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Settlement Characteristics of Expansive Soils Stabilized With Agricultural Waste Using Corn-Cob Ash

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ABSTRACT

The compaction and consolidation of clayey soil significantly impacts crucial factors such as serviceability, durability, functionality as well as the safety of the structure; thus, it must be meticulously considered during the planning of any construction to be placed on it. Portland cement has successfully been utilized to enhance engineering characteristics of certain local soils enhancing the creation of reinforced pavement layers, fortified earthen structures and foundation support layers. Nevertheless, cement can be costly and its utilization is not sustainable, highlighting the need to explore alternative materials for complete or partial substitution. This study aim to examine the effect of stabilizing with Corn Cob Ash (CCA) on the engineering properties and consolidation characteristics of expansive soils to determine its appropriateness for use in pavement layer and structural materials. Soil samples obtained from the borrow pit taken in Iju/Ota, Sango-ota area of Ogun state, southwestern, Nigeria was investigated through laboratory tests such as X-ray fluorescence (XRF) technique, permeability, specific gravity, compaction test, California bearing ratio, consistency limits and consolidation characteristics taken three CCA blends with five CCA contents, differing from 0 to 15% and classified as silty-clayey with liquid, plastic and shrinkage limit of 57.0%, 23.0% and 26.1% respectively. The 60C:40CA blend exhibited the most favorable geotechnical properties. The PI exhibited a reduction as CCA content increased which is attributed to a rise in strength coupled with a decrease in compressibility. Optimal compaction of soil samples was reached at Maximum Dry Density (MDD) of 1553kg/m3 and corresponding Optimum Moisture Content (OMC) of 27.5%. The addition of CCA diminished the MDD of clay soil specimens from 1566kg/m3 in natural soil to 1553kg/m3 when treated with 8% CCA. The OMC also decreased from 29.20% in natural soil to 23.00% for samples treated with 15% CCA. The compressive strength increased with each blend, with the 60C:40CA blend showcasing the highest compressive strength at varying CCA percentages: 0%, 4%, 8%, 12%, and 15%, recording values of 129.5kN/m2, 146.0kN/m2, 196.9kN/m2, 239.7kN/m2 and 273.3kN/m2, respectively. Hence, the void ratio for expansive soil reduces with the addition of CCA; natural soil specimens at 0% CCA had e = 0.998 while samples treated with 4%, 8%, 12%, and 15% CA presented e= 0.881, 0.657, 0.529, and 0.493 respectively. The Cv values decreasing from 0.84cm2/min to 0.73cm2/min for 15% CCA and compression index (Cc) showed a decrease as CCA content increased. This study's findings indicate that the incorporation of CCA positively influenced both the consolidation behavior and engineering properties of expansive soils, as the porosity and density of CCA are less than those of the natural soil. The incorporation of CCAs on the soil typically indicates a reduction in their plasticity, potential for expansion, permeability and improved during strength. Stabilization of CCA not only increased the geotechnical properties of soil in its use as a road layer and material applications as well as inexpensive and environmental compatibility as a cement stabilization.

Keywords: Expansive soil, Swelling, Dry Density, Compression Index (Cc), Void ratio(e)

1. INTRODUCTION

Swelling soil deposits can pose a significant challenge to engineering projects based on its tendency to expand or contract in relation to seasonal variations in water levels, local impacts such as leaks from rain gutters, pipes supplying water or alterations in surface drainage and landscaping, or as a result of planting, removing, or severely trimming trees and shrubs. Numerous of the globe's populous cities and urban areas, along with their primary services, transportation networks and infrastructures which is been located in rocks and clay-dominant soils. Residential buildings and other low-rise constructions, walkways, poles, drainage systems, and other shallow utilities are particularly at risk of damage because they are less capable of accommodating uneven movements compared to heavier, multi-story buildings. Walkways are also extremely prone to damage due to their relatively lightweight structure spread over a large area. In civil engineering constructions, a variety of soil types are utilized; however, some soil deposits in their unaltered state are apt for building purposes, while others are deemed unsuitable without intervention, akin to problematic soils.

These soils must undergo excavation and replacement, or their characteristics ought to be adjusted prior to supporting the loads imposed by the structures above. Characteristic of problematic soils are the swelling soils, which are frequently noted due to their prevalence all over the world excluding arctic regions (Steinberg, 2000). Soils like this particular type has resulted in considerable damage across the United States (Jones and Holtz, 1973) because of its high susceptibility to volumetric changes, which are influenced by moisture content. The fundamental volumetric change attributes of expansive soils are significantly derived from their fine-grained clay mineral composition. Due to financial considerations, geotechnical engineers often opt to modify the traits of fine-grained soils in situ through stabilization rather than opting for soil replacement in practice (Hussey *et. al*., 2010). Generally, the typical expansive soils can be easily identified from their high malleability, extreme heave, and high swell- shrink potential which are made up of marl, shale or clay (Abiodun and Nalbantoglu, 2015).

Broad soils expands when wet, loses quality and shrinks when dry. This will change a significant amount. The construction on problematic floors has caused problems for a variety of civil engineering projects, including highways, railroads, levees and foundations. In this way, broad floor improvements are important, especially for road construction. Changes in the quality of this type of bed can be derived from the inclusion of another material, and this study has been selected. The vast bed is primarily transmitted on earth in some of the countries around the words secured by this soil (Briddle, 2003). Overall, it expands when the moisture content increases and when the moisture content decreases. They are problematic soils for civil engineering projects due to their cyclical threshold behavior and poor quality. In circumstances, construction cannot be escaped on such ground, and the source of suitable materials may not be accessible to the location, and transport requires serious effort. Further development of this type is extremely important. These changes include improved quality and strength of broad soils, reduced consistency limits and reduced swelling behavior (Khadka *et. al*., 2020). Furthermore, there are no factories in Nigeria to recycle waste. Therefore, they throw a large amount of them each year (Dang *et. al*., 2016). Additionally, there is the ecological and profitable advantage of using waste for many geological applications. Hence, Corn-cob ash (CCA) is an important waste material that could be considered for soil stabilization.

1.1 Aim and Objectives

The aim of this study is to investigate the effect of stabilizing with Corn-cob ash (CCA) on the engineering properties and consolidation characteristics of expansive soils. In the organization of this study, the specific objectives are to:

i. determine the characteristics of expansive soils to point out the effect of the corn-cob ash for stabilization.
ii. using corn-cob as source material to increases the soil compacted strength as well as reduces health threats and disturbance of the environment.
iii. evaluate the optimal percentage of corncob ash for stabilization.
iv. provide an assessment on the consolidation characteristics and behavior of stabilized expansive soil, its effects on the structures and possible remedial measures.

2. LITERATURE REVIEW

Portland cement can be termed as a material in tropical and subtropical countries - the most effective and most frequently used floor stabilizers, including some late-stage beds used as materials in tropical and subtropical countries (Awoyera and Akinwumi, 2014). It's one of them. Subsequently, it is important that our world advances towards total or partial substitution of Portland cement as a stabilizer for soil. Cement and its derivatives are essential man-made commodities worldwide. The application of pozzolans during building projects has gained momentum lately, motivated by the demand for sustainable substitutes for cement. Calcined kaolin is a natural pozzolan that is presently under investigation, with ideal pozzolanic effectiveness linked to its manufacturing conditions (Ayininuola and Adekitan, 2017).

Thus, we require innovation that can assist us save cost, progressing road effectiveness, and significantly diminishing construction costs, whereas moreover minimizing covering open road networks and expanding construction-related air pollution. The most prominent hindrance to completing the network of the road network in developing countries such as India is the shortage of cash accessible to construct roads utilizing conventional procedures (Onyelowe, *et. al.,* 2019). Sustainable development requires cost control, security and execution (Liu *et*. *al*., 2019). Furthermore, it is important to implement one of the appropriate economic road construction methods to meet the growing demand for transportation infrastructure. Increased soil reinforcement is a process that changes the properties of available local soils to increase technical effects such as strength, stability, compressibility, permeability, process ability, and sensitivity.

The concept of ground-stability road construction highlights the effective use of local floors and other suitable stabilizers. Stabilization applies to a variety of infrastructure projects, with roads and airports being built in most cases. Further examples of soil stabilization applications include the construction of commercial roads, bridge renovations, maintenance of dirt highways, intergovernmental improvements, street improvements, parking spaces, landing routes and large-scale filling projects. Soil reinforcement can be filled either manually or by incorporating additives, so that stabilized soil can act as building materials. Lime and cement are the most important materials used for stabilization (Soltani, *et. al*., 2017).

Nevertheless, the lime and cement production process was expensive and with increasing demand for these materials in the construction sector, the pursuit of alternatives has led to researchers' benefits. Consideration of sustainable practices and the use of locally available and affordable raw materials offer economically practical options. In this regard, the research efforts focused on improving and strengthening the soil using waste from industries such as flight ash, polypropylene fiber, rice shells, shells, ash, hand surfaces, jute, coconut, cosnuts, recycled carpet fibers and other agricultural waste. Morin (1971) used various culture residues to stabilize the worsened soil. Oluwatuyi, *et*. *al*., (2018) grounded eggshells were used as soil stabilizers. The use of agricultural waste for soil stabilization is attractive due to its simple accessibility, cost-effective cost, tumor properties, and role in reducing waste. Maize-Cob cannot be used directly as a raw material as it decomposes in the ground over time.

However, Corn Cob Ash (CCA) has a substantial amount of silica with puzzle-based activity that can bond soil particles and significantly improve strength (Obakin and Oladunmoye, 2020). A small amount of cement must be added to achieve optimal stabilization. Some agrarian waste mixed with cement for concrete for the properties of pozzolan products such as rice husk ash, corncob ash and sawdust ash. According to findings by Jimoh and Apampa (2014), the soil's peak maximum density shows minimal decline as the proportion of corncob ash rises. Initially, unsoaked and soaked UCS and CBR values increases, but then they dropped after the addition of three (3) corncob ash. It was discovered that Unconfined Compressive Strength (UCS) boosted up with the increase of cement and corncob ash proportions in all composites, with specific mixture of corncob ash to cement yielding superior unconfined compressive strength. Thus, they exert corncob ash and cement composites on both the California bearing ratio, atterberg limit, and soil permeability and swelling potential in both soaked and unsoaked CBRs but did not investigate the effect of the materials.

Apart from studies by Jimoh and Apampa (2014), there are no different findings available in public literature regarding lateritic soil improvement (stabilizing) using mixtures corn cob and cement produced ash. Portland cement has proven to enhance the engineering characteristics of various natural soils for the development of reinforced pavement surfaces, fortified earth formations, and subgrade layers supporting structural foundations. Cement is valuable and thus the consumption is not sustainable, prompting the need of substitute materials to replace it entirely or partially. Oladunmoye, 2017 and Oladunmoye *et. al.,* 2021 conducted a study to evaluate the impacts of incorporating cement and sawdust into lateritic soil bricks on their compressive strength, utilizing different mixes of cement and sawdust at proportions of 5%, 10%, and 15% respectively.

The results indicated that the additives of cement and sawdust have a constructive influence on enhancing the compressive strength of the stabilized laterite bricks, peaking at 10%. Furthermore, the research demonstrated that the ideal level for water absorption during sawdust stabilization occurs at 15% cement with a 10% sawdust replacement. Finally, utilizing agricultural waste products as soil additives not only enhances soil properties but also contributes to waste management and environmental conservation. This approach offers a practical and eco-friendly alternative to traditional soil stabilization methods.

2.1 Soils with expansive properties in construction

The potential for shrinkage and/or swelling due to various factors can frequently be anticipated in numerous engineering scenarios. Nonetheless, owing to the distinctions between natural and tree-induced shrink-swell effects, as well as different initial conditions, the basic allowance to volume changes at specific location which may not consistently align for a particular geographical formation or type of soil.

Residences likewise low-lying structures, pavements, pipelines, other shallow infrastructure and arches are especially prone to different kind of failure occurring through shrink-swell clays, as are less equipped to mitigate differential settlements compared to heavy and multi-level buildings. Because of the widespread occurrence of shrink-swell soils, numerous methods for managing this issue have been developed, which can vary widely. Expansive soils pose a significant risk to infrastructure due to their volume changes. The identification of these soils is essential for implementing effective mitigation measures. Chemical stabilization methods, such as cement and lime stabilization, have proven effective in treating expansive soils by altering their physical and chemical properties, reducing their susceptibility to volume changes, and enhancing their stability. Additionally, mechanical stabilization, the use of geosynthetics, and drainage systems can be employed to address the challenges posed by expansive soils. Mechanical stabilization involves compacting and densifying the soil, improving its load-bearing capacity, while geosynthetics like geotextiles and geomembrane provide additional reinforcement and stability. Effective drainage systems control the moisture content in the soil, reducing its potential for swelling and shrinking.

Comprehensive identification and appropriate stabilization techniques are crucial for managing expansive soils in construction projects. By understanding the behavior of these soils and employing suitable methods, engineers can minimize the risks and costs associated with expansive soils, ensuring the success and longevity of infrastructure projects. Radevsky (2001) in his survey, gives a report analysis of these issues of how distinctive nations bargain with shrink–swell soil issues, and a point by point enlightening ponder from the joined together States has more as of late been displayed by Houston, *et*. *al*. (2011). Typical examinations of structures related to most influence through shrink–swell soils which are not satisfactory but regular. Intensive or In-depth location (site) examination is needed for swell-shrink soils so as to give an adequate data.

Soil swelling potential is influenced by its mineral composition, in-situ dampness substance, and thickness. Soil porousness also affects the rate of swelling. Clays with high flexibility lists, fluid limits, and water content close to plastic restraint will prone to swelling. Soil expansion degree can be classified as seen in Table 1 below. Abundance and presence of different broken components or particles affect the shrinkage and contracting possibilities of clayey soils. Swelling potential of soils concurring to the liquid compel, flexibility list and shrinkage control values and the classification of shrink conceivable outcomes based on the flexibility list is submitted in the building properties of typical clearing soils inspected around the world.

Table 1: Prediction of the degree of expansion in fine-grained soils (IS 1498, 1970)

	Degree of expansion			
Soil properties	Low	Medium	High	Very High
Liquid limit	25-35	35-50	50-70	70-90
Plasticity index	<12	12-23	23-32	>32
Shrinkage index	<15	15-30	30-60	>60
Free swell percentage	<50	50-100	100-200	>200

3. METHODOLOGY

3.1. Materials: The materials used in this study were Expansive soil (SC), Water, Corn-cob Ash (CCA), Ordinary Portland cement (OPC)

3.1.1 Swelling Soil (SC)

Soil sample was collected for the study at a borrow pit (latitude 6.405201deg N, and longitude 3.856053deg E) at a construction site in Ado/Odo-Ota local government area, beside River Atuwara, Iju/Ota, sango-ota, Ogun state by a method of bulk disturbed sampling and store in jute bags (Dauda, *et. al*., 2018). They were collected at a depth of 1m to 2m (i.e. depth not <1m) at a natural ground level below with an inscription of date and depth of sampling following thick top soil layer removal (at about 20mm). The soil was left to dry at ambient temperature, and afterward, it was fragmented using a rubber mallet into fine particles that could pass through a 2.36mm sieve, categorized as A-4-5 per American Association of State Highway and Transportation Officials (AASHTO) classified as Silty clay (SC) according to Unified Soil Classification System (UCS), as illustrated in Plate 1 below. The geotechnical attributes of the soil, such as particle size distribution, consistency limits, and specific gravity, was be assessed in alignment with AS1289. The soil is to be classified as high plasticity silty-clay (MH). The particle size distribution graph for this soil, established through wet sieving, along with the index characteristics of the expansive soil, was depicted through figure 1 below.

Plate 1: Pulverized sample (laboratory work)

3.1.2. Water

A fresh and clean water was collected with a container at the taps in geotechnical laboratory of Covenant University.

3.1.3 Corn-cob Ash

The corncobs utilized in this study were procured from the open markets and farms located in Iju-Ota market, Ado/Odo-Ota, Ogun state, Nigeria. After being air-dried under the sun for a week to lower their moisture levels, the corncobs were crushed through milling machine to lower its average particle size to about 4mm.

Plate 2: Corn-Cob calcined at 600⁰C at 4-5hrs (The temperature of the furnace was maintained between 625-650℃ for about 4-5hours*)*.

3.1.4 Portland cement

Commercially obtained grade 32.5 Portland cement (OPC), was used in this study which are gotten from the open market.

3.2 Methodology: The tests were performed at Geotechnical Engineering laboratory, Department of Civil Engineering, Covenant University Ota, Ogun state.

3.2.1 Mix design

The research looks into examining experimental performance regarding the geotechnical characteristics for swelling soil reinforced with cement-corncob ash to determine its appropriateness as a resource for various applications and engineering projects. Various tests (of specific gravity, permeability, consistency limits, unconfined compressive strength (UCS) and compaction), using three (3) CCA blends and five (5) CCA contents, differing proportions starting from 0% to 15%, were to be carried out. Blends of CCA consisting 60%cement and 40%corncob ash (60C:40CA), 40%cement and 60%corncob ash (40C:60CA) and 50%cement and 50%corncob ash (50C:50CA) was formulated to serve as mixtures for soil stabilization. Individual blend was incorporated into the soil at ratios 0%, 4%, 8%, 12%, and 15% on unit dry density, and thoroughly mix in achieve wholeness, resulting in thirteen combinations of CCA-enhanced soil.

3.2.2.Various Tests Carried Out

The various analyses conducted on the settlement traits of expansive soil are detailed as follows:

X-ray fluorescence (XRF) techniques

Chemical makeup of the Portland cement and corncob ash will be assessed through X-ray fluorescence (XRF) techniques focusing on oxides. The geochemical profile of the soil will be evaluated via an atomic absorption spectrophotometer. Moisture content in its natural state of soil was accessed through the oven-drying approach in the laboratory, and its particle size distribution being ascertained through hydrometer and sieve assessments.

Natural water content (m)

The soil samples used for this assessment were stored in airtight bags upon extraction from the test pit to ensure that the real moisture in the soil remained in its native state. We recorded the weight of the moisture socket next to the saturated floor as M_2 which is then placed in the electric oven. The weight of the moisture box is recorded as M_1.

Sieve Analysis

Representative soil samples weighing approximately 1000 g (1 kg) were used for this analysis. Soaked, cleaned and allowed to dry in the oven 24 hours a day. The sieve process was mechanically performed on an automatic shaker using a 7person sieve in accordance to sieve BS no. and collective shells.

Atterberg Limit Test

Liquid and plastic limit were carried out according to the standards of BS (1990). Plasticity Index (PI): The difference between liquid limits and plastic limits is called the plastic index. It is expressed as: PI=LL-PL.............. (1), PI=plasticity index, LL= liquid limit, PL= Plastic limits.

Specific Gravity Test

A 50 mL pycnometer was used for this method and air-dried soil tests passed through BS No. 4, sieve 4.75mm were measured at 0.02kg. The weight of the pycnometer was recorded along with the weight of the pycnometer and soil (M2) and (M1), the weight of the pycnometer containing both soil and distilled water (M3), and the weight of the pycnometer only with distilled water (M4). The waterproofing is probably 1000kg/m3 or 1g/cm3.

Compression Test (West Africa Standard)

This procedure used a 4.5 kg compactor and a 1000 cm^3 ($1x10^{-3}m^3$) format. Air-dried soil test that can pass 20mm openings, and adding 11% and 13% of water depending on the waterproof capacity. The floor was compressed in five layers, at a height of 450mm with 10 uniformly distributed hits. The soil dry density was then covered with moisture content, and the maximum dry density (MDD) and optimal moisture content (OMC) were defined as the peaks in the graph plotted.

Uniform compressive strength, permeability, and California bearing ratio

When assessing the likelihood of swelling, soil samples compressed in the form of CBR for 24hours were soaked in water to promote swelling. The displacement values were noted down at regular intervals. The likelihood of a threshold for a particular sample is determined by the standard height (original) in relation to amount of quantity.

Unified compressive Strength test samples of 50mmx100mm were generated, drawn out from the cylindrical shape, and stored through airtight plastic bags for curing. UCS for each after days of curing for a day and 28days were measured. The permeability coefficient of soil specimen was examined through a constant head permeameter as shown in plate 2,3 and 4 respectively.

Plate 2: Unconfined compressive strength test specimens (50mm x 100mm), prepared and extruded from a cylindrical mold

Plate 3: The CBR test

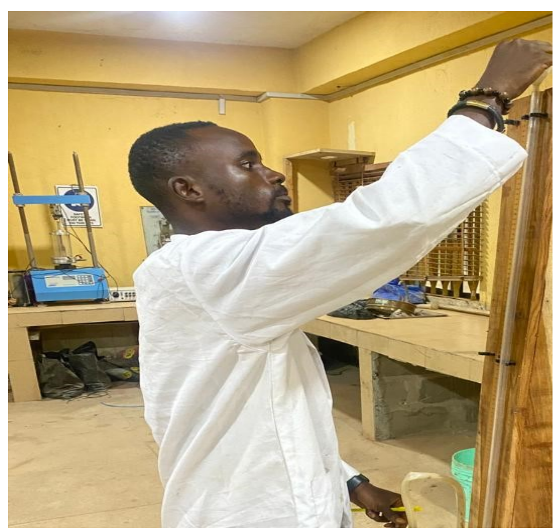

Plate 4: Permeability Apparatus process

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Consolidation Characteristics (Oedometer Test)

Consolidation assessments were conducted employing a comprehensive consolidometer testing setup to ascertain the compressibility characteristics of the soil specimens subjected to various compressive stresses (25, 50, 100, 200, 400, and 800 kPa) along with confining pressures. Entire apparatus comprises the consolidator, pneumatic regulators, multi-channel communication interface, and data acquisition system. This configuration facilitated both standard and swift consolidation evaluations to calculate the consolidation characteristics parameters. The samples for the consolidation evaluations were shaped in a 20mm (2cm) deep cylinder featuring an inner diameter of 61.8mm as shown in plate 5 below. The oedometer test is employed to examine the degree and velocity of one-dimensional consolidation within a saturated soil specimen formed as a disc, constrained laterally, subjected to vertical axial load from above, and allowed to drain freely from both the top and bottom surfaces. The compression index was derived from the void-pressure log graph.

Thus,

$$C_c = \frac{e_o - e}{\log(\sigma'/\sigma'_o)} = \Delta e / \Delta$$

where: σ_o" =initial effective stress, σ" = effective stress due to consolidation (change in effective stress), e = void ratio corresponding to increase in effective stress, Cc= compression, e_o = initial void ratio

Plate 4: An Oedometer apparatus set-up (Consolidometer test)

4. RESULTS AND DISCUSSION

4.1. The physical and geotechnical characteristics of the soil

Table 2 below illustrates the results conducted from the laboratory on natural state of the soil sample taken for the study without any addition of stabilization agent. The plasticity index of 34, can be classified as an A-4-5 according to AASHTO classification and falls into the silty-clayey in the USCS. It was discovered that soil has a liquid limit of 57.0%, a plastic limit of 23.0% and a linear shrinkage of 26.1%.

From these parameters, the soil which has high shrinkage and swelling characteristics is considered as a critical expansive soil, and may causes problem to pavements and foundational problems. The soil has a natural moisture content of 29.2% which depicts the high-water adsorption capability of the clay material. It is used as an indicator for the shear strength of soils. Thus, increase in the moisture content also results in a decrease in the shear strength of the material. The difference in moisture content can be attributed to the seasonal changes, time of collection and their storage conditions. In comparison with the literature review, according to Ola, 1981; using the relationship between the plasticity index and swelling potential of soil indicated that the expansive soil used for the study which has a PI of 34% is considered a swelling soil with a High potential, which is shown in Table 3 below.

Table 2: The Expansive Soil Engineering Characteristics

Parameters	Description
USCS classification of the soil	Silt-Clay (SC)
AASHTO classification	A-4-5
Particle size analysis (%)	
Gravel	0.00
Sand (4.75-0.075mm)	48.90
Silt & Clay (<0.075)	51.10
Atterberg limits	
Liquid limit (%)	57.00
Plastic limit (%)	23.00
Plasticity Index (%)	34.00
Linear shrinkage (%)	26.01
Liquidity index (%)	0.18
Natural Moisture content	29.2
Specific gravity (Gs)	2.45
Optimum moisture content (%)	19.50
Maximum dry density (kg/m^3)	1566
Unconfined compressive strength (kN/m^2)	129.50
Permeability (cm/s)	3.01×10^{-5}
CBR Unsoaked (%)	3.10
Swelling potential classification of the soil	High

Table 3: Relationship Between Plasticity And Swelling Potential (Ola, 1981)

Plasticity Index	Swelling Potential
0-15	Low
15-25	Medium
25-35	High
>35	Very High

The consistency limit properties of the clay samples show that the samples fall into inorganic clay of medium to high plasticity and compressibility in the Casagrande Plasticity Chart. The sample cluster above the A-Line was indicative of materials with a high plastic nature of samples agrees according to Ola (1981) who drawn out a relation between swelling potential with plasticity index of clays.

Thus, plasticity index of the sample is high, thus exhibiting swelling potential that is very high because the more plastic the material, the higher the swell potential and they are likely to have a higher percentage of expansive clays.

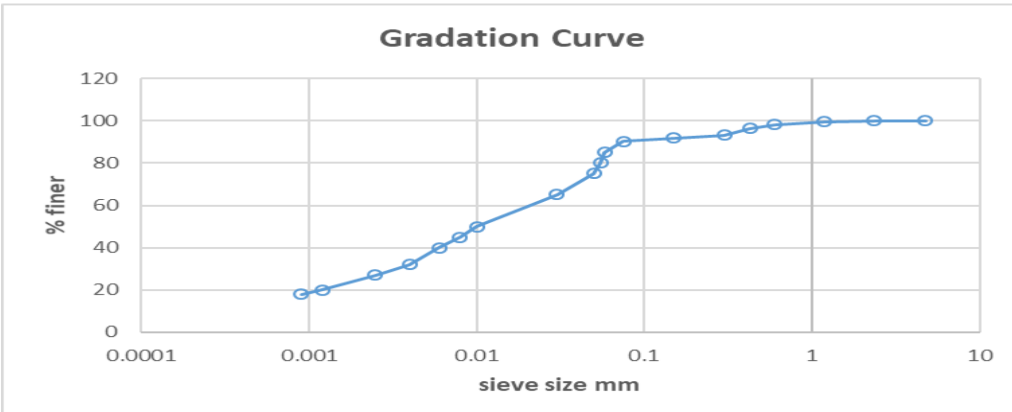


Figure 1: Particle Size Distribution of The Utilized Expansive Soil

4.2. Characterization of Materials as Pozzolanic Material

To chemically characterize the materials used for the study, Explorer X-ray fluorescence machine was used. The chemical composition of Corn-Cob ash, Ordinary Portland cement (OPC) as well as the soil used is presented in the table 2.3 below in the form of their oxides. The result implies that the quartz (SiO) is a major mineral constituents of the soil at 78.25% as detected from the test which is an effect due to the sand in the soil. As a recommendation made by ASTM C618 (2003), the sum of SiO_2+Al_2O_3+Fe_2O_3 must be a minimum of 70% for material to be use as a pozzolanic material in concrete. Hence, for corn-cob ash gives 74.38% which shows that it is a pozzolan material since it react easily with CaO to produces permanent compounds and contains constituent's elements that gives reaction in the sight of moisture.

The ordinary Portland cement used in this study predominantly contains Al_2O_3(aluminum oxide), SiO_2(silicon dioxide), CaO(calcium oxide), and Fe_2O_3(iron(III) oxide). These compounds are the primary components that contribute to the cement's properties. When examining the composition of corn-cob ash (CCA), we observe striking similarities to Portland cement, particularly in terms of the presence and proportions of these key compounds. This similarity suggests that CCA possesses cementitious characteristics, making it a viable alternative for soil stabilization. As indicated in table 4 below, CCA and Portland cement share common constituents at different percentage compositions, which explain CCA's ability to act as a stabilizing agent.

The inclusion of such stabilizers aims to enhance the soil's engineering properties such as compressibility, strength and cohesion. This makes CCA an effective and sustainable option for improving weak soils, especially in regions where traditional stabilizers might be cost-prohibitive or less environmentally friendly. Overall, the use of CCA provides a practical solution for soil stabilization by leveraging its chemical composition, which mirrors that of ordinary Portland cement. This not only supports sustainable construction practices but also offers an economical alternative to conventional chemical additives, contributing to reduced CO_2 emissions and a smaller environmental footprint.

Table 4: Chemical composition of Corn-cob ash, OPC as a Pozzolan Material

Elemental Oxides	CCA (%)	Cement (OPC) (%)	Soil
SiO_2	60.05	21.40	70.52
Al_2O_3	9.08	5.03	12.65
$Fe2O_3$	5.25	4.40	2.12
CaO	15.01	61.14	0.02
MgO	5.07	1.35	0.43
SO_3	3.00	2.53	
K2O	4.92	0.48	0.14
Na2O	0.41	0.24	7.83
LOI	-	1.29	0.42

4.3 Specific gravity

From the literature, Mamlouk and Zaniewski, 2006; the typical specific gravity value of ordinary Portland cement is 3.15 and the specific gravity of the corncob ash and soil sample, average values were found to be 2.29 and 2.45 respectively, which falls within the recommended range of 2.10 to 2.40 specified by ASTM C168 for pulverized fuel ash. The specific gravity variation is due to the CCA blend additions to the soil drawn out through Figure 2 below. Initially, an increase in specific gravity was noticeable before a decrease and as such with reference to increased CCA content for 60C:40CA and 50C:50CA blends. Hence, the specific gravity decreased in the 40C:60CA blend, with CCA content increasing. The differing outcomes of incorporating CCA mixtures on the soil's specific gravity emanate from the distinct specific gravities of the blends CCA and batches, when compared to some natural soil are high and reduced for others.

Figure 2, demonstrated the effect of adding CCA blends in different percentages (from 0%, 4%, 8%, 12% and 15%) on the specific gravity (S.G) of the soil. With addition of 60C:40CA, it is deduced that the S.G progressively increases and obtain its higher value (2.76) at 8%, before decreasing as the CCA content increases as well as the 50C:50CA blend as a stabilizing agent. The specific gravity values were decreasing gradually as the CCA content increases for the 40C:60CA blend which shows that it is not good for use. Hence, the 60C:40CA blends shows as a better stabilizing agent with higher specific gravity is of great importance in which load carrying capacity of soil also increases (i.e. strength increment) for roads as well as foundations.

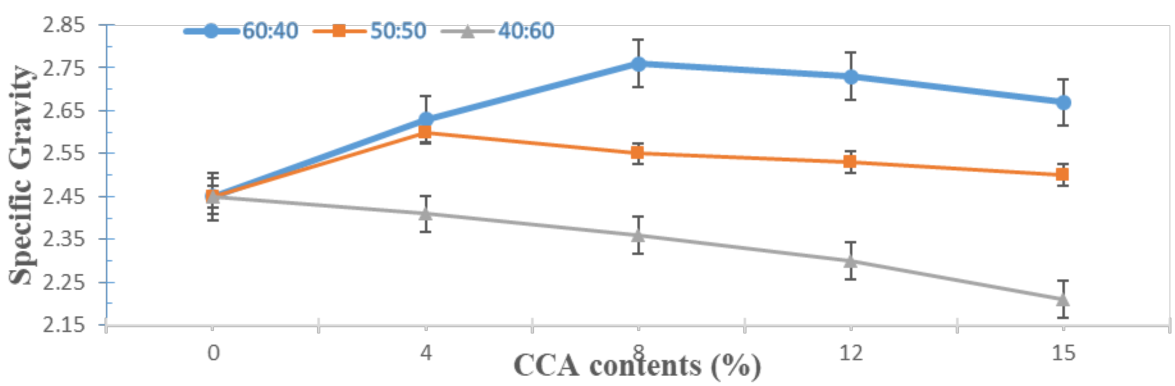


Figure 2: Different Variations of Specific Gravity with CCA Content

5.4 Liquid limit, Plastic limit and Plastic Index

Liquid limit, plastic limits and plasticity index variations of the soil in different percentages using CCA contents added, thus also for each of the CCA blends as depicted with figures 3,4 and 5 below. Soil's liquid limit decreases for each of the CCA blends with CCA content increasing likewise, plastic limit of the soil was also increased. As the CCA content increased across all blends, the plasticity index representing the soil's plasticity level, reduced. When 15% CCA was incorporated into the soil, its plasticity experienced a decline of 77%, 82% and 80%, and for the 40C:60CA, 60C:40CA, 50C:50CA and mixtures accordingly.

The effect of increasing CCA blends in varying proportions on the liquid limit (LL) of the soil shows that with the addition of each CCA blends, the LL continuously decreases. Thus, at the higher addition of 15% CCA content, the LL decreases for 60C:40CA by 15.26%, 50C:50CA by 16.84% and 40C:60 by 21.05% blends. The swelling and compressibility characteristics of soil is highly affected by the variation in liquid limit which implies a reduced compression ratio and swelling rate. During the usage of each blends as stabilizing agent, LL reduces and results to a rise in plastic limit has been illustrated with figure 3.3 below. The reduction of LL stipulates that the installation of corncob ash improves the overall behavior of the soil, and therefore the formation of cementless compounds, i.e., interaction of CCAs between soil particles and soil particles, completely lost the soil liquid limit for calcium silicate particles (Adesanya and Raheem, 2009).

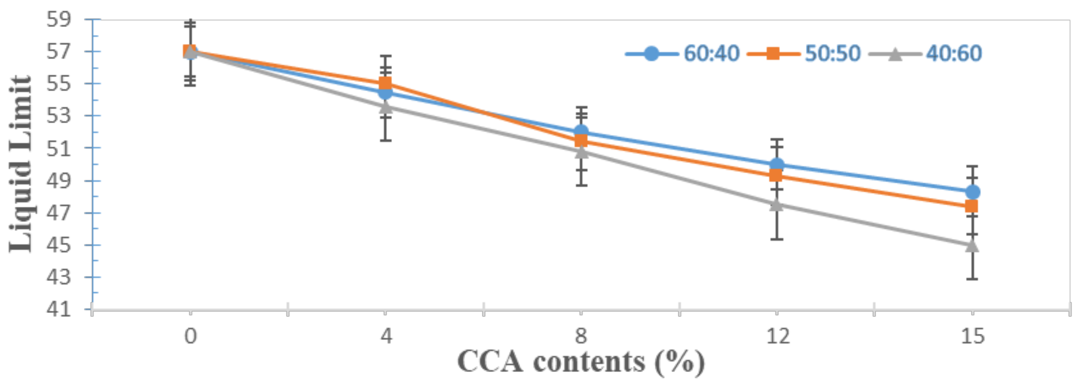


Figure 3: Variation of Liquid limit with CCA content

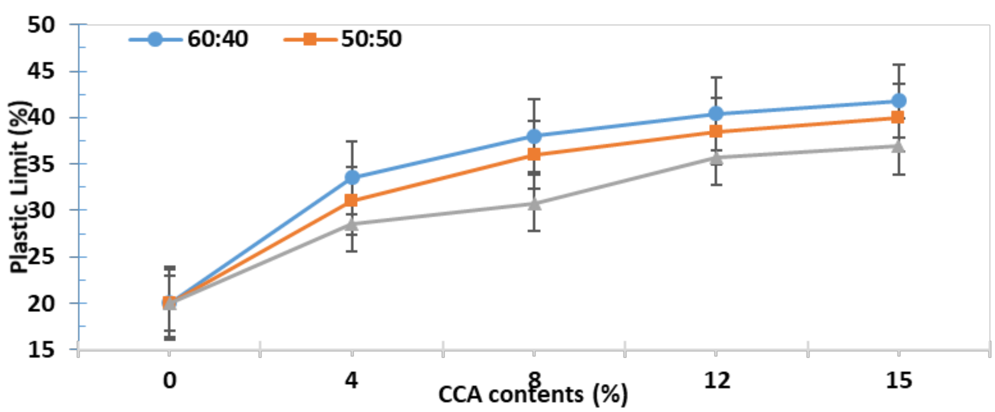


Figure 4: Variation of Plastic limit with CCA content

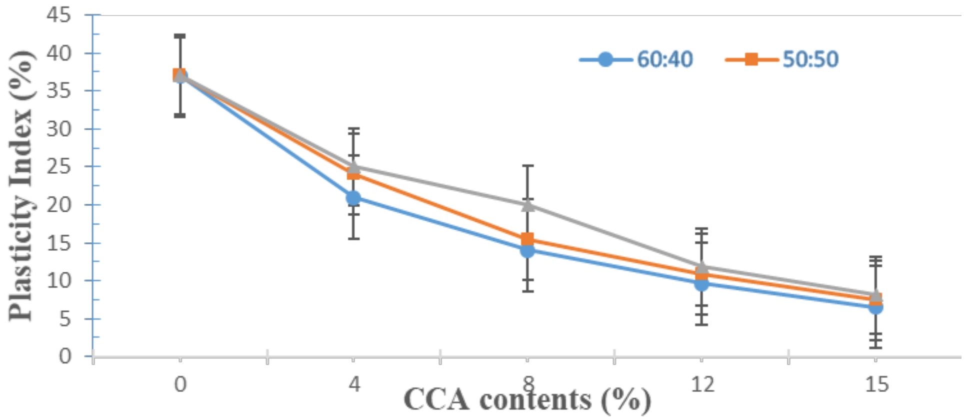


Figure 5: CCA content in relation with varying Plasticity index

4.5. Maximum Dry density (MDD) and Optimum moisture content (OMC)

The maximum dry densities of the expansive soil increase as the percentages of the stabilizing agent of the CCA blends increases. Figure 6 below, shows the variation of MDD in different blends at varying percentage of CCA contents. However, the peak MDD was reached for each blends 60C:40CA, 50C:50CA and 40C:60A at 8% respectively as further increase in the percentages from 12% to 15% CCA content leads to reduction in the soil's dry density from 1542kg/m^3 to 1537kg/m^3. Furthermore, it can be deduced that the 50C:50CA blend is the better stabilizer for the soil with 1553kg/m^3. With CCA content increasing, the 40C:60CA stabilizer decreases in dry unit density (maxium). Illustration in figure 7 depicts how the CCA content influences the rate of compaction properties of the soil. At each of the (3) three CCA mixtures used, soil's optimum moisture content (OMC) generally increases with respect to the CCA content within the soil increases.

Initially, the OMC increased, but subsequently declined after the incorporation of 8% CCA for 60C:40CA and the 50C:50CA mixes, with OMC increasing consistently alongside the CCA content for these blends. Conversely, unit dry density (maximum) of used soil stabilizer diminishes as CCA content escalates for 40C:60CA mixture. The impact on maximum dry unit weight parallels that observed in the specific gravity of the CCA-modified soil, likely resulting from changes in the stabilized soil specific gravity in relation to the CCA content. It was noted that OMC enhanced when the CCA content rose and soil content fell, which could be linked to a growing proportion of coarser materials in the mixture consuming water due to the presence of corn-cob ash, leading to a reduction in silt and clay. It suggests that additional water is necessary for the mixture compaction. With increased CCA content across all mixtures, a decrease was recorded in dry unit density (maximum). This drop experienced in dry density can be associated to its particles changes with CCA particles in the blends, thus possesses a lower S.G than the natural soil and filled the soil voids.

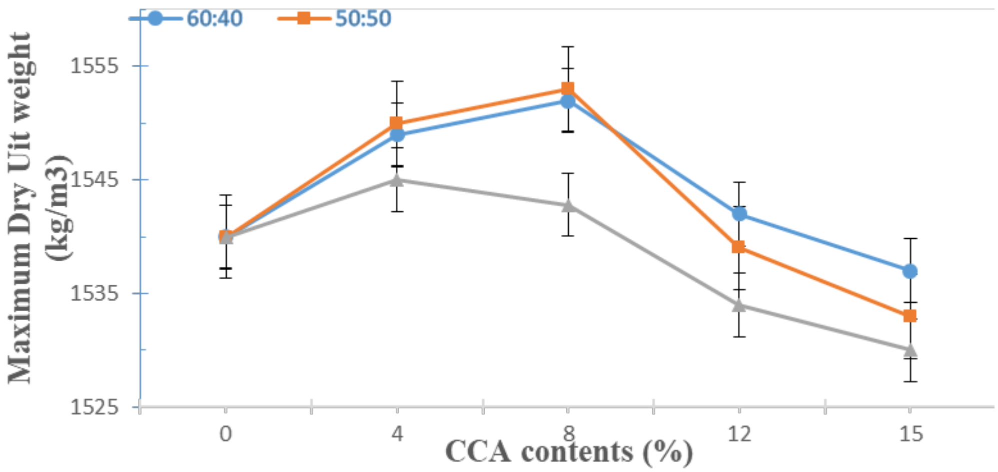


Figure 6: Varying Maximum dry unit weight with CCA contents

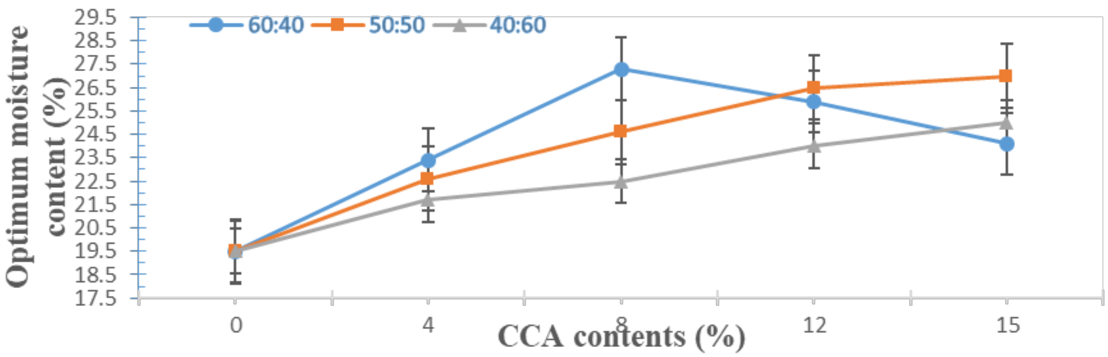


Figure 7: Varying optimum moisture content with CCA contents

4.6 California Bearing ratio (CBR)

The analysis as depicted in figure 8 of unsoaked CBR values with differing CCA mixtures at different penetrations of 2.5mm and 5mm in the blend shows the differences in the unsoaked CBR values of stabilized CCA soil at OMC. This indicates that the unsoaked CBR values generally rise considerably with an increase in CCA content within the mixtures. The unsoaked CBR values of the natural soil are relatively low (i.e., 3.1%). Natural soils meet the criteria defined in TRL (1993) and general Nigerian specifications, as CBR values and plasticity indexes exceed 30% (3.10%) or 12% (34%). Specification (Nigeria General Specification ((1997)) for the use of sub-grade materials. When stabilizing soil at 12% CCA content via three CCA mixtures, the soil's unsoaked CBR values and plasticity index exceeds 30%, as soil is qualified as a basic material, 12%. It is evident the CBR values of the 60C:40CA mixture improved up to 12% CCA content, followed by a noticeable decline. Addition of CCA gives increased unsoaked CBR ranging from 0-15% may be linked to the formation of calcium silicate resulting from a reaction between soil and silica. The subsequent drop in unsoaked CBR suggests that an excess of silica does not engage with the soil particles, adversely affecting their cohesion.

The highest California Bearing Ratio (CBR) of 12.3% was observed in stabilized soil with 12% Corn-Cob Ash (CCA) content and a 60C:40CA mix after 28 days of curing. Generally, CBR values increased with longer curing times and higher CCA content. For a 50C:50CA mix, the CBR improved from 4.8% to 12.3% as CCA content increased from 4% to 15% over 28 days. In samples with lower CCA content (60C:40CA), CBR initially rose with increasing CCA content up to 12% and then decreased at 15%. Conversely, in samples with higher CCA content (40C:60CA), CBR continued to rise as CCA content increased from 4% to 12%.

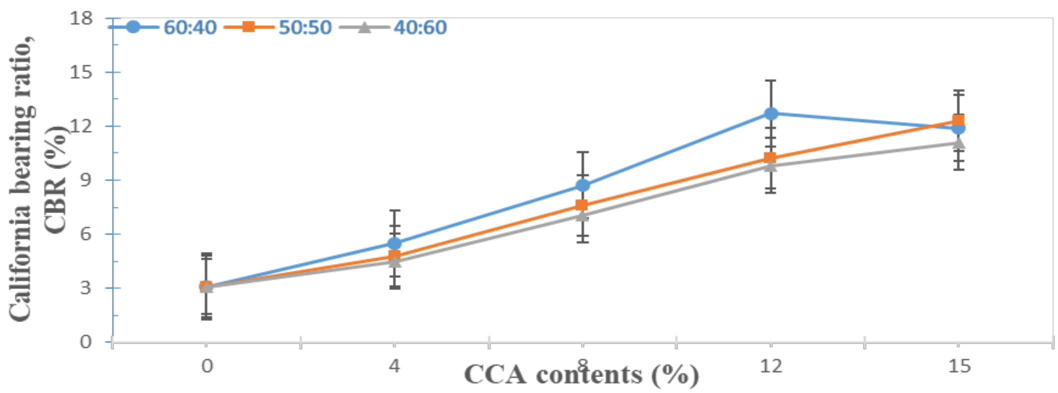
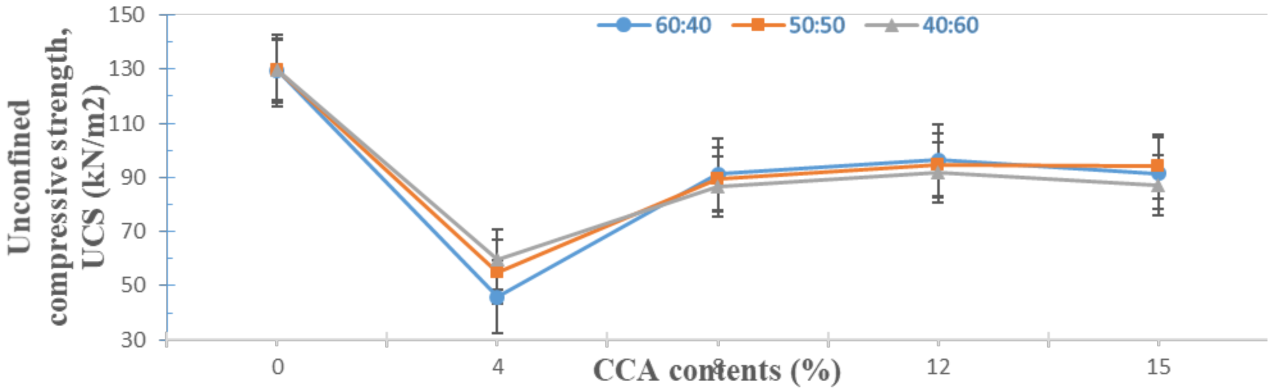


Figure 8: Variation of CBR with CCA contents

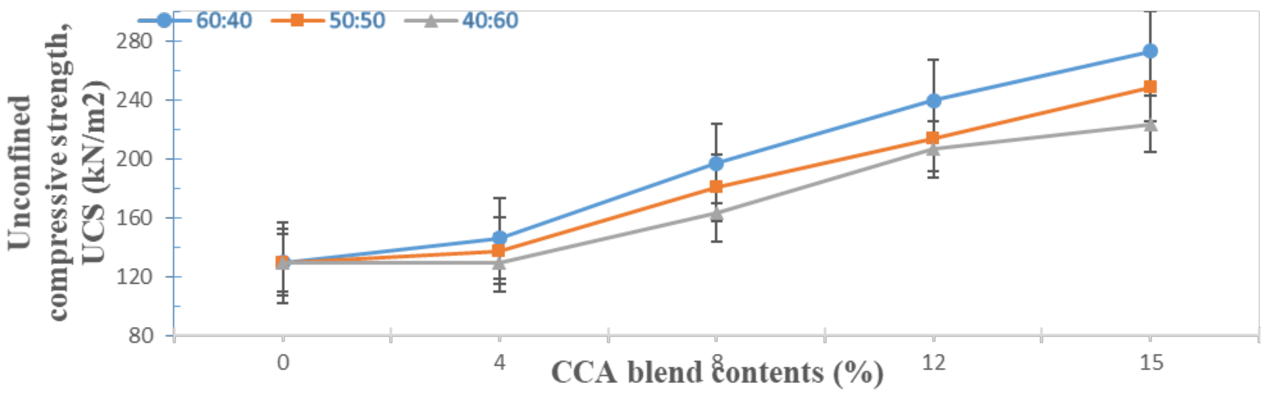
4.7 Unconfined compressive strength (UCS)

Figure 9a and b illustrate the impact on the compressive strength of the CCA-enhanced soil through CCA content cured at a day and 28 days period. In samples cured for 1 day, UCS markedly declines as the CCA content rises across all CCA content. Conversely, after 28-day curing duration for each of the CCA mixtures, the UCS displays an upward indication as CCA content increase. A reduction in UCS observed in 1-day cured samples with greater CCA content can be attributed to a significant reduction in its C_3S content, has been recognized as crucial for the development in materials that are cementitious an early strength (Mamlouk and Zaniewski, 2006). The enhancement of UCS in samples for 28 days curing, correlating with higher CCA content, is partially due as a result of subsequent rise in its C_2S content, known and acknowledged for contributing to the development of later strength in cementitious materials, assuring superior ultimate strength.

The byproduct of the pozzolanic reaction facilitated by the CCA might also contribute to increases in the UCS in the 28 days cured samples. It can be deduced that the UCS increases across each blend in which the 60C:40CA blends give the maximum compressive strength at each CCA contents percentages of 0%, 4%, 8%, 12% and 15% which are attained at 129.5kN/m², 146.0kN/m², 196.9kN/m², 239.7kN/m² and 273.3kN/m² respectively. The UCS of stabilized soil (60C:40CA, 50C:50CA, 40C:60CA) with varying CCA content at 0% to 15% was 2.11, 1.92 and 1.73 times greater than the (untreated) natural soil respectively. Hence, the UCS of the soil was increased 2.99, 2.64 and 2.57times after it was cured for 28days. The UCS outcomes for the specimens cured for 28 days across all mixtures closely mirrored those documented through Jimoh and Apampa (2014). Hence, soil's CCA proportion rose up, likewise the UCS of the specimens cured 28 days increased. Treated soil compressive strength also exhibited an upward trend with higher cement proportions in the mixtures, with the peak UCS recorded for the 60C:40CA mixture.



(a)



(b)

Figure 9: The CCA contents showing variation of UCS for (a) 1day curing and (b) 28days curing periods

4.8 Coefficient of Permeability

The impacts of CCA substance on soil stabilized at each of the CCA mixes on permeability rate as depicted in Figure 10 below. Permeability coefficient of the soil stabilized diminishes as CCA substance increases thoroughly the soil as thus for individual CCA mixes. Its decrease may be ascribed to the reduction in the soil's porosity and void proportion (Akinwumi, *et. al*., 2014) which result from binding of soil fragments together. A Reduced permeability of a surface layer material caused by the erosion of the surface layer due to water will diminish the chances of failure. At lower to moderate CCA contents (0% to 4%) the reduction in permeability starts gradually due to the initial bonding and filling of soil pores. The soil structure starts exhibiting better cohesion and compaction, which is evident in the reduced permeability. Likewise, moderate to high CCA Content (4% to 12%) as CCA content increases, more soil pores get filled, cementing particles further and drastically reducing permeability. The soil reaches a state where it becomes significantly compacted, leading to very low permeability. Also, for Very High CCA Content (12% to 15%) almost all voids get filled, and the soil structure becomes almost impermeable. Beyond a certain CCA threshold, further additions do not significantly improve permeability reduction but contribute to strengthening and cohesive stability of the soil.

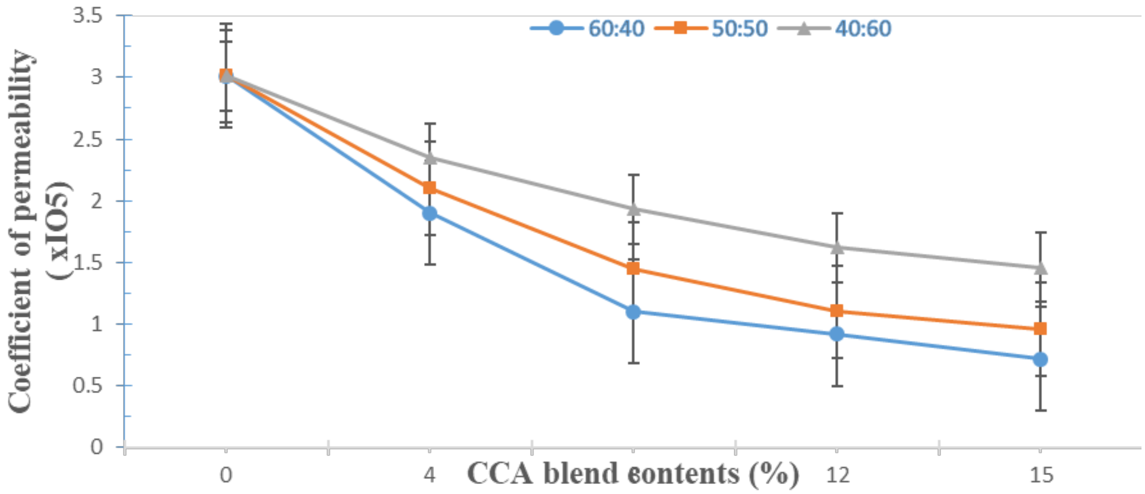
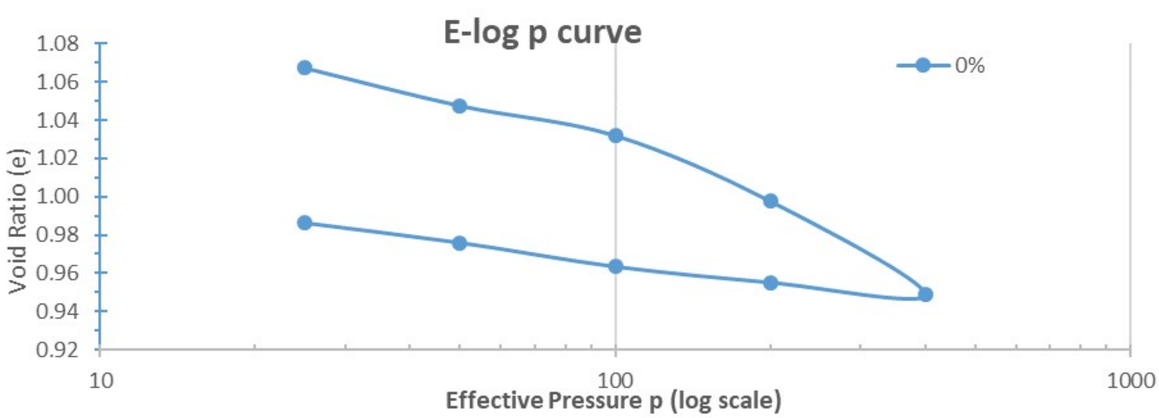


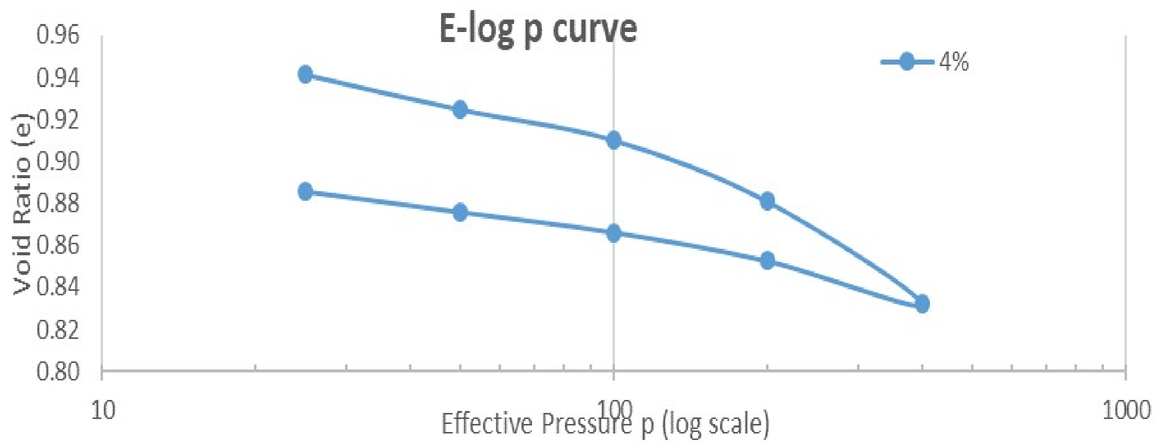
Figure 10: Variation of permeability with CCA contents

4.9 Consolidation Characteristics

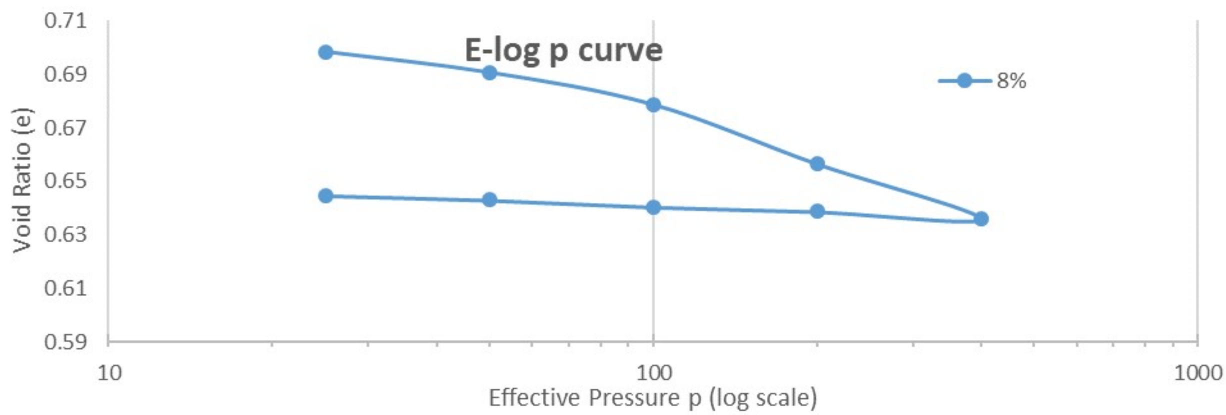
The consolidation behavior of the expansive soil sourced from Iju/Ota, Ogun State in southwestern Nigeria was examined on the 60C:40CA mixture at varying CCA concentrations of 0%, 4%, 8%, 12%, and 15%. The results, illustrated in plots of void ratio (e) against log-pressure (p), indicate that the e-logP graph for pressures exceeding the swelling pressure exhibits a more pronounced slope, as demonstrated in Figures 11(a) to (e) respectively. For consolidation to occur, the soil must be exposed to a pressure surpassing the swelling pressure (ASTM, 2003). The void ratio and compression curves of both untreated and treated soil are depicted below: the void ratio declined from 1.07 to 0.98 for natural (untreated) soil at 0%, and from 0.94 to 0.89, 0.69 to 0.64, and 0.54 to 0.47 for treated soil with 4%, 12%, and 15% CCA content respectively. The reduction in void ratio can be ascribed to CCA particles filling the voids and diminishing the overall porosity of the soil. This indicates that the natural soil has the highest equilibrium void ratio, whereas the treated expansive soils exhibit lower equilibrium void ratios when saturated after immersion.



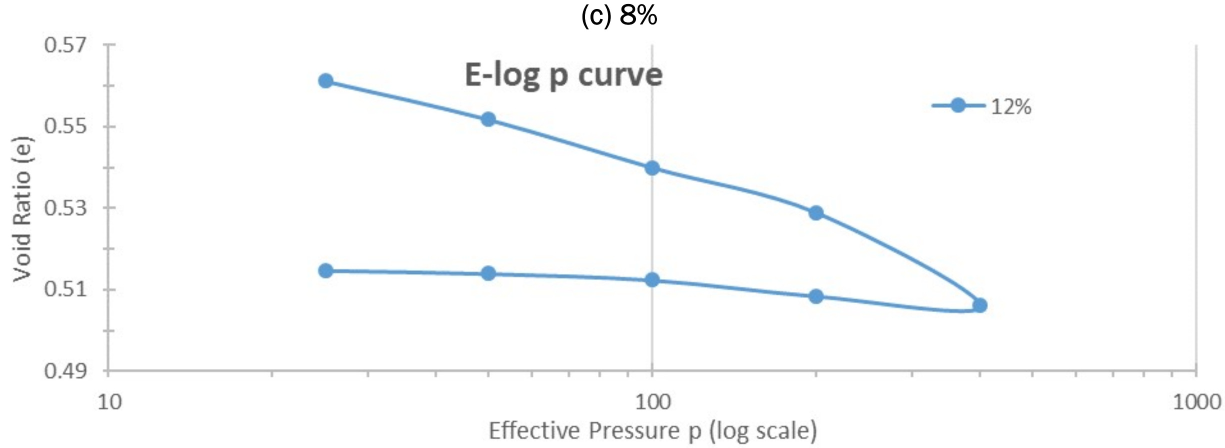
(a) 0%


E-log p curve
4%
Void Ratio (e)
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
10
100
1000
Effective Pressure p (log scale)

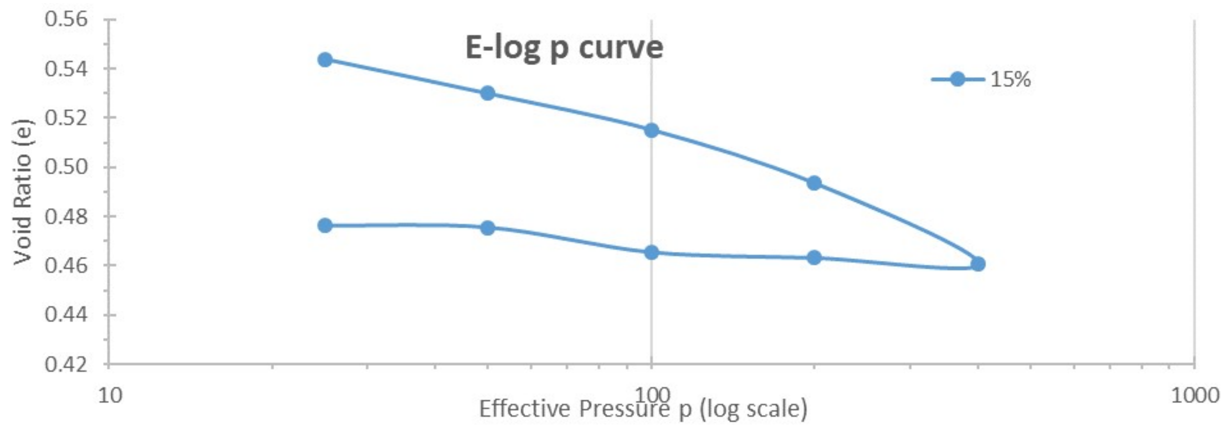
(b) 4%


E-log p curve
8%
Void Ratio (e)
0.71
0.69
0.67
0.65
0.63
0.61
0.59
10
100
1000
Effective Pressure p (log scale)

(c) 8%


E-log p curve
12%
Void Ratio (e)
0.57
0.55
0.53
0.51
0.49
10
100
1000
Effective Pressure p (log scale)

(d) 12%



(e) 15%

Figure 11a-e: Graph of void ratio and logP pressure for CCA contents at varying percentages (0%, 4%, 8%, 12% and 15%) of CCA contents

The Cv reflects the rate at which expansive soil consolidates, determined by analyzing the void ratio derived from the compression curves displayed above. The results indicate a decline in Cv from a range of 0.84 cm²/min to 0.74 cm²/min for untreated soil, compared to a range of 0.83 cm²/min to 0.72 cm²/min for 15% CCA. This observed reduction in Cv is likely attributed to the CCA generating entanglements and frictional interactions within the soil matrix, as well as the initial characteristics of expansive soil (including water content or void ratio), establishment of a torsional flow path in the expansive soil, or intrinsic properties of the expansive soil (such as specific gravity, particle size distribution, or mineral makeup). Khan and Azam (2016) also state that an increase in effective stress results to a reduction of Cv characteristics of clay soils, while an increment in void ratio enhances it.

The compression indices (Cc) recorded are 0.11394, 0.09712, 0.07379, 0.07229 and 0.03667 for 0%, 4%, 8%, 12%, and 15% CCA content, respectively. Consequently, coefficient of volume compressibility (mv) calculated may be referred to as alteration of volume per increment in unit stress (effective), is 1.6×10^{-4}, 1.5×10^{-4}, 1.3×10^{-4}, 1.4×10^{-4} and 0.7×10^{-4} kPa for content ranging from 0% to 15%, respectively. These moderate compressibility values render these soil samples appropriate for construction applications. These results reveal that corn-cob ash is more effective in minimizing swell capacity than the compressibility of the specimens. The ash functions as a binding agent, maintaining the particle cohesion and mitigating fissures during drying, which create preferential flow channels when saturated, thus facilitating easier infiltration access.

5. CONCLUSION

Upon reviewing multiple research outcomes concerning the replacement of CCA with cement by various researchers, we arrive at the following conclusion: A series of laboratory examinations were conducted to assess the efficacy of incorporating CCA to enhance expansive soil characteristics, specifically concerning compaction properties, strength metrics, and consolidation behavior.

The outcomes of these examinations yield the following inferences:

- Chemical makeup of corncob ash and cement suggests the products are abundant in silica and lime.
- An increase in CCA content within the soil resulted in reduced plasticity, permeability and swelling potential of the expansive soil, while enhancing profound long-term strength and bearing capacity.
- Higher proportions of corncob ash inputs to CCA blend correspond to increased permeability, plasticity and swelling potential of the soil; additionally, an increase in the unconfined compressive strength of the soil (UCS) correlates with higher bearing capacity.
- Among the three (3) blends analyzed, the 60C:40CA blend exhibited the most favorable geotechnical properties.
- The Plasticity Index (PI) exhibited a reduction as CCA content increased. This enhancement in PI can be attributed to a rise in strength coupled with a decrease in compressibility.
- Optimal compaction of soil samples was reached at the determined Maximum Dry Density (MDD) of 1553kg/m3 and corresponding Optimum Moisture Content (OMC) of 27.5%. The addition of CCA diminished the MDD of clay soil specimens from 1566kg/m3 in natural soil to 1553kg/m3 when treated with 8% CCA. The OMC also decreased from 29.20% in natural soil to 23.00% for samples treated with 15% CCA in a 60C:40CA blend.
- The unsoaked CBR values gives a note-worthy increase in each of the blends as the CCA content increases. The soil in its natural state has an unsoaked CBR value that is low (i.e. 3.1%). The CBR value is less than 30% (3.10%) and its natural soil plasticity index which also is greater than 12% (34%). The highest California Bearing Ratio (CBR) of 12.3% was observed in stabilized soil with 12% Corn-Cob Ash (CCA) content and a 60C:40CA mix after 28 days of curing. Stabilizing with 12% CCA content of 60C:40CA produces an unsoaked CBR value that is required, to be suitable as a base material as highlighted through Nigerian General Specification (1997).
- Regarding strength parameters, the Unconfined Compressive Strength (UCS) increased with each blend, with the 60C:40CA blend showcasing the highest compressive strength at varying CCA percentages: 0%, 4%, 8%, 12%, and 15%, recording values of 129.5kN/m2, 146.0kN/m2, 196.9kN/m2, 239.7kN/m2, and 273.3kN/m2, respectively, indicating significant improvement with CCA addition.
- The void ratio for expansive soil showcased a decline with the introduction of CCA; natural soil specimens at 0% CCA had a void ratio of e = 0.998 while samples treated with 4%, 8%, 12%, and 15% CCA presented void ratios of e = 0.881, 0.657, 0.529, and 0.493 correspondingly.
- The established correlation between the average consolidation coefficient Cv and consolidation pressure was consistent for both natural and CCA-treated soils, with Cv values decreasing from 0.84 cm2/min to 0.73 cm2/min for 15% CCA.
- The rate of settlement (S) reduces likewise the compression index (Cc) showed a decrease as CCA content increased in proportions which indicates that the soil becomes less compressible.
- This study's findings indicate that the incorporation of CCA positively influenced both the properties and consolidation behavior of expansive soils, as the porosity and density of CCA are less than those of the natural soil.

6. RECOMMENDATIONS

To efficiently employ CCA in soil reinforcement, several practical suggestions must be taken into account. It is crucial to perform thorough laboratory assessments to ascertain the ideal CCA concentration for particular soil categories. Generally, a dosage between 2.5% and 10% CCA by mass has shown effectiveness. Thus, laboratory results indicate that the 60C:40CA mixture solidified soil at 8% and 12% aligns with the required engineering specifications. Research is a continuous process. Hence, the heightened California Bearing Ratio (CBR) values of CCA-stabilized soils indicate enhanced strength and load-bearing capacity, rendering them suitable for numerous construction endeavors. The ecological benefits of using an agricultural by-product like CCA highlight its potential as a sustainable and economically advantageous solution for soil stabilization, decreasing agricultural waste and fostering greener construction practices.

With varying percentages of CCA content, it is vital for applications such as road building to optimize CCA content to strike a balance between low permeability and cost-efficiency. Reduced permeability assists in guaranteeing that pavement layers maintain stability and durability over time, hence diminishing maintenance and repair requirements. Increasing CCA content consistently bolsters the stability and integrity of soils by lowering permeability, making it a remarkably effective technique for soil stabilization in construction. This becomes particularly beneficial in regions susceptible to heavy rainfall or flooding, where minimized permeability is essential for averting structural degradation. An agricultural by-produce (corn cob) increasingly investigated for its potential to stabilize expansive soils, providing a sustainable and economical solution to a common geotechnical issue.

Implementing corncob (a plentiful waste generated from agricultural process) into construction will alleviate the environment of such problems related with their disposal improperly and also deliver many landfill capacities. Besides being environmentally friendly and more economical than cement stabilization, the stabilization process through CCA possesses the ability for its ultimate strength increasing and a yielding strength in long term enhancements that comes as a product of high levels of pozzolan compounds in the corncob ash (Al_2O_3, Fe_2O_3 and SiO_2,). The potential of CCA to tackle the challenges posed by expansive soils underscores its significance in contemporary geotechnical engineering practices- a reflection of the growing inclination towards sustainable and innovative construction approaches.

Future studies should persist in exploring the long-term performance and optimization of CCA-treated soils to further validate its efficacy and expand its application in various geotechnical contexts. If the structural loads do not exceed 100kPa, differential settlements or other settlement forms are not anticipated. Future research on soil samples in the study area should include Electron Microscopy and additional mineral analyses to identify the clay minerals present. Besides their suitability as subgrade, subbase, and base course materials in highway construction, these soils can also be recommended for producing mud blocks, which offer a cost-effective alternative to the increasingly expensive cement blocks.

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