INTERNATIONAL JOURNAL OF GEOMATICS AND GEOSCIENCES
Volume 5, No 3, 2015

Research article ISSN 0976 – 4380

Effect of Corncob ash on the geotechnical properties of Lateritic soil stabilized with Portland cement

Akinwumi I.I., Aidomojie O.I.
Department of Civil Engineering, Covenant University, Ota, Nigeria
isaac.akinwumi@covenantuniversity.edu.ng

ABSTRACT

Portland cement has been effectively used to improve the engineering properties of some local soils for construction of stabilized pavement layers, stabilized earth buildings and support layer for the foundation of buildings. However, cement is expensive and its use is unsustainable, necessitating the search for alternative materials for its total or partial replacement. This paper aims at providing experimental insights on the engineering properties of lateritic soil stabilized with cement-corncob ash (CCA) to ascertain its suitability for use as a pavement layer material. Series of specific gravity, consistency limits, compaction, California bearing ratio (CBR) and permeability tests, considering three CCA blends and four CCA contents, varying from 0 to 12%, were carried out. The results show that the addition of CCA to the soil generally reduced its plasticity, swell potential and permeability; and increased its strength. CCA-stabilization, aside being more economical and environment-friendly than cement-stabilization, improved the geotechnical properties of the soil for pavement layer material application.

Keywords: cement; corncob ash; sand; stabilization; tropical soils

1. Introduction

Corn is grown widely throughout the world. It is the largest produced grain annually. Worldwide production of corn, for 2012/2013 calendar year, is 868.80 million metric tons, with United States (US) and China producing 273.83 and 205.61 million metric tons, respectively; and the worldwide production is estimated to reach 979.02 million metric tons for 2013/2014 (USDA, 2014). Corncob is a by-product of corn production, with about 160-180 kg corncobs generated for every 1 ton of corn produced (Zhang et al., 2013). Consequently, 139-156.38 million metric tons of corncob was generated worldwide for 2012/2013 year. However, most of the corncobs generated worldwide are still discarded as waste (Zhang et al., 2010). The disposal of this enormous waste can constitute pollution of the environment. Thus, many researchers have considered recycling it for various applications.

Corncob has been considered or used for heavy metal removal from wastewater (Garg et al., 2007; Garg et al., 2008); biofuel production (Zhang et al., 2010; Liu et al., 2010; Sonobe et al., 2008); as a source of arabinoxylan for preparation of films (Egues et al., 2014); combined with apatite to form a novel bioactive material for bone-repairing (Ye et al., 2008); production of cellulose nanocrystals for use as reinforcing agent in nanocomposites (Silverio et al., 2013); preparation of high surface area carbons for the adsorption of dyes and phenols from water, and for hydrogen storage (Tseng et al., 2006; Sun and Webley, 2010); composting of swine manure (Zhu, 2006); production of thermally insulated building materials such as particleboard or sandwich panel products (Pinto et al., 2011) and the use of

Submitted on October 2014 published on January 2015

its ash as an admixture to Portland cement concrete (Binici et al., 2011; Adesanya and Raheem, 2009a).

On the other hand, Portland cement is one of the most effective and commonly used stabilizers of soils, such as some lateritic soils that have been used as a road pavement layer material, fill material and earth building material (Ola, 1974; Billong et al., 2009; Akinwumi, 2014a; Awoyera and Akinwumi, 2014) in tropical and subtropical countries because of their availability. However, Portland cement is expensive and its production is known to release a large quantity of greenhouse gases that is causing environmental concerns in our world today (Ezziane et al., 2011; Faleschini et al., 2014). Consequently, it is imperative that our world move towards a partial or total replacement of Portland cement as a soil stabilizer.

Some agricultural waste products that have been blended with cement, because of their pozzolanic properties, for concrete production include rice husk ash (Nehdi et al., 2003), sawdust ash (Udoeyo, 2002) and corncob ash (Adesanya and Raheem, 2009a). Although research works on corncob ash blended with Portland cement to produce concrete have been carried out, only Jimoh and Apampa (2014) has investigated the effects of corncob ash on the index properties, California bearing ratio (CBR) and unconfined compressive strength (UCS) of a lateritic soil. Corncob ash was applied to the soil in increments of 1.5% from 0 to 7.5%. The plasticity index and OMC of the stabilized soil increased as the corncob ash content increased. The maximum dry density of the soil, investigated by Jimoh and Apampa (2014), slightly reduced as the corncob ash content increases. The unsoaked and soaked CBR, and UCS initially increased and later decreased after the application of 3% corncob ash. They also reported results of their investigation of the effect of blending corncob ash and cement, in ratios 1:2, 1:1 and 2:1, on the UCS of the soil. They found out that the UCS increased with increase in the corncob ash and cement content for all the blends and that the 1:2 blend of corncob ash to cement gave higher UCS. However, they did not investigate the effects of the blends of corncob ash and cement on the Atterberg limits, compaction characteristics, unsoaked and soaked CBR, swell potential and permeability of the lateritic soil. Aside the research works of Jimoh and Apampa (2014), no other study has been reported in open literature on the stabilization of lateritic soil with blends of cement and corncob ash.

Consequently, this research work is significant because it is aimed at providing experimental insights on the engineering properties of lateritic soil stabilized with cement-corncob ash (CCA) to ascertain its suitability for use as a pavement layer material. This research pioneers the study of effects of the blends of corncob ash and cement on the Atterberg limits, compaction characteristics, unsoaked and soaked CBR, swell potential and permeability of lateritic soil.

2. Materials and methods

2.1 Materials and preparation

Corncobs, obtained from the Covenant University Farm, were air-dried for a week before being ground to a diameter of about 4 mm. According to Adesanya and Raheem (2009b), grinding corncobs to about 4 mm before burning them to ashes enhance adequate combustion and reduce the carbon content that affects their pozzolanic properties. The ground corncobs were burnt continuously in open air for 10 hours with temperatures reaching 560^{o}C. The resulting ashes easily passed through the sieve with openings of 0.075 mm. Ordinary Portland cement of grade 32.5, obtained commercially from the open market, was used in this study.

The soil sample, which is classified as A-2-6 (1) according to the American Association of State Highway and Transportation Officials (AASHTO) soil classification system (AASHTO, 1986) and clayey sand (SC) according to the Unified Soil Classification System (ASTM, 1992), was collected from the borrow pit (latitude 06°40′24"N and longitude 03° 09′12"E) behind Covenant University student hostels, by a method of bulk disturbed sampling. They were collected at a depth of 1 to 2 m below the ground, after the removal of 0.2 m thick topsoil layer. Soil sample for natural moisture content determination was collected in a watertight (polythene) bag. Other samples collected were air-dried, prior to conducting any laboratory test on them, in the Geotechnical Engineering laboratory of the Department of Civil Engineering, Covenant University, Ota.

2.2 Methods

The chemical compositions of the corncob ash and Portland cement were determined using X-ray fluorescence (XRF) analyses in terms of oxides. The geochemical characterisation of the soil was determined using atomic absorption spectrophotometer. The natural moisture content of the soil was determined using laboratory oven-drying method while its particle size distribution was determined from sieve and hydrometer analyses. CCA blends of 60% cement and 40% corncob ash (60C:40CA), 50% cement and 50% corncob ash (50C:50CA), and 40% cement and 60% corncob ash (40C:60CA) were prepared for use as the soil stabilizing agent blends. Each of these blends was added to the soil in proportions of 0, 4, 8 and 12%, by dry weight of the soil and thoroughly mixed to ensure homogeneity, thereby producing ten batches of CCA-stabilized soil. For each of these batches, specific gravity, Atterberg limits, compaction, California bearing ratio (CBR), unconfined compression and permeability tests were performed in triplicate and their mean values were computed.

Sieve analysis was carried out on samples of soil retained on a sieve with 0.075 mm opening while hydrometer analysis, using sodium hexametaphosphate, was conducted on the soil sample passing the sieve. The index properties tests performed on each of the batches of the natural and stabilized soil samples were in accordance with BSI (1990a, 1990b). The modified proctor energy was used to prepare specimens for compaction and CBR tests. After curing the specimens for CBR tests for 6 days under controlled temperature (25 ± 2°C) and relative humidity (100%), the specimens were afterwards immersed in water for 24 hours before testing to determine their soaked CBR values (Nigerian General Specification, 1997). Specimens for unsoaked CBR tests were cured for 7 days under the controlled temperature. In order to determine the swell potential, soil samples compacted in the CBR mould and subjected to a preloading pressure were immersed in water for 24 hours, allowing them to swell. Displacement readings were taken periodically.

The swell potential of a sample was calculated as the ratio of the change in height of the sample to its initial height. Unconfined compressive strength (UCS) test specimens (50 mm x 100 mm), prepared and extruded from a cylindrical mould, were cured in sealed plastic bags. The UCS for each test batch was determined after 1 day and 28 days of curing. Constant head permeameter was used to determine the coefficient of permeability of the samples. Modified Bogue Model equations, which are stated as follows:

$$C_3S = 4.07(CaO - CaO_{free}) - 7.6\,SiO_2 - 2.24Al_2O_3 - 4.29Fe_2O_3 - 2.85SO_3 \tag{1}$$

$$C_2S = 8.6SiO_2 + 1.69\,Al_2O_3 + 3.24Fe_2O_3 + 2.15SO_3 - 3.07(CaO - CaO_{free}) \tag{2}$$

$$C_3A = 2.65Al_2O_3 - 1.69Fe_2O_3 \quad (3)$$

$$C_4AF = 3.043Fe_2O_3 \quad (4)$$

were used to estimate the percentages of the main compounds in the cement and CCA blends. Firstly, the oxide composition of the CCA blends were estimated based on the assumption that the oxide composition of each blend is equal to the percentage of the material used multiplied by the oxide composition of the material. The addition of the calculated oxide compositions for the cement and corncob ash gives an estimate of the oxide composition of the CCA blends. It is based on these oxides composition and taking zero as the value for the free lime content (CaO_{free}) that alite (C_3S), belite (C_2S), celite (C_3A) and ferrite (C_4AF) were calculated.

3. Results

3.1 Chemical composition of soil, corncob ash and cement

The chemical composition of each of the soil, corncob ash and cement used is presented in Figure 1, in the form of their oxides composition. The sum of SiO_2, Al_2O_3 and Fe_2O_3 for corncob ash gives 74.38%, which is greater than the minimum 70% recommended by ASTM C618 (2003) for using a pozzolanic material in concrete. The cement and corncob ash are essentially rich in CaO and SiO_2, respectively. Tables 1 and 2 present the estimated oxides and main compounds composition of the CCA blends, respectively. CaO and SO_3 decreases with increasing corncob ash content in the CCA blends while SiO_2, Al_2O_3, Fe_2O_3 and MgO increases with increasing corncob ash content (Table 1). C_3S and C_3A decreases with increasing corncob ash content while C_2S and C_4AF increases with increasing corncob ash content in the CCA blends (Table 2).

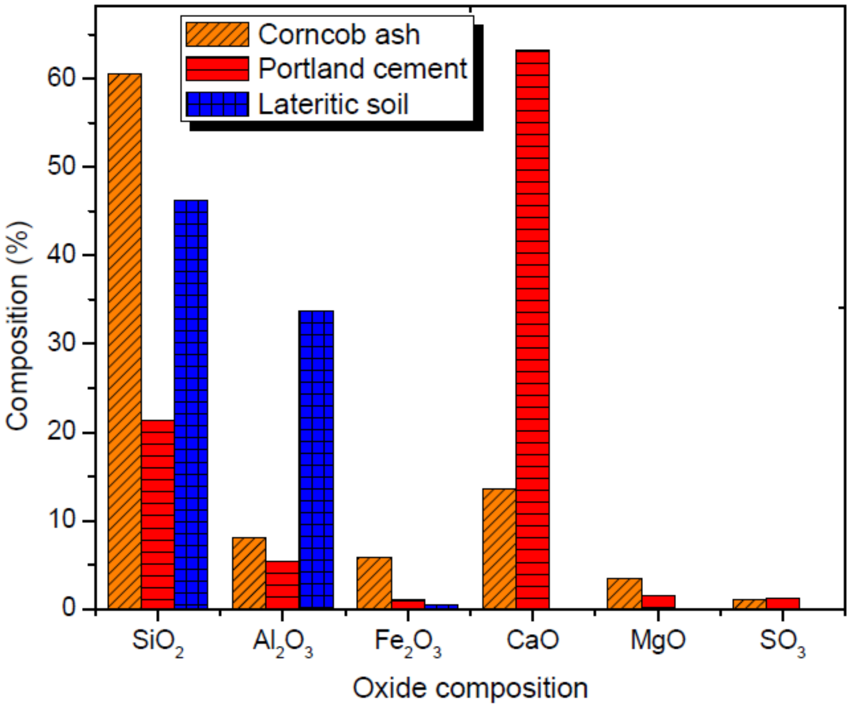


Figure 1: Chemical composition of materials used

Table 1: Estimated oxides composition of the CCA blends

	60C:40CA	50C:50CA	40C:60CA
C (CaO)	43.38	38.42	33.46
S (SiO_2)	36.99	40.91	44.82
A (Al_2O_3)	6.5	6.77	7.04
F (Fe_2O_3)	2.92	3.4	3.87
SO_3	1.168	1.16	1.152
MgO	2.28	2.48	2.67

Table 2: Estimated potential composition of main compounds in CCA blends

	100C:0CA	60C:40CA	50C:50CA	40C:60CA
Alite (C_3S)	75.2	-135	-187.6	-240.1
Belite (C_2S)	4.4	207.9	258.8	309.6
Celite (C_3A)	12.7	12.3	12.2	12.1
Ferrite (C_4AF)	3.1	8.9	10.3	11.8

The ratio of silica-sesquioxides [$SiO_2/(Al_2O_3 + Fe_2O_3)$] for the soil was calculated to be 1.35, which indicates that the soil is lateritic. According to the Schellmann (1986) scheme of classification of weathering products, this soil sample was classified as being taken from a kaolinized profile (Figure 2).

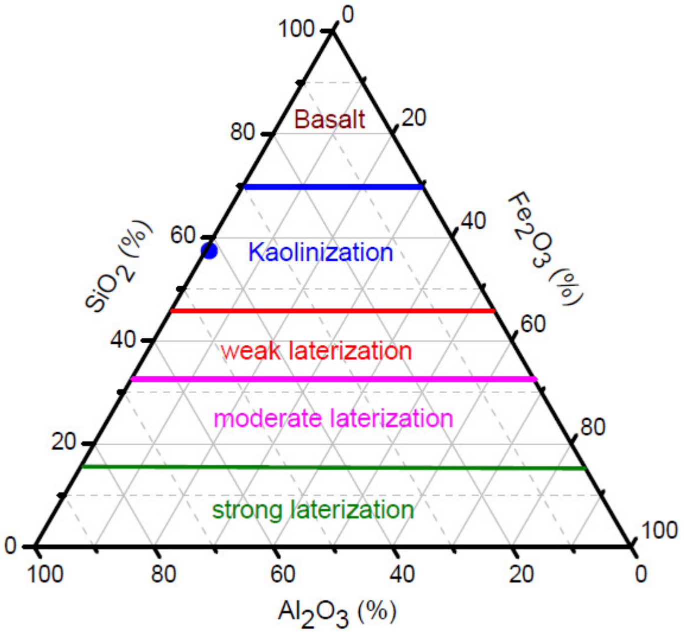


Figure 2: Al_2O_3-SiO_2-Fe_2O_3 (wt %) ternary plot for the soil sample

3.2 Natural soil

Table 3 gives a summary of the geotechnical properties of the natural soil. This soil has a natural moisture content of 15.7%. According to AASHTO soil classification system, this soil is classified as A-2-6 (1).

The results of sieve and hydrometer analyses on the natural soil sample are presented in Figure 3, in form of its particle size distribution. It shows that the soil is granular but has the percentage passing the BS No. 200 sieve (0.075 mm) to be 29.1%. This fraction of the soil will, however, considerably influence the properties of the soil. The liquidity index of the soil was calculated to be 0.27, indicating that the soil was in its plastic state (having intermediate strength and deforms like a plastic material) at the time of its collection. Figure 3 shows that the fines are predominantly clayey. The activity of the soil was determined to be 1.08 indicating that the soil is normally active.

Table 3: Geotechnical Properties of the Natural Soil

Properties		Quantity / Description
Gradation / Classification	Gravel (>4.75 mm), %	12.5
	Sand (0.075 - 4.75 mm), %	58.4
	Silt and Clay (<0.075 mm), %	29.1
	AASHTO Soil Classification System	A-2-6 (1)
	Unified Soil Classification System	SC - Clayey Sand
Physical	Colour	Brown
	Natural Moisture Content (%)	15.7
	Specific Gravity	2.54
	Liquid Limit (%)	29.0
	Plastic Limit (%)	10.8
	Plasticity Index (%)	18.2
	Linear Shrinkage (%)	4.0
	Maximum Dry Unit weight (kN/m^3)	17.5
	Optimum Moisture Content (%)	14.7
	Permeability (cm/s)	8.58 x 10^{-5}
	Swell Potential (%)	0.287
Strength	Unsoaked CBR (%)	56
	Soaked CBR (%)	29
	Unconfined Compressive Strength (kN/m^2)	1304

3.3 Effects of adding CCA to the natural soil

The specific gravity of the soil sample and corncob ash was determined to be 2.54 and 1.90, respectively, while the typical value of that of ordinary Portland cement is known from literature (Mamlouk and Zaniewski, 2006) to be 3.15. Variations of the specific gravity of soil with addition of the CCA blends are presented in Figure 4. The specific gravity of the soil was initially increased before decreasing with increasing CCA content for 60C:40CA and

50C:50CA blends. For the 40C:60CA blend, the specific gravity decreased with increasing CCA content. The varying effects of the addition of the CCA blends on the specific gravity of the soil are caused by the varying specific gravities of the CCA batches and blends, which are higher than the specific gravity of the natural soil for some CCA batches and lower for others.

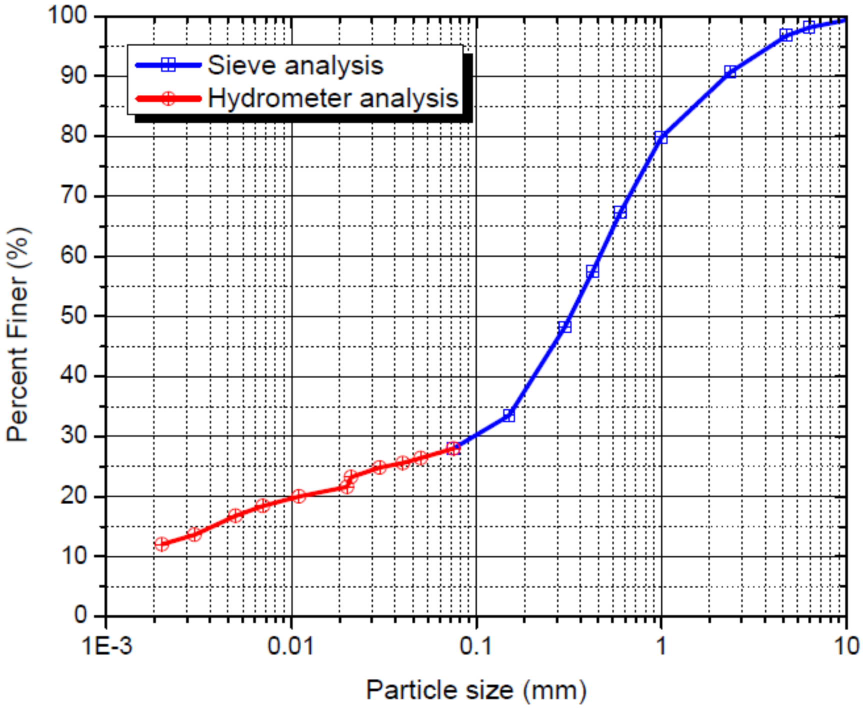


Figure 3: Particle size distribution of the natural soil

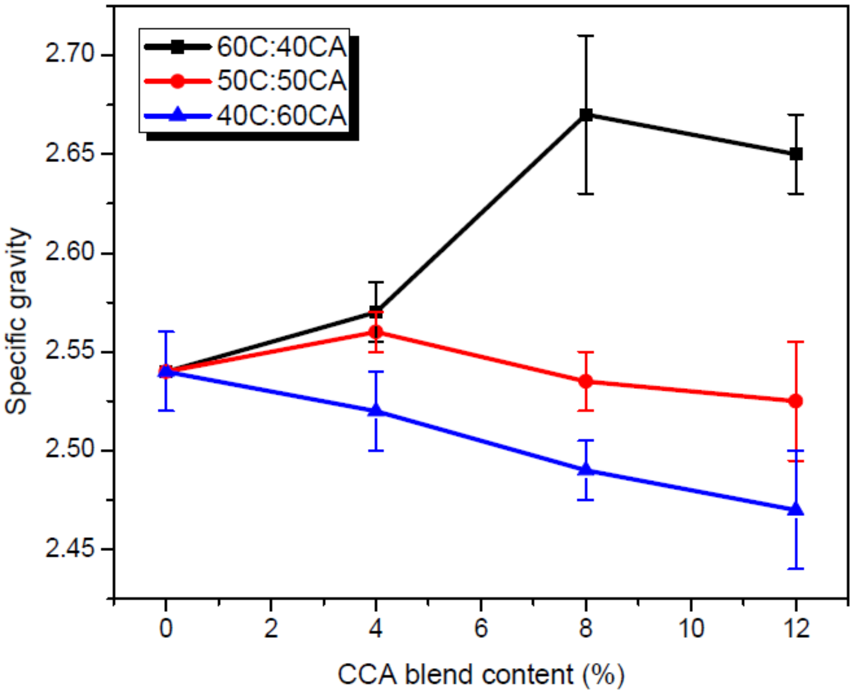


Figure 4: Variation of specific gravity with CCA content

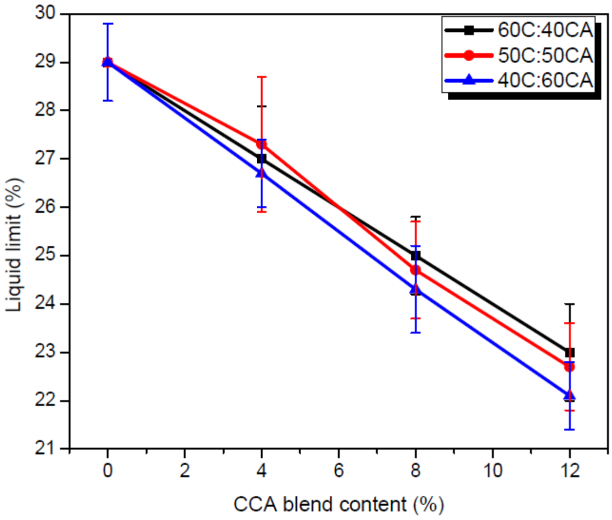
Variations of the liquid and plastic limits, linear shrinkage and plasticity index of the soil with addition of the various percentages of CCA and for each of the three CCA blends are presented in Figure 5. The liquid limit of the soil decreased with increasing CCA content for each of the CCA blends while the plastic limit and linear shrinkage were increased. The plasticity index, which is a measure of the plasticity of the soil, decreased with increasing CCA content for each of the blends. After the addition of 12% CCA to the soil, its plasticity was reduced by 52%, 47% and 46%, for 60C:40CA, 50C:50CA and 40C:60CA blends, respectively.

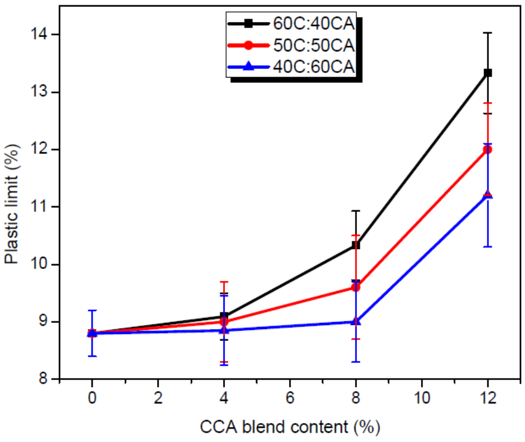
An exchange of the cations between the lime-rich cement and water in the stabilized soil, and subsequent dissociation is responsible for the reduction in plasticity index of the soil after the addition of varying percentages of the CCA blends. This led to the absorption of Ca^{2+} by some of the clay particles of the soil and the clay-size particles of the corncob ash, thereby minimizing the interaction between the water and clay-size particles (Akinwumi, 2014b, 2014c; Kampala and Horpibulsuk, 2013; Akinwumi et al., 2014b). The moisture-holding capacity of the soil was consequently reduced, making the soil more workable.

$$CaO + H_2O \rightarrow Ca(OH)_2 \qquad \text{(Cation exchange)}$$

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2(OH)^- \qquad \text{(Dissociation)}$$

The natural soil has a low linear shrinkage and this became slightly increased by the application of the CCA blends.





(b)

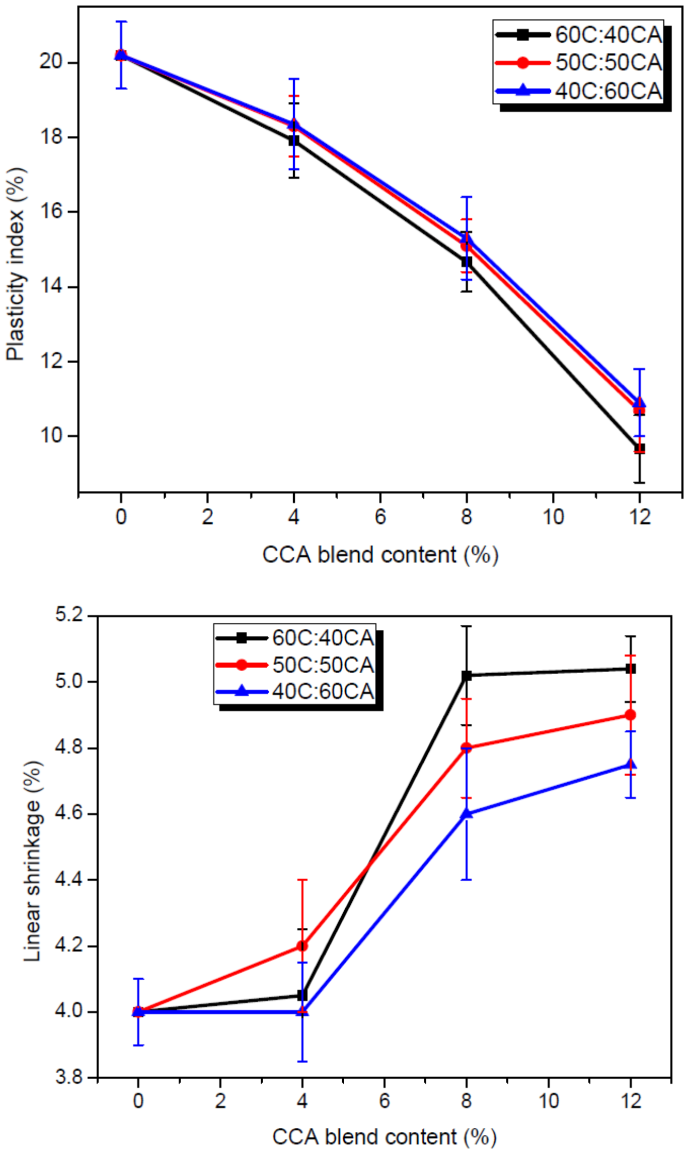


Figure 5: Variation of Atterberg limits with CCA content (a) Liquid limit (b) Plastic limit (c) Plasticity index (d) Linear shrinkage

Figure 6 is the AASHTO plasticity chart with plots of the plasticity indices against the liquid limits for the natural and CCA-stabilized soils. It shows that the plot for the natural soil fell within the part where soils classified as A-2-6 occupies but progressively shifts toward the part of the chart occupied by A-2-4 soils as the percentage of CCA increased, for each of the three CCA blends. For the addition of 12% of the 60C:40CA blend to the soil, the plot clearly falls within the part of the chart occupied by A-2-4 soils. Figure 7 shows the effect of CCA content on the compaction characteristics of the soil. For each of the three CCA blends, the optimum moisture content (OMC) of the soil tends to generally increase as the CCA content in the soil increases. The maximum dry unit weight initially increased but later decreased after the addition of 4% CCA for each of the 60C:40CA and 50C:50CA blends with the soil. For the 40C:60CA blend, the maximum dry unit of the stabilized soil decreases as the CCA content increases. These effects on the maximum dry unit weight is similar to that on the specific gravity of the CCA-stabilized soil and could have resulted from the variation of the specific gravity of the stabilized soil with the CCA content.

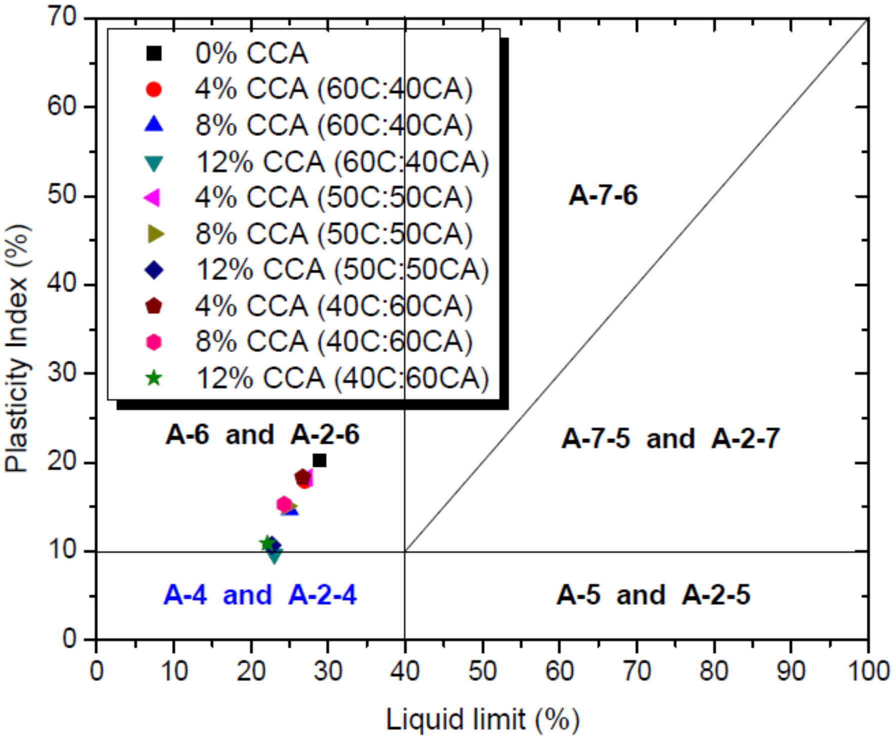
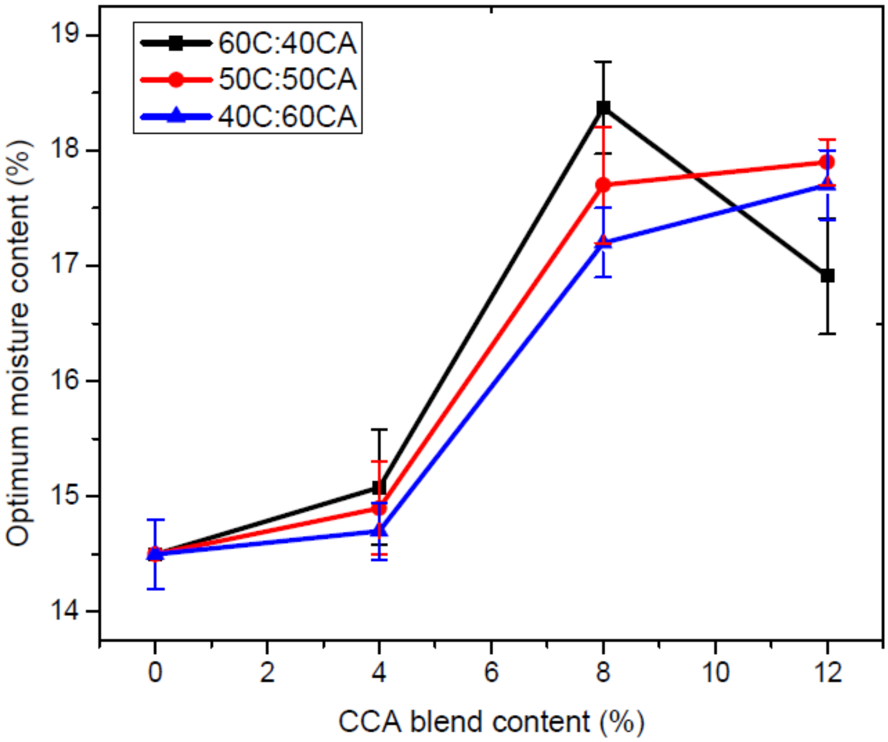
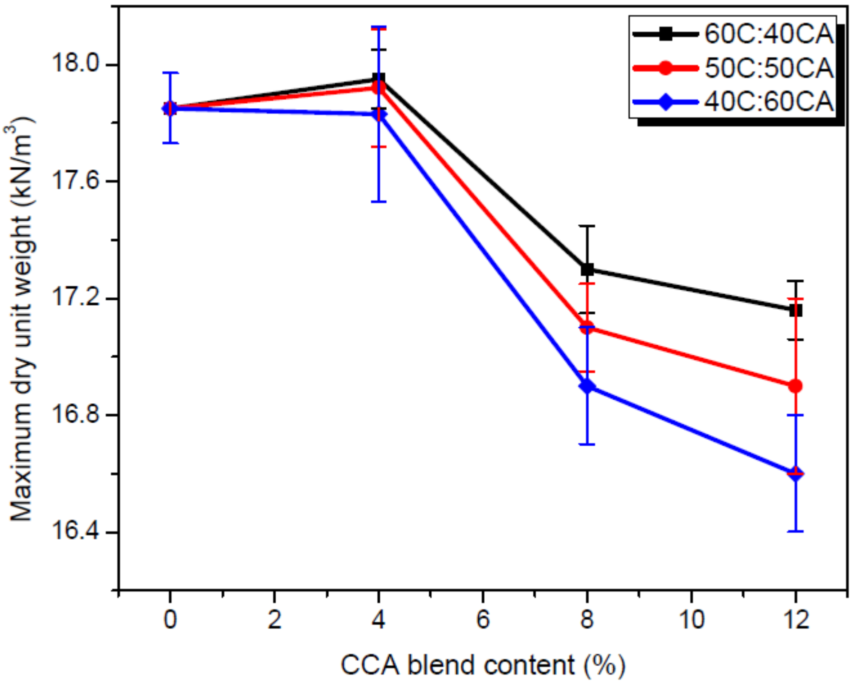


Figure 6: Plasticity charts showing variation of plasticity of the soil with CCA content



(a)



(b)

Figure 7: Variation of compaction characteristics with CCA content

The variations of the unsoaked and soaked CBR values of the CCA-stabilized soil at the OMC are shown in Figure 8. It shows that the unsoaked and soaked CBR values tend to significantly increase as the CCA content increases for the blends. The unsoaked and soaked CBR values of the natural soil are low. Since the soaked CBR value and the plasticity index of the natural soil is less than 30% and greater than 12%, respectively, the natural soil only satisfy the requirements of TRL (1993) and the Nigerian General Specification (1997) for use as subgrade material. After stabilization of the soil with 12% CCA content for the three CCA blends, the soaked CBR value and the plasticity index of the natural soil became significantly greater than 30% and less than 12%, respectively. Consequently, this stabilized soil became suitable for use as a subbase material for flexible pavement application. The stabilization with 8% CCA content for 60C:40CA gave a soaked CBR value that is greater than the 80% requirement, by the Nigerian General Specification (1997), for a soil to be used as a base material. However, the plasticity index of this stabilized soil is not less than the required 12% by this standard, making it unsuitable for such an application. The swell potential of the natural soil is low and it became further reduced with addition of the CCA blends, as can be seen in Figure 9. The low swell potential of the natural soil suggests that kaolinite is its predominant clay mineral, which is supported by the ternary plot shown in Figure 2. Figure 10 shows the effects of CCA content on the UCS of the CCA-stabilized soil cured for 1 day and 28 days. For the 1 day cured samples, the UCS significantly decreases with increasing CCA content, for each of the CCA blends. However, after a 28 days curing period for all the CCA blends, the UCS increases with increasing CCA content. The decrease in the UCS of the 1 day cured samples as the CCA content increases is due to the consequent significant decreases in its C_3S content (Table 2), which is known to be responsible for early strength development of cementitious materials (Mamlouk and Zaniewski, 2006). The increase in the UCS of samples cured for 28 days as the CCA content increases is partly due to the consequent increases in its C_2S content (Table 2), which is known to be responsible for the later strength development of cementitious materials and gives assurance of a high ultimate strength (Mamlouk and Zaniewski, 2006). The product of the pozzolanic reaction due to the CCA may also be responsible for the increased UCS for samples cured for 28 days.

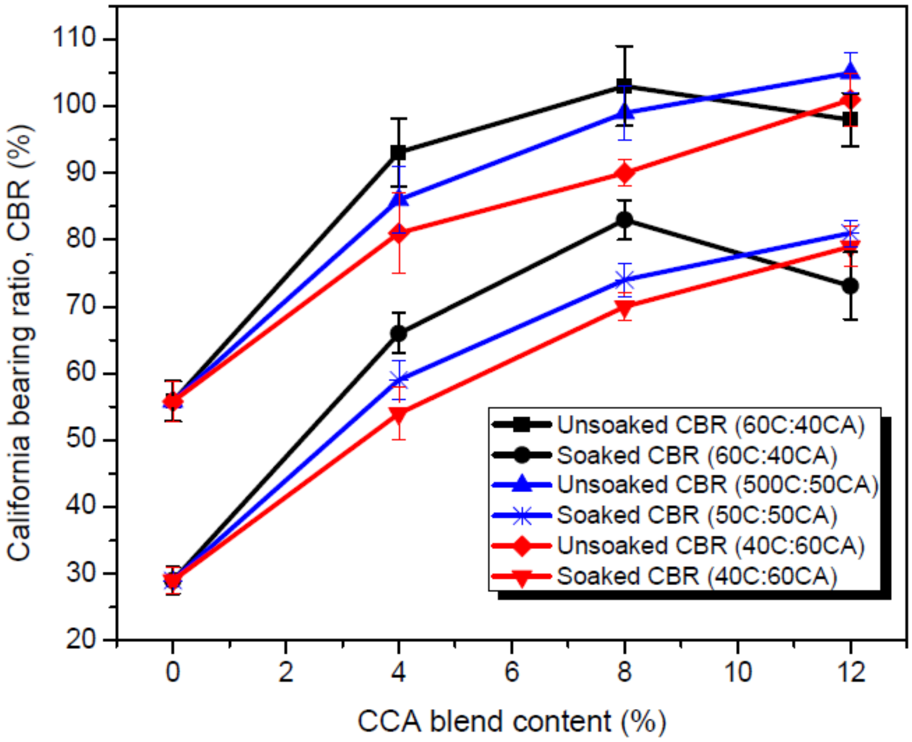


Figure 8: Variation of CBR with CCA content

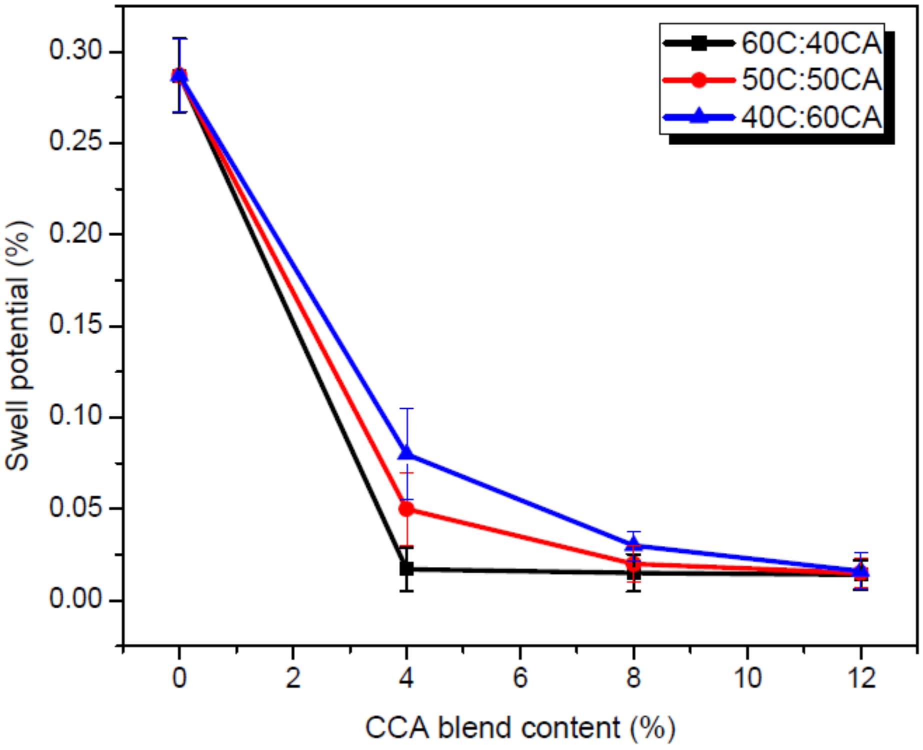
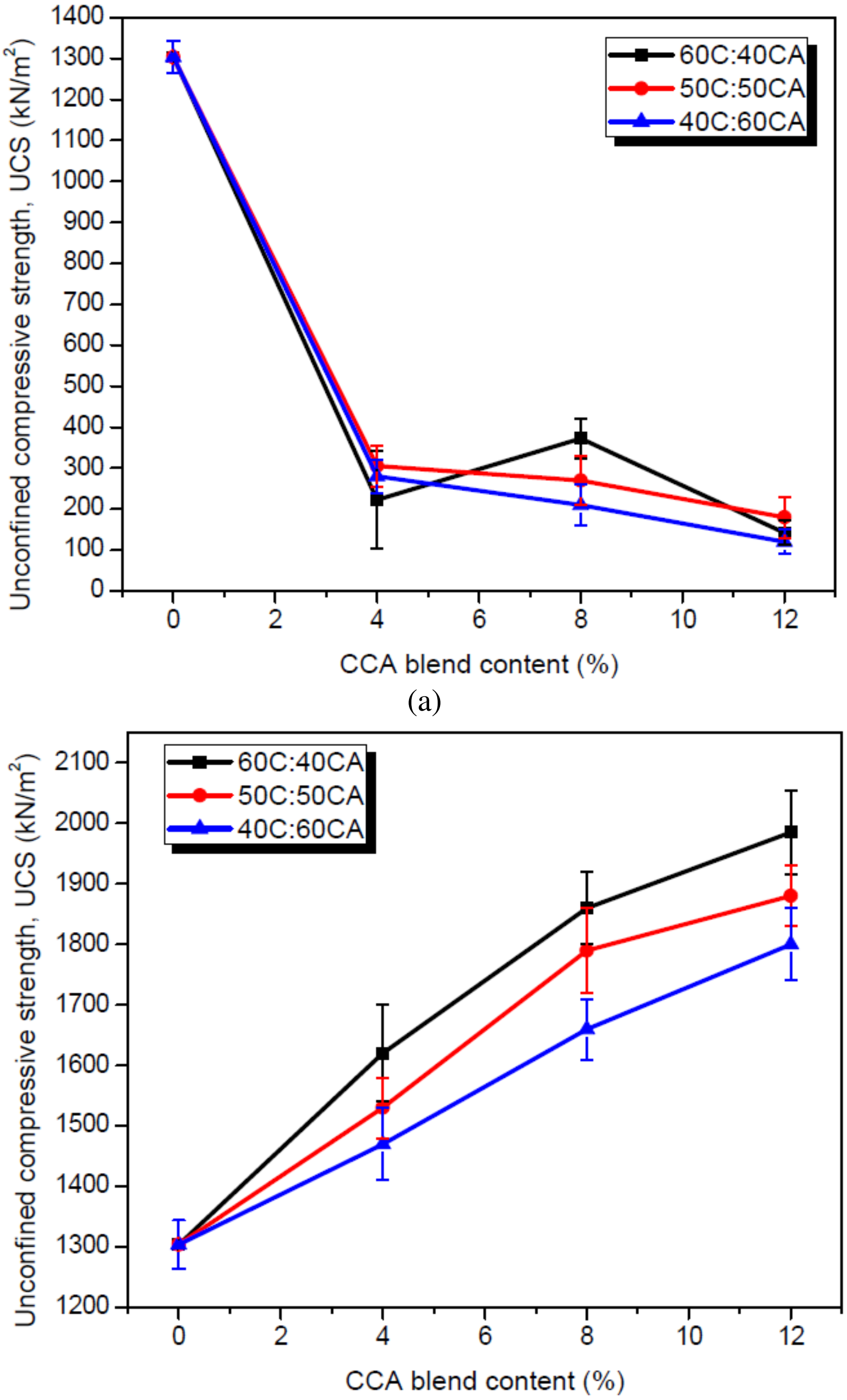


Figure 9: Variation of swell potential with CCA content



(a)

(b)

Figure 10: Variation of UCS with CCA content for (a) 1 day curing and (b) 28 days curing periods

The effects of the CCA content on the permeability of the stabilized soil for the three CCA blends are shown in Figure 11. The coefficient of permeability of the stabilized soil decreases with increasing CCA content in the soil, for each of the CCA blends. This decrease may be attributed to the decrease in the void ratio and porosity of the soil (Akinwumi et al., 2012; Akinwumi et al., 2014a;), resulting from the cementing together of the soil particles. Low permeability of a pavement layer material will reduce the likelihood of failure resulting from the weakening on the pavement layer by water.

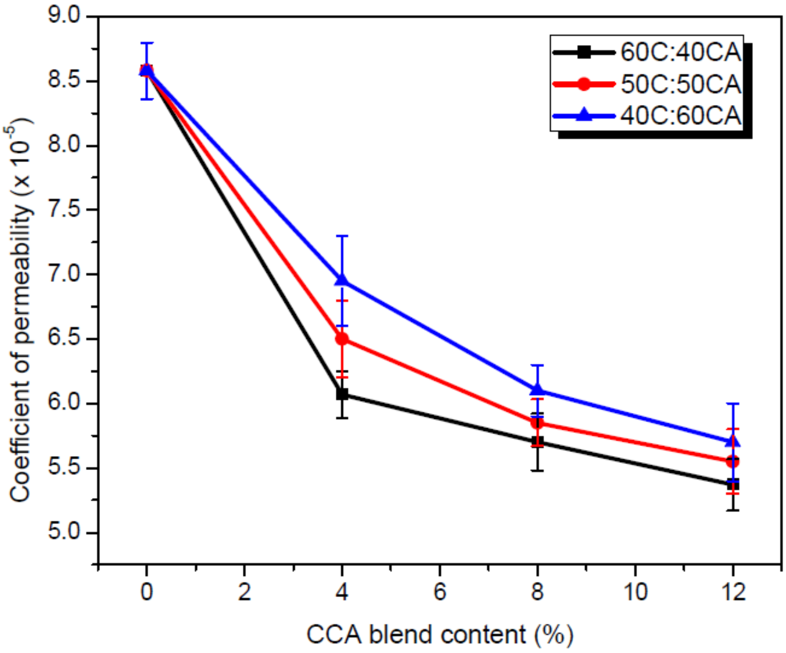


Figure 11: Variation of permeability with CCA content

4. Discussion

Joel and Agbede (2011) studied the stabilization of a lateritic soil (A-2-7) with cement and sand mixtures. They found out that sand enhanced the effective stabilization of the lateritic soil with cement. The effects of the stabilization of the lateritic soil with cement and sand on the liquid limit and plasticity index were found to be similar to that of the CCA-stabilized lateritic soil. In both studies the liquid limits and plasticity indices decreased with increasing stabilizer contents. The plastic limit of the cement-sand stabilized soil decreased with increasing cement-sand contents while that of the CCA-stabilized soil increased with increasing CCA content. The unsoaked and soaked CBR of the stabilized soils in both studies increased with increasing stabilizer contents. Joel (2010) reviewed research works on the use of agricultural waste products such as acha husk ash, bambara groundnut husk ash, bone powder ash, groundnut husk ash, rice husk ash and wood ash to partially replace cement as a binder. He found out that the compressive strength of most of the cement agro waste products were lower than that of the cement products. He attributed this decrease in compressive strength to the increase in SiO_2 and the decrease in CaO contents of the cement-agro waste products compared with those of the cement products.

The results of UCS for the 28 days cured specimens, for all the blends, were similar to that reported by Jimoh and Apampa (2014). As the CCA content in the soil increased, the UCS of the 28 days cured specimens increased. The UCS of the stabilized soil were also higher with increasing cement content in the blends, such that the highest UCS were obtained for the 60C:40CA blend. An application of corncob (an abundant agricultural waste) in construction will rid our environment of the nuisance associated with their improper disposal and may free some landfill space. Aside being more economical and environment-friendly than cement stabilization, CCA stabilization has the potential for long-term strength development or increased ultimate strength that results from the high content of pozzolanic materials (SiO_2, Al_2O_3 and Fe_2O_3) in the corncob ash.

5. Conclusion

This paper presents the results of series of laboratory tests investigating the suitability of the use of CCA-stabilized lateritic sand as a pavement layer material. From the results obtained, the following conclusions were made:

1. The chemical compositions of the cement and corncob ash indicate that they are rich in lime and silica, respectively.
2. As the CCA content in the soil increased, the plasticity, swell characteristics and permeability of the lateritic soil decreased while the bearing capacity and long-term strength increased.
3. The natural soil, which only satisfy the requirements of TRL (1993) and the Nigerian General Specification (1997) for use as a subgrade material, became improved by CCA stabilization such that it satisfies their requirements for use as a subbase material.
4. The higher the corncob ash content in the CCA blend, the higher the plasticity, swell potential and the permeability of the soil; and the lower the bearing capacity and strength of the soil. Of the blends, 60C:40CA blend gave the best geotechnical properties.

Mixture of cement and corncob ash, which is cheaper than wholly using cement, can be used to improve soils with similar geotechnical properties to that of the soil used in this study in order to make them better suited for use as pavement layer materials.

6. References

1. AASHTO (1986). Standard for transportation materials and methods of sampling and testing, fourteenth edition. AASHTO: Washington, DC.
2. Adesanya, D. A., and Raheem, A. A. (2009a). A study of the workability and compressive strength characteristics of corn cob ash blended cement concrete. Construction and Building Materials, 23, pp 311-317.
3. Adesanya, D. A., and Raheem, A. A. (2009b). Development of corn cob ash blended cement. Construction and Building Materials, 23, pp 347-352.
4. Akinwumi, I. I., Adeyeri, J. B., and Ejohwomu, O. A. (2012). Effects of steel slag addition on the plasticity, strength and permeability of a lateritic soil, in 2nd International Conference of Sustainable Design, Engineering and Construction proceedings, ASCE, Texas, 457-464.
5. Akinwumi, I. I., Diwa, D., and Obianigwe, N. (2014a). Effects of crude oil contamination on the index properties, strength and permeability of lateritic clay. International Journal of Applied Sciences and Engineering Research, 3(4), pp 816-824.
6. Akinwumi, I. I., Maiyaki, U., Adubi, S., Daramola, S., and Ekanem, B. (2014b). Effects of waste engine oil contamination on the plasticity, strength and permeability

of lateritic clay. International Journal of Scientific and Technology Research, 3(9), pp 331-335.

7. Akinwumi, I. I. (2014a). Earth building construction processes in Benin City, Nigeria and engineering classification of earth materials used. Indian Journal of Traditional Knowledge, 13(4), pp 686-690.
8. Akinwumi, I. I. (2014b). Soil modification by the application of steel slag. Periodica Polytechnica Civil Engineering, 58(4), pp 371-377.
9. Akinwumi, I. I. (2014c). Plasticity, strength and permeability of reclaimed asphalt pavement and lateritic soil blends. International Journal of Scientific and Engineering Research, 5(6), pp 631-636.
10. ASTM (1992). Annual book of ASTM standards. American society for testing and materials, ASTM International: West Conshohocken, PA.
11. ASTM C618 (2003). Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. American society for testing and materials, ASTM International: West Conshohocken, PA.
12. Awoyera, P., and Akinwumi, I. I. (2014). Compressive strength development for cement, lime and termite-hill stabilised lateritic bricks. The International Journal of Engineering and Science, 3(2), 37-43.
13. Billong, N., Melo, U. C., Louvet, F., and Njopwouo, D. (2009). Properties of compressed lateritic soil stabilized with a burnt clay-lime binder: Effect of mixture components. Construction and Building Materials, 23, pp 2457-2460.
14. Binici, H., Yucegok, F., Aksogan, O., and Kaplan, H. (2008). Effect of corncob, wheat straw, and plane leaf ashes as mineral admixtures on concrete durability. Journal of Materials in Civil Engineering, 20(7), pp 478-483.
15. BSI (1990a). Methods of test for soils for civil engineering purposes. British Standards Institution, BS1377: London.
16. BSI (1990b). Stabilized materials for civil engineering purposes: General requirements, sampling, sample preparation and tests on materials before stabilization. British Standards Institution, BS 1924: Part 1: London.
17. Egues, I., Stepan, A. M., Eceiza, A., Toriz, G., Gatenholm, P., and Labidi, J. (2014). Corncob arabinoxylan for new materials. Carbohydrate Polymers, 102, pp 12-20.
18. Ezziane, K., Kadri, E., and Siddique, R. (2011). Investigation of slag cement quality through the analysis of its efficiency coefficient. European Journal of Environmental and Civil Engineering, 15, pp 1393-1411.

19. Faleschini, F., De Marzi, P., and Pellegrino, C. (2014). Recycled concrete containing EAF slag: environmental assessment through LCA. European Journal of Environmental and Civil Engineering, 18, pp 1009-1024.

20. Garg, U. K., Kaur, M. P., Garg, V. K., and Sud, D. (2007). Removal of hexavalent chromium from aqueous solution by agricultural waste biomass. Journal of Hazardous Materials, 140, pp 60-68.

21. Garg, U., Kaur, M. P., Jawa, G. K., Sud, D., and Garg, V. K. (2008). Removal of cadmium (II) from aqueous solution by agricultural waste biomass. Journal of Hazardous Materials, 154, pp 1149-1157.

22. Jimoh, Y. A., and Apampa, O. A. (2014). An evaluation of the influence of corn cob ash on the strength parameters of lateritic soils. Civil and Environmental Research, 6(5), pp 1-10.

23. Joel, M. (2010). A review of partial replacement of cement with some agro wastes. Nigerian Journal of Technology, 29(2), pp 12-20.

24. Joel, M., and Agbede, I. O. (2011). Mechanical-cement stabilization of laterite for use as flexible pavement material. Journal of Materials in Civil Engineering, 23(2), pp 146-152.

25. Kampala, A., and Horpibulsuk, S. (2013). Engineering properties of silty clay stabilized with calcium carbide residue. Journal of Materials in Civil Engineering, 25(5), pp 632-644.

26. Liu, K., Lin, X., Yue, J., Li, X., Fang, X., Zhu, M., Lin, J., Qu, Y., and Xiao, L. (2010). High concentration ethanol production from corncob residues by fed-batch strategy. Bioresource Technology, 101, pp 4952-4958.

27. Mamlouk, M. S., and Zaniewski, J. P. (2006). Materials for Civil and Construction Engineers, second edition. Pearson Education, Inc.: New Jersey.

28. Nehdi, M., Duquette, J., and El-Damatty, A. (2003). Performance of rice husk ash produced using a new technology as a mineral admixture in concrete. Cement and Concrete Research, 33, pp 1203-1210.

29. Nigerian General Specification (1997). Roads and Bridges. Federal Ministry of Works, Lagos.

30. Ola, S. A. (1974). Need for estimated cement requirement for stabilizing lateritic soil. Journal of Transportation Engineering, 100(2), pp 379-388.

31. Pinto, J., Paiva, A., Varum, H., Costa, A., Cruz, D., Pereira, S., Fernandes, L., Tavares, P., and Agarwal, J. (2011). Corn's cob as a potential ecological thermal insulation material. Energy and Buildings, 43, pp 1985-1990.

32. Schellmann, W. (1986). A new definition of laterite. Geological Survey of India Memoir, 120, pp 1-7.

33. Silverio, H. A., Neto, W. P. F., Dantas, N. O., and Pasquini, D. (2013). Extraction and characterization of cellulose nanocrystals from corncob for application as reinforcing agent in nanocomposites. Industrial Crops and Products, 44, pp 427-436.

34. Sonobe, T., Worasuwannarak, N., and Pipatmanomai, S. (2008). Synergies in co-pyrolysis of Thai lignite and corncob. Fuel Processing Technology, 89, pp 1371-1378.

35. Sun, Y., and Webley, P. A. (2010). Production of activated carbons from corncob with large specific surface area by a variety of chemical activators and their application in gas storage. Chemical Engineering Journal, 162, pp 883-892.

36. TRL (1993). Overseas Road Note 31: A guide to the structural design of bitumen-surfaced roads in tropical and sub-tropical countries. Transport Research Laboratory (TRL): Berkshire.

37. Tseng, R., Tseng, S., and Wu, F. (2006). Preparation of high surface area carbon from corncob with KOH etching plus CO2 gasification for the adsorption of dyes and phenols from water. Colloids and Surfaces A: Physicochemical engineering Aspects, 279, pp 69-78.

38. Udoeyo, F. F. (2002). Sawdust ash as concrete materials. Journal of Materials in Civil Engineering, 14(2), pp 173-176.

39. USDA (2014). World agricultural supply and demand estimates, WASDE-529. United States Department of Agriculture: Washington.

40. Ye, Y., Huang, C., Wang, Q., Li, Q., Chen, Z., and Bao, C. (2008). Biomimetic synthesis of a novel HA/corncob composite. Applied Surface Science, 255, pp 548-551.

41. Zhang, M., Wang, F., Su, R., Qi, W., and He, Z. (2010). Ethanol production from high dry matter corncob using fed-batch simultaneous saccharification and fermentation after combined pretreatment. Bioresource Technology, 101, pp 4959-4964.

42. Zhang, C., Geng, Z., Cai, M., Zhang, J., Liu, X., Xin, H., and Ma, J. (2013). Microstructure regulation of super activated carbon from biomass source corncob with enhanced hydrogen uptake. International Journal of Hydrogen Energy, 38, pp 9243-9250.

43. Zhu, N. (2006). Composting of high moisture content swine manure with corncob in a pilot-scale aerated static bin system. Bioresource Technology, 97, pp 1870-1875.