 32.73% and plasticity index of 17.7%.

The soil has a maximum dry density of 1.223 g/cm^3 and an optimum moisture content of 22.48% using the West African Standard compactive effort. The soil has a volumetric shrinkage value of 3.54% when compacted at the obtained OMC using the WAS compactive effort after air-drying for 30 days in the laboratory. Also, the compactive effort yielded a hydraulic conductivity value of 1.03×10^{-8} cm/s at the obtained OMC. This shows that both the volumetric shrinkage and hydraulic conductivity of the natural soil itself satisfies the requirements of barrier materials used in waste containment structures. Although the natural soil meets the volumetric shrinkage and hydraulic conductivity requirements for landfill liner applications, long-term durability, strength, and resistance to environmental changes are crucial factors. Stabilization with Corn Cob Ash (CCA) enhances these properties by improving compaction characteristics, increasing resistance to cracking and permeability fluctuations, and promoting sustainable material use. This study further investigates the effect of CCA on lateritic soil to optimize its performance as a barrier material in waste containment structures.

Table 1: Properties of the Natural Soil

Properties	Quantity
Natural moisture content (%)	7.49
Specific gravity	2.27
Liquid limit (%)	50.7
Plastic limit (%)	32.73
Plasticity index (%)	17.77
% Passing BS No. 4 sieve	91.8
% Passing BS No. 200 sieve	52.7
Maximum dry density (g/cm^3)	1.223
Optimum moisture content (%)	22.48
AASHTO classification	A–7–5 (7)
USCS classification	CL
Volumetric shrinkage (%)	3.64
Hydraulic conductivity (cm/s)	1.03 x 10^{-8}
Colour	Reddish-brown
Dominant clay mineral	Halloysite

a. Index properties of the soil sample

The curve for the soil sample is as shown in Figure 1. Both AASHTO and USCS classification system was adopted in classifying the soil as silty-clay material and coarse-grained material respectively. The soil sample belongs to A–7–5 (7) group under AASHTO classification with more than 35% passing sieve No 200 and CL group under USCS classification with more than 50% passing sieve No 200.

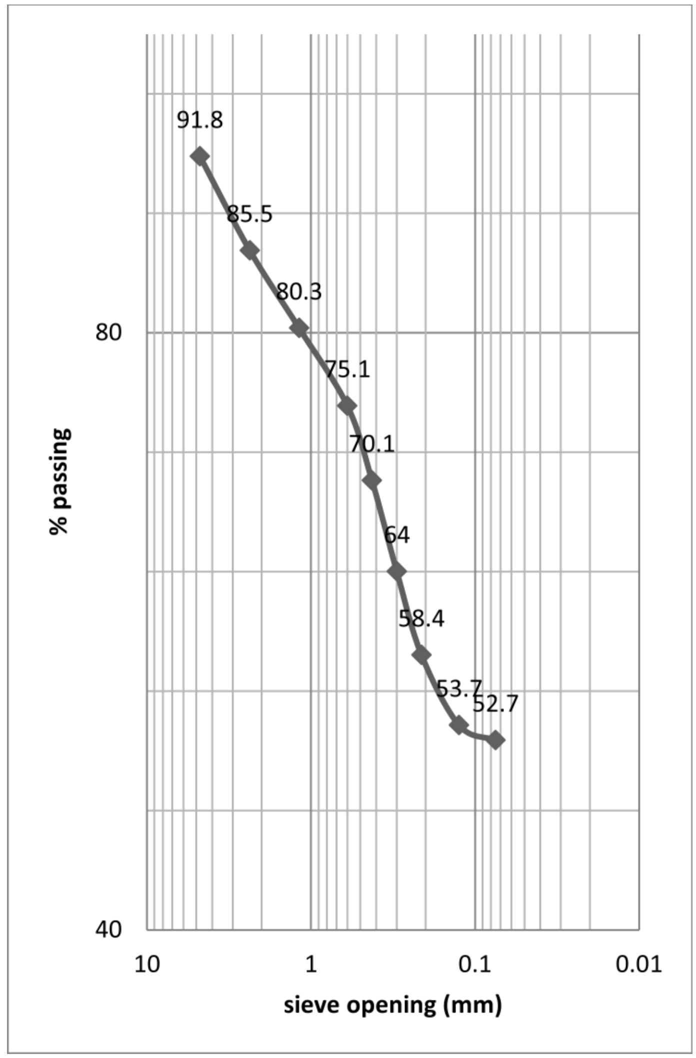


Figure 1: Particle size Distribution Curve for the Soil Sample

ii. Corn Cob ash

The oxide composition test of the CCA used in this study was conducted at Iwaloye Science Ventures, Odo-Ona, Ibadan and the result is as shown in Table 2. The higher concentration of silicon oxide in the CCA tends to improve the engineering properties of the lateritic soil used. Also, the CCA used has a specific gravity of 2.71. The high concentration of silicon oxide (SiO_2) in Corn Cob Ash (CCA) contributes significantly to enhancing the engineering properties of lateritic soil. Silicon oxide acts as a pozzolanic material, reacting with calcium hydroxide in the soil to form additional cementitious compounds, thereby improving soil strength and durability [16]. This enhancement is particularly beneficial for applications in road construction and other geotechnical projects.

Table 2: Oxides Composition of the Corn Cob Ash used

Oxides	Value (%)
SiO_2	65.19
Al_2O_3	6.78
Fe_2O_3	2.33
CaO	0.61
Na_2O	0.56
K_2O	0.88
MnO	0.36
EC(μS/cm)	3567.2
MgO	0.74
Organic carbon	0.69
pH	6.47

B. Compaction Characteristics

The effect of CCA content (0%, 3%, 6%, 9% and 12%) on the maximum dry density and the corresponding optimum moisture content of the lateritic soil are discussed below regarding their summary and variation.

i. Maximum dry density

The Curve of maximum dry densities of the soil-CCA mixture using WAS compactive effort is as shown in Figure 2. The Maximum Dry Density (MDD) values generally increase as the moisture content rises for soil mixtures containing 0%, 3%, 6%, 9%, and 12% CCA.. The MDD increased from a value of 1.223 g/cm^3 for the natural soil to 1.46g/cm^3 at 12% CCA content. This is so because the ash fills up the void within the soil matrix and in addition to the flocculation and agglomeration of the clay particles due to ion exchange[17].

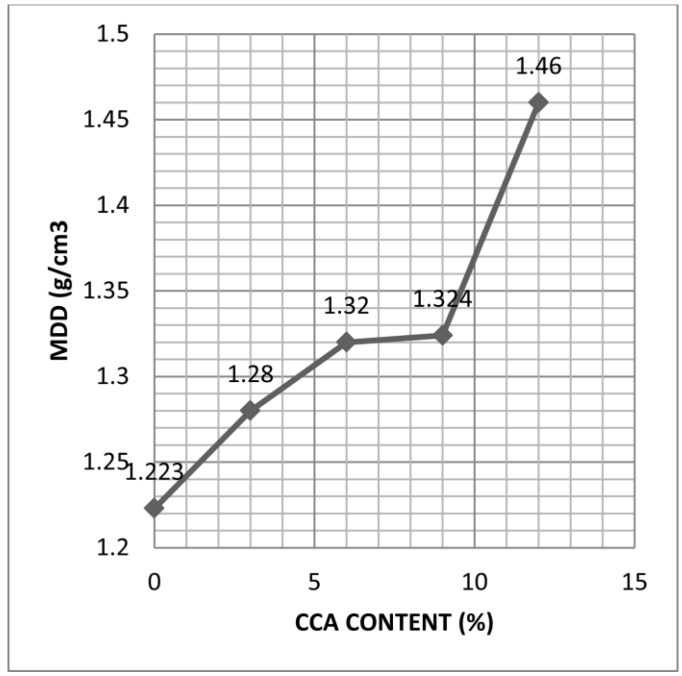


Figure 2: MDD Curve for the Soil-CCA Mixture

ii. Optimum moisture content

The curve of optimum moisture contents of the soil-CCA mixture using WAS compactive effort is as shown in Figure 3. It was observed that the OMC values vary (increases and decreases) with increasing CCA content. The observed variation in OMC with increasing CCA content can be attributed to changes in the soil's water absorption behavior. At lower CCA contents, the OMC increases due to the high surface area and pozzolanic nature of CCA, which enhances water absorption. However, at higher CCA contents, the OMC decreases as the mixture exhibits coarser-grained behavior, reducing the surface area available for water retention. Additionally, excessive CCA content leads to agglomeration of soil particles, limiting the water required for compaction. Similar trends have been reported in previous studies on lateritic soil stabilization with pozzolanic materials[18][19].

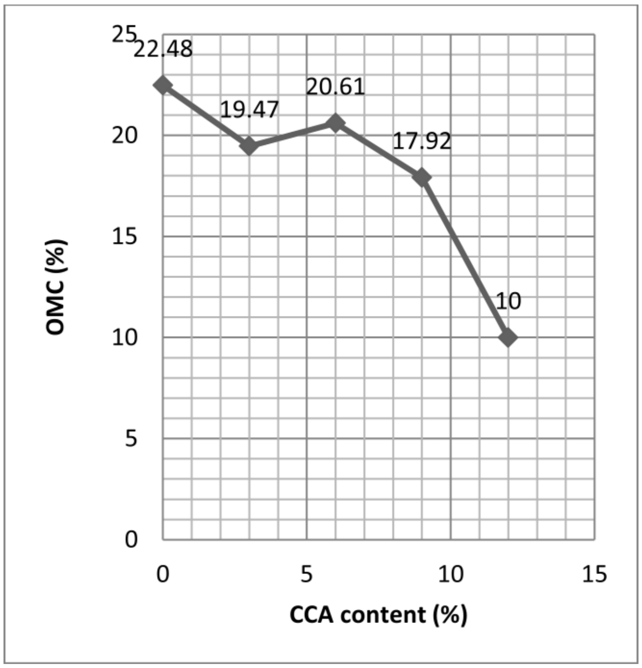


Figure 3: OMC Curve for the Soil-CCA Mixture

iii. Volumetric shrinkage

The volumetric shrinkage behavior of the soil-CCA mixtures, compacted at their respective optimum moisture contents (OMC), is illustrated in Figure 4. Over a 30-day drying period, it was observed that volumetric shrinkage values decreased with increasing CCA content, reaching a peak reduction at 6% CCA. Beyond this percentage, additional CCA resulted in marginal changes in shrinkage behavior.

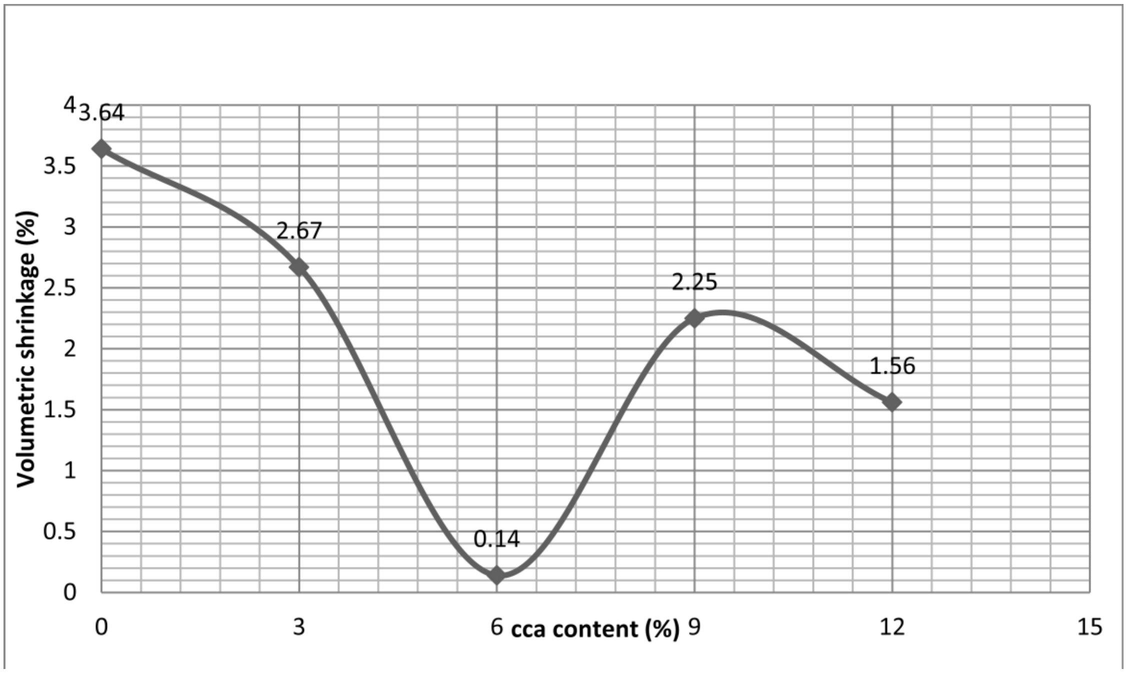
The reduction in volumetric shrinkage with increased CCA content can be attributed to the pozzolanic reactions between the silica-rich CCA and soil minerals, leading to enhanced particle bonding and reduced shrinkage potential. Similar findings were reported by [20], who observed significant decreases in shrinkage strain when lateritic soil was stabilized with corncob ash.

Moisture content variations also influence volumetric shrinkage strain (VSS). Soils compacted at moisture contents below OMC may not achieve optimal particle arrangement, leading to higher shrinkage upon drying. Conversely, soils compacted at moisture contents above OMC can have higher initial void ratios, resulting in greater shrinkage strains during drying. This behavior aligns with the findings of [21], who reported increased VSS with higher compaction water content in lateritic soils.

These results indicate that incorporating 6% CCA effectively reduces volumetric shrinkage, ensuring that the stabilized soil meets the requirements for waste containment structures, which typically specify volumetric shrinkage strains below 4%. Therefore, CCA stabilization not only improves shrinkage resistance but also promotes the sustainable use of agricultural waste in geotechnical applications.

iv. Hydraulic conductivity

The hydraulic conductivity of the soil-CCA mixtures at various mix contents is presented in Figure 5. The results show that hydraulic conductivity decreased with increasing CCA content, reaching its lowest value at 9% CCA, after which a slight increase was observed at 12% CCA. This reduction is attributed to pozzolanic reactions, which enhance particle bonding and reduce void spaces, making the soil more impervious. Similar trends have been reported by [22][23], where permeability decreased with optimal stabilization but increased slightly at excessive additive content. The natural soil (0% CCA) already met permeability requirements (1.03×10^{-8} cm/s),



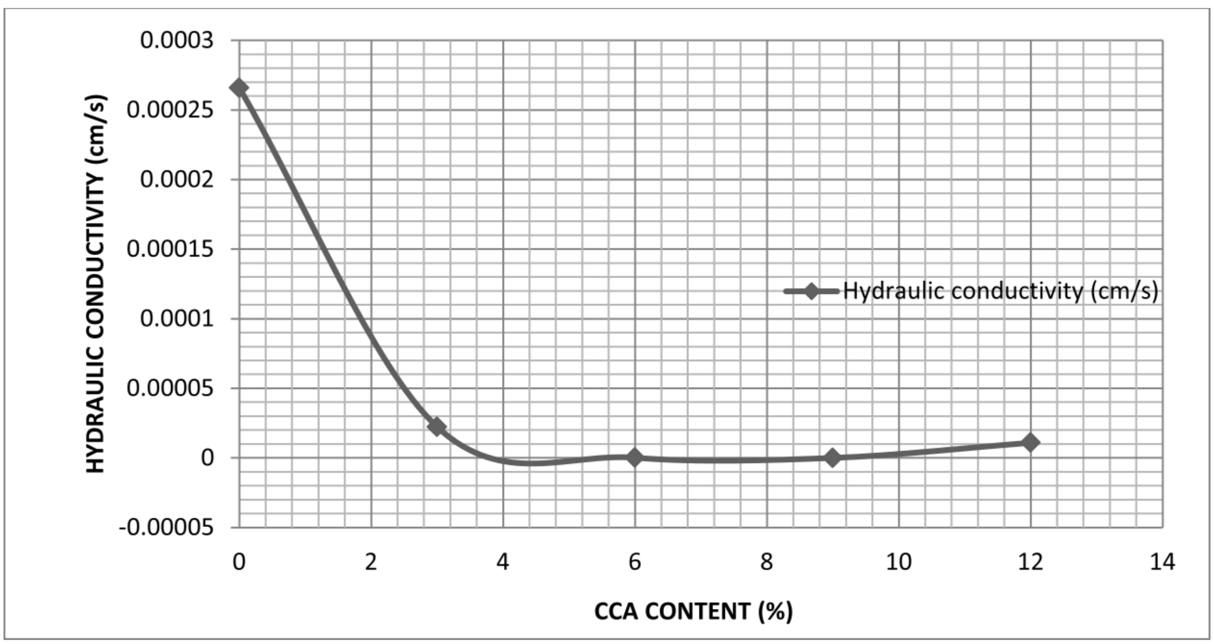


Figure 5: Hydraulic conductivity Curve for the Soil CCA Mixture

but CCA further improved long-term durability. Moisture variation also influences permeability—low moisture content leads to high void ratios, while excessive moisture prevents effective compaction. At OMC, the soil is best compacted, achieving the lowest hydraulic conductivity. The 6% and 9% CCA mixtures are thus optimal for landfill liner applications.

IV. Conclusion

An experimental program was undertaken to investigate the effect of Corn Cob ash on the geotechnical characteristics of a lateritic soil. The following conclusions can be drawn from the study: The natural soil used in the work is an A-7-5(7) soil according to the AASHTO soil classification system or CL in the USCS. The OMC and MDD of the treated Corn Cob Ash Stabilization of Lateritic Soil generally showed trends of decrease and increase respectively with higher corn cob ash contents.

The volumetric shrinkage of the sample decreases to corresponding minimum value of 0.14% at 6% CCA content such that further increase in CCA content shows a minimal rise in the volumetric shrinkage value to 2.25% at 9% CCA content and which decreases to 1.56% at 12% CCA content. Also, the hydraulic conductivity of the sample decreases to corresponding minimum value of 1.88×10^{-8} cm/s at 9% CCA content and which increases at 12% CCA content to 1.09×10^{-8} cm/s.

This study therefore shows that not more than 6% and 9% CCA by dry unit weight of soil can be effectively used to stabilize A-7-5 lateritic soil to reduce volumetric shrinkage and hydraulic conductivity respectively. Hence, the soil-CCA mixture can be used as barrier material in waste containment structures.

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