Environmental Technology & Science Journal
Vol. 9 Issue 1 June 2018

Performance of Corncob Ash as Partial Replacement of Portland Cement in Lateritic Soil Stabilization

***[1]Salahudeen, A.B. and [2]Sadeeq, J. A.**
[1]Samaru College of Agriculture, Division of Agricultural Colleges, Ahmadu Bello University, Zaria, Nigeria.
[2]Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria.
basalahudeen@gmail.com

The growing cost of traditional soil stabilizing agents and the need for the economical utilization of industrial and agricultural waste for beneficial engineering purposes has led to extensive research on the use of industrial and agricultural wastes as alternative deficient soil treatment materials. The soil used in this study was classified as inorganic clay of low plasticity (CL) based on the unified soil classification system (USCS) and as A-6 using the American Association of State Highway and Transportation officers (AASHTO) classification system. Laboratory tests were performed to determine the index and strength properties of the natural soil and corncob ash (CCA) and Portland Cement (PC) treated soil samples in accordance with BS 1377 (1990) and BS 1924 (1990), respectively. A total of 16 soil/admixture samples were prepared for the study. All tests carried out were done at 0, 3, 6 and 9 % CCA/PC treatment by dry weight of the natural soil. There was an improvement in the Atterberg limits values of the soil with CCA/PC treatment. A minimum plasticity index value of 8.37 % at 9%CCA/9%PC content was observed. A peak value of maximum dry density (MDD) of 1.86 kN/m^3 and minimum value of optimum moisture content (OMC) of 13% were observed at 9%CCA/9%cement treatment. Peak UCS values of 710, 759 and 955 kN/m^2 were observed at 9%CCA/9%PC content for 7, 14 and 28 days curing periods which were improvements from the natural lateritic soil values of 266, 398 and 534 kN/m^2 for 7, 14 and 28 days curing periods respectively. An optimum CCA content of 9% by weight of the dried lateritic soil and 9% PC can be recommended for better results and stability.

Keywords: Atterberg limits; Cement; Corncob Ash; Lateritic soil; Maximum dry density; Optimum moisture content; Unconfined compressive strength

Introduction

Laterite is a soil and rock type rich in iron and aluminium, and is commonly considered to have formed in hot and wet tropical areas (Salahudeen, 2014). Nearly all laterites are of rusty red coloration, because of high iron oxide content. Typical laterite is porous and claylike. It contains the Iron oxide minerals, goethite ($HFeO_2$); lepidocrocite ($FeO[OH]$) and hematite(Fe_2O_2). It also contains titanium oxides and hydrated oxide of aluminium, the most common and abundant of which is gibbsite ($Al_2O_3.3H_2O$). The aluminium rich representative of laterite are bauxites (Osinubi, 1995; 2000).

A lot of laterite gravels, which are good for gravely roads, occur in tropical counties of the world, including Nigeria (Osinubi, 1994). There are instances where a laterite may contain substantial amount of clay minerals that its strength and stability cannot be guaranteed under load, especially in presence of moisture. These types of laterite are also common in many tropical regions including Nigeria where in most cases sourcing for alternative soil may prove economically unwise but rather to improve the available soil to meet the desired objective (Osinubi, 1994). The need for good road networks are extremely increased with increase in population so also the maintenance of the existing ones. The physical properties of laterite can be improved with addition of certain industrial and/or agricultural wastes (Salahudeen *et al*., 2014). Soil improvement could either be by modification or stabilization or both. However due to the increasing cost of cement and lime which are the two conventional materials used for stabilizing soils, the use of industrial wastes, such as corncob ash (CCA) will considerable reduce the cost of constructions as well as reducing environment hazards they cause if found to be useful.

Cement is the oldest binding agent since the invention of soil stabilization technology in 1960's. It may be considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required (Sherwood, 1993; EuroSoilStab, 2002). Cement reaction is not dependent on soil minerals, and the key role is its reaction with water that may be available in any soil (EuroSoilStab, 2002). This can be the reason why cement is used to stabilize a wide range of soils. Numerous types of cement are available in the market; these are ordinary Portland cement, blast furnace cement, sulphate resistant cement and high alumina cement. According to Jaritngam *et al.* (2014), cement stabilization involves three processes: cement hydration, cation exchange reaction and pozzolanic reaction. Cement hydration is a chemical reaction between cement and water whereby calcium hydroxide or hydrated lime $Ca(OH)_2$ is produced. The soil-cement reaction involves the replacement of divalent calcium (Ca^{2+}), absorption of $Ca(OH)_2$ by particles and cementation at inter-particle contacts by the compounds responsible for strength increases in the treated soil (Jaritngam *et al.*, 2014).

Corn cob is the waste product obtained from maize or corn, which is the most important cereal crop in sub-Saharan Africa. According to food and agriculture organization (FAO) data, 589 million tons of maize was produced worldwide in the year 2000. The United States was the largest maize producer having 43% of world production. Africa produced 7% of the world's maize. Nigeria was the second largest producer of maize in Africa in the year 2001 with 4.62 million ton. South Africa has the highest production of 8.04 million ton (FAO, 2002).

Soil improvement could either be by modification or stabilization, or both. Soil modification is the addition of a modifier (cement, lime, cement kiln dust) to a problem soil to improve its index properties for better usefulness, while soil stabilization is the treatment of problem soils to improve their index properties and strength characteristics such that they permanently become suitable for construction and meet engineering design standards (Salahudeen & Akiije, 2014).

The over dependence on the utilization of industrially manufactured soil improving additives (cement, lime, etc.) have kept the cost of construction of stabilized road financially high (Salahudeen, 2014). Thus, the possible use of industrial and/or agricultural wastes such as corncob will considerably reduce the cost of construction and as well as reduce or eliminate the environmental hazards caused by such wastes. In a bid to achieve alternative low cost roads where the production of aggregates for road work is very expensive, corncob ash (CCA), a waste product is substituted as a soil stabilizer. Corncob Ash (CCA) is cheaply available locally and is obtained through the burning of maize waste which is agricultural by-product .Therefore the use of corncob ash as an additive for soil stabilization will go a long way in reducing the cost of soil stabilization. The aim of this study is to evaluate the possibility of using CCA as a partial replacement of cement in lateritic soil to improve the index and strength properties as well as the workability of the soil.

Materials and Methods

Materials

Lateritic Soil

The lateritic soil used in this study was collected from a borrow pit in Shika village, Zaria, Kaduna State in the northern part of Nigeria (latitude $11^0$15' N and longitude 7^0 45' E), by using the method of disturbed sampling at 1m depth from the natural earth surface to avoid organic matter influence. This depth corresponds to the B – horizon usually characterized by the accumulation of material leached from the overlying A – horizon. A study of the Nigerian soils by Salahudeen (2017) reveals that the soil belongs to the group of ferruginous tropical soils derived from acid igneous and metamorphic rocks.

Corncob Ash

Corncob was locally obtained from maize in Samaru, Zaria area of Kaduna State. The corn waste (Corncob) was collected, air-dried and burnt under atmospheric conditions. The residue obtained after burning was the ash used for the partial replacement of cement in this study. The ash was passed through B.S. sieve no. 200 (0.075 mm) to meet the requirements of BS 1924 (1990). Table 1 shows the oxide composition of Corncob Ash used for this study. The chemical compositions of the Corncob Ash (CCA) and PC were determined at the Centre for Energy Research and Training (CERT), ABU, Zaria using the method of Energy Dispersive X-Ray Fluorescence.

Cement

The cement used in this study was Portland Cement (PC) obtained from an open market in Samaru market, Zaria, Kaduna State. Table 1 shows the oxide composition of Portland Cement used for this study.

Table 1: Chemical composition of Corncob ash and Ordinary Portland Cement

Oxide Compounds	Composition values (%)	
	CCA	OPC
CaO	5.89	65
SiO_2	65.77	21
Al_2O_3	6.40	6.15
Fe_2O_3	3.78	3.92
MgO	3.10	1.23
SO_3	2.05	1.02
K_2O	10.62	0.2
Na_2O	0.70	0.11
TiO_2	-	0.28
MnO	-	0.01
BaO	-	0.02
V_2O_5	-	0.02
P_2O_5	3.32	-
Loss on Ignition	10.45	0.81

Methods

Soil properties tests

Laboratory tests were performed to determine the index properties of the natural soil and CCA/PC treated lateritic soil in accordance with BS 1377 (1990) and BS 1924 (1990), respectively. A total of 16 soil/admixture samples (S1 – S16) were prepared for the study. All tests carried out were done at 0, 3, 6 and 9 % of CCA and PC treatments and their several combinations by dry weight of the natural soil as shown in Table 2:

Table 2: Samples of soil/CCA/PC batching

Sample Number	Sample Composition	Sample Number	Sample Composition
S1	0%CCA + 0%PC	S9	3%CCA + 6%PC
S2	0%CCA + 3%PC	S10	3%CCA + 9%PC
S3	0%CCA + 6%PC	S11	6%CCA + 3%PC
S4	0%CCA + 9%PC	S12	6%CCA + 6%PC
S5	3%CCA + 6%PC	S13	6%CCA + 9%PC
S6	6%CCA + 6%PC	S14	9%CCA + 3%PC
S7	9%CCA + 6%PC	S15	9%CCA + 6%PC
S8	3%CCA + 3%PC	S16	9%CCA + 9%PC

Compaction

The compaction tests were performed on the natural soil and the CCA/PC treated soils using the British Standard light (BSL) energy.

Strength tests

The strength test performed in this study was used to determine the unconfined compressive strength (UCS) values of the soil samples. The UCS test specimens were compacted at BSL energy and cured for 7, 14 and 28 days before testing.

Results and Discussion

Properties of the Natural Soil

Preliminary tests performed show that the natural soil is an A-6 (15) soil according to the AASHTO classification system (AASHTO, 1986) and low plasticity clay (CL), using the USCS (ASTM, 1992). The natural soil has low moisture content value of 16 %, specific gravity of 2.73, liquid limit of 45%, plastic limit of 22% and plasticity index of 23% with 71 % of the soil particles passing through the BS. No 200 sieve. Table 3 shows the summarized properties of the natural soil.

Table 3: Properties of the Natural Lateritic Soil

Properties	Description
Percent passing BS sieve No.200	70.85
Liquid limit (%)	45
Plastic limit (%)	22
Plasticity index	23
Linear shrinkage (%)	3.6
Group index	15
AASHTO classification	A-6
UCS classification	CL
Specific gravity	2.73
Maximum Dry Density (Mg/m^3)	1.7
Optimum Moisture content (%)	18.9
Natural moisture content (%)	15.82
7days Unconfined Compressive Strength (KN/m^2)	266
14days Unconfined Compressive Strength (KN/m^2)	398
28days Unconfined Compressive Strength (KN/m^2)	534
Colour	Reddish brown

Effect of CCA and PC on Particle Size Distribution of Lateritic Soil

The results in Figure 1 show a change in the positions of the particle size distribution curve of the natural lateritic soil due to the influences of CCA and PC. Generally, a slight increase in the coarser particles was observed. This change is an indication that with increase in CCA/PC content, modification reaction between CCA, PC and clay minerals increased which facilitated the formation of relatively coarser particles (Osinubi, 2000; Salahudeen, 2014).

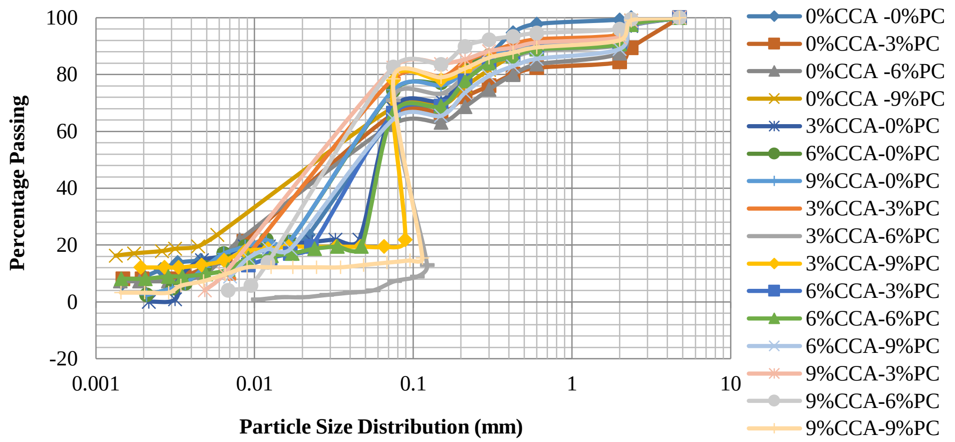

Figure 1: Particle size distribution curve for the natural and CCA/PC treated lateritic soil

Effect of CCA and PC on Specific Gravity of Lateritic Soil

The specific gravity of solid particles is the ratio of the mass of a given volume of solids to the mass of an equal volume of water. Specific gravity is an important parameter used for the determination of the void ratio and particle size of any soil particle (Salahudeen & Sadeeq, 2016a; b). The variation of specific gravity with CCA/PC admixtures is shown in Figure 2. The specific gravity of the natural soil (2.73) decreased consistently with increase in CCA and PC content. The decrease in specific gravity is due to the lower specific gravity of CCA compared to that of the untreated soil (Osinubi, 1995; Salahudeen, 2014).

Effect of CCA and PC on Atterberg Limits of Lateritic Soil

The variations of Atterberg limits (i. e. liquid limit, plastic limit and plasticity index) of lateritic soil with varied CCA/PC contents are shown in Figures 3 - 5. The plastic limits of the lateritic soil increased with increased CCA content while the liquid limits decreased. The increase in plastic limits can be attributed to addition of CCA/PC which introduced more pozzolanic substance into the specimen that required more water for hydration to be completed. However, the decrease in liquid limits and plasticity indices can be associated with the agglomeration and flocculation of the clay particles which is as a result of exchange of ions at the surface of the clay particles.

This observed trend is in agreement with Ramzi *et al.* (2001), Venkaramuthyalu *et al.* (2012), Salahudeen and Ochepo (2015), Sadeeq *et al.* (2014a; b; c) Sadeeq *et al.* (2015), Salahudeen and Sadeeq (2016a; b) and Sadeeq and Salahudeen (2017). Ramzi *et al.* (2001), Suhail *et al.*, (2008), Venkaramuthyalu *et al.* (2012) and Salahudeen and Sadeeq (2016a; b) reported that the reduction in plasticity index with chemical treatment could be attributed to the depressed double layer thickness due to cation exchange by potassium, calcium and ferric ions. The minimum plasticity index value of 8.37 % at 9%CCA/9%PC content meets the maximum values of 12 % plasticity index specified by clause 6201 of the Nigerian General Specifications (1997) for sub-base materials.

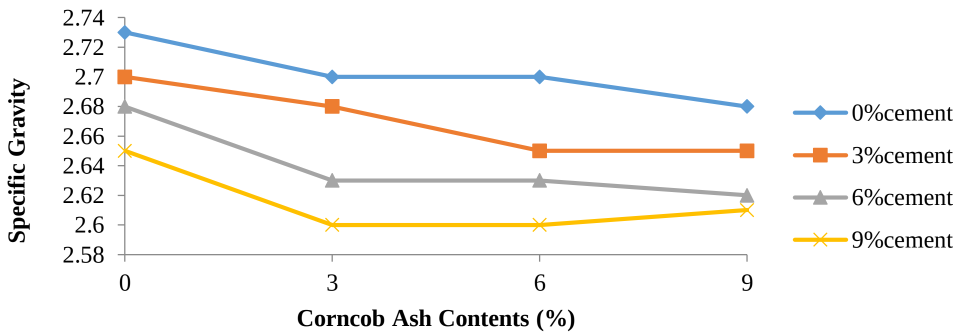

Figure 2: Variation of specific gravity of lateritic soil with CCA/PC content

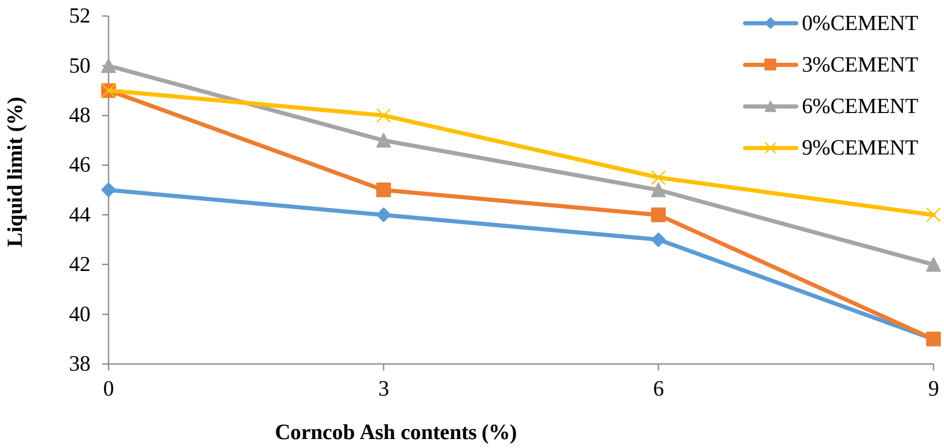

Figure 3: Variation of liquid limit of lateritic soil with CCA/PC content

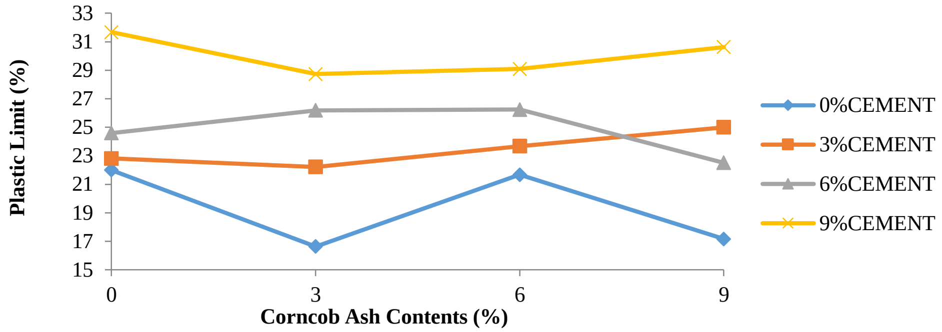

Figure 4: Variation of plastic limit of lateritic soil with CCA/PC content

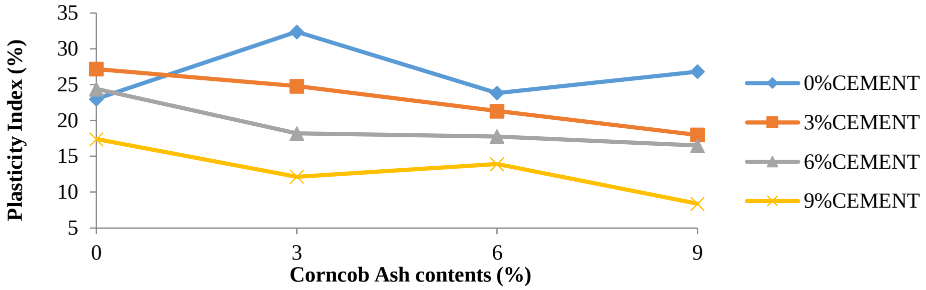

Figure 5: Variation of plasticity index of lateritic soil with CCA/PC content

Effect of CCA and PC on Compaction Characteristics of Lateritic Soil

The variations of maximum dry density (MDD) and optimum moisture content (OMC) of the lateritic soil used in this study with CCA/PC content are shown in Figures 6 and 7 respectively. A peak value of MDD of 1.86 kN/m^3 and minimum value of OMC of 13% were observed at 9%CCA/9%PC treatment. Generally, an increase in both MDD and OMC was observed up to 6%CCA treatment then the values decreased. It was also observed that the MDD continuously increased with increase in cement content while the OMC inversely decreased. According to Alhassan (2008) and Salahudeen (2014), the increase in the MDD can be attributed to the replacement of soil by CCA/cement in the mixture. It may also be attributed to coating of the soil by the CCA and cement which resulted to formation of larger particles and hence the increase in MDD. This increase in the MDD may also be explained by considering the

CCA and cement as fillers in the soil voids which increased the weight of the soil/CCA/cement matrix. According to Salahudeen et al. (2014) and Salahudeen (2014), the increase in MDD could be due to CCA/PC mixture occupying the voids within the soil matrix as well as the flocculation and agglomeration of the clay particles due to exchange of ions. The observed trend is in line with Osinubi (1999). The subsequent decrease in MDD may be due to the addition of CCA and PC, which decreased the quantity of free silt and clay fraction and coarser materials with larger surface areas formed. The subsequent decrease in OMC with increase in CCA/PC content might be due to cation exchange reaction that caused the flocculation of clay particles (Salahudeen and Akiije, 2014; Salahudeen et al. 2014; Sadeeq and Salahudeen, 2017).

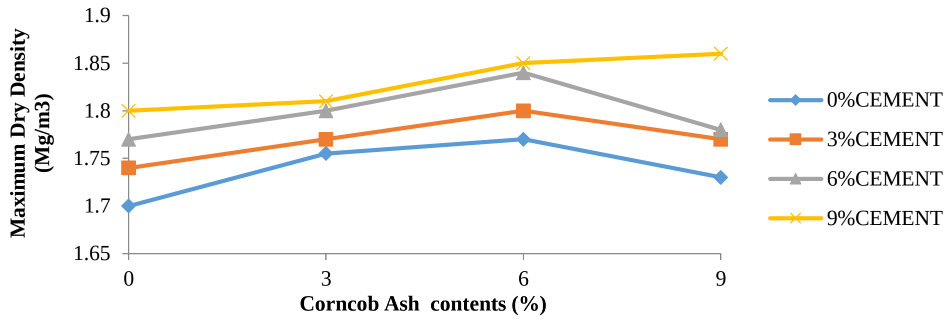

Figure 6: Variation of maximum dry density of lateritic soil with CCA/PC content

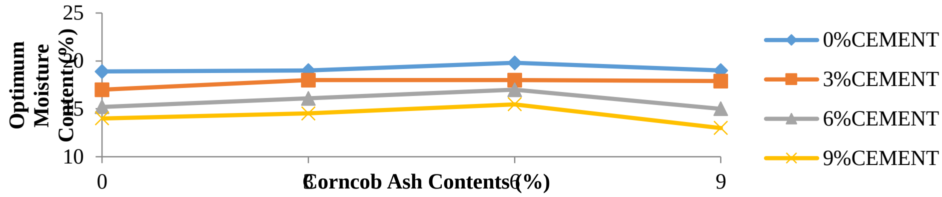

Figure 7: Variation of optimum moisture content of lateritic soil with CCA/PC content

Strength Characteristic

Unconfined compressive strength (UCS) has been the most common and adaptable method of evaluating the strength of stabilized soil. It is the main test recommended for the determination of the required amount of additive to be used in stabilization of soil (Signh, 1991). The result of UCS tests of the soil stabilized with cement and Corncob Ash are shown in Figures 8 – 10 for 7, 14 and 28 days curing periods. A tremendous improvement in the UCS values with addition of Cement and corncob Ash to the natural soil was observed. The UCS values increased with increase in both Cement and Corncob Ash content having peak values at 9%CCA/9%PC content for all the three curing periods considered in this study.

Peak UCS values of 710, 759 and 955 kN/m^2 were observed at 9%CCA/9%PC content for 7, 14 and 28 days curing periods which were improvements from the natural lateritic soil values of 266, 398 and 534 kN/m^2 for 7, 14 and 28 days curing periods respectively. The observed trends can be attributed to ion exchange at the surface of clay particles. The Ca^{2+} in CCA and cement reacted with the lower valence metallic ions in the clay microstructure which resulted in agglomeration of the clay particles (Osinubi and Medubi, 1997; Osinubi and Stephen, 2006; Salahudeen et al., 2014). The increase of the UCS values was primarily due to the formation of various compounds such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) and micro fabric changes, which are responsible for strength development (Jones and Holtz, 1973; Osinubi et al., 2011).

The application of corncob (an abundant agricultural waste) as admixture in deficient soil treatment in the construction industry will rid our environment of the nuisance associated with their improper disposal, free some landfill space and mitigate the health hazards associated with their burning in the open air. Aside of being more economical, easy to handle and environment-friendly than cement stabilization, CCA stabilization has the potential for long-term strength development and/or increased ultimate strength that results from the high content of pozzolans content (SiO_2, Al_2O_3 and Fe_2O_3) in the corncob ash.

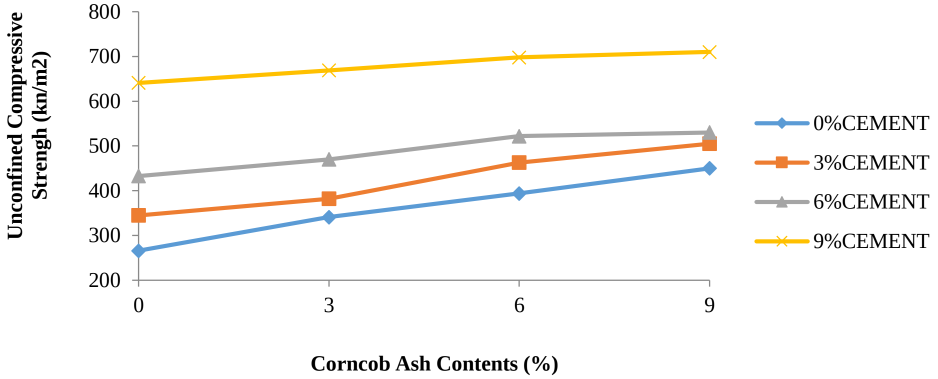

Figure 8: Variation of 7 days curing UCS of lateritic soil with CCA/PC content

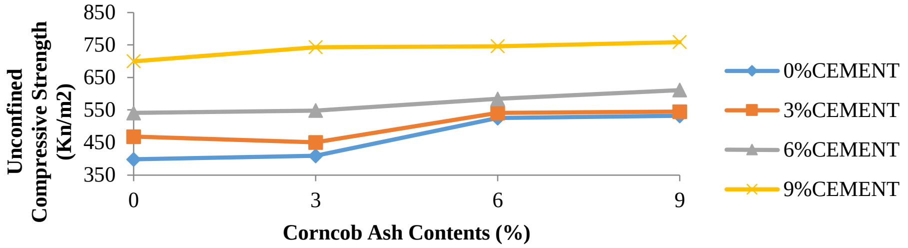

Figure 9: Variation of 14 days curing UCS of lateritic soil with CCA/PC content

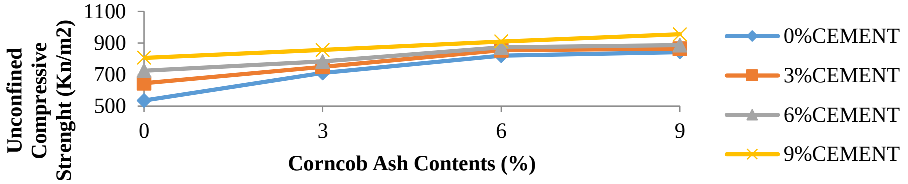

Figure 10: Variation of 28 days curing UCS of lateritic soil with CCA/PC content

Conclusion

The laboratory investigations conducted on the natural soil samples used in this study show that the soil is lateritic identified to be A-6 soil based on ASSHTO (1986) classification system and CL according to UCS classification. The natural soil has liquid limit of 45%, plastic limit of 22%, plastic index of 23%, linear shrinkage of 3.6%, specific gravity of 2.73 and natural moisture content of 15.82% with 70.85% of it passing through sieve No. 200. Furthermore, the following conclusions were drawn from the results of this study:

1. There was an improvement in the Atterberg limits values of the soil with CCA/PC treatment. The minimum plasticity index value of 8.37 % at

9%CCA/9%PC content meets the maximum values of 12 % plasticity index specified by clause 6201 of the Nigerian General Specifications (1997) for sub-base materials.

2. A peak value of MDD of 1.86 kN/m^3 and minimum value of OMC of 13% were observed at 9%CCA/9%PC treatment. Generally, an increase in both MDD and OMC was observed up to 6%CCA treatment then the values decreased. It was also observed that the MDD continuously increased with increase in cement content while the OMC inversely decreased.
3. A tremendous improvement in the UCS values with addition of Cement and corncob Ash to the natural soil was observed. The UCS values increased with increase in both Cement and Corncob Ash content having peak values at 9%CCA/9%PC content for all the three curing periods considered in this study. Peak UCS values of 710, 759 and 955 kN/m^2 were observed at 9%CCA/9%PC content for 7, 14 and 28 days curing periods which were improvements from the natural lateritic soil values of 266, 398 and 534 kN/m^2 for 7, 14 and 28 days curing periods respectively.
4. Mixture of cement and corncob ash, which is cheaper than wholly using cement, can be used to improve deficient soils with similar geotechnical properties to that of the soil used in this study in order to make them suitable for use in flexible pavement construction. Specifically, an optimum Corncob ash content of 9% by weight of the dried lateritic soil and 9% cement can be recommended for stabilization of lateritic soils for better results and stability.

References

Alhassan, M. (2008). *Potential of Rice Husk Ash for Soil Stabilization*. *Assumption University Journal of Technology*. 11(4),246-250.

American Association of State Highway and Transportation Officials (AASHTO), (1986) Washington, D. C.. "Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Twentieth Edition".

ASTM C618-93 specification (1992). Fly Ash and Raw or Calcined Natural Pozzolan for use as Mineral Admixture in Portland Cement Concrete.

British Standard (BS). 1377 (1990) Methods of Test for Soils for Civil Engineering Purposes.

British Standard (BS). 1924 (1990). *Methods of Tests for Stabilized Soils.* British Standards Institute, London.

EuroSoilStab. (2002). Development of Design and Construction Methods to Stabilize Soft Organic Soils: Design Guide for soft soil stabilization. CT97-0351, European Commission, Industrial and Materials Technologies Programme (Rite-EuRam III) Bryssel.

FAO. Records, Retrieved December 15, 2002, from http://apps.-fao.org/default.htm cement. *The Professional Builder* 2001;June:3–10.

Jaritngam, S., Somchaiuek, O. & Taneerananon, P. (2014). Feasibility of Laterite-Cement Mixture As Pavement Base Course Aggregate. IJST, *Transactions of Civil Engineering*, (381), 278.

Jones, D. and Holtz, J. (1973). Expansive soils: Hidden Disaster." *Civil Engineering*, *American Society of Civil Engineers*, 43, 54 - 67.

Nigerian General Specification (1997): Road Works and Bridges, Federal Ministry of Works and Housing, Abuja, Nigeria.

Osinubi, K. J. (1995). Lime modification of black cotton soils. *Spectrum Journal*, (21 & 2), 112 – 122.

Osinubi, K. J. (1999). Evaluation of admixture stabilization of Nigerian black cotton soil. *Nigerian Society of Engineers Technical Transactions*, (343), 88-96

Osinubi, K. J. (2000). Laboratory trial of soil stabilization using pulverised coal bottom ash. *Nigerian Society of Engineers Technical Transactions*, (35 4), 13 – 21.

Osinubi, K. J. & Medubi, A. B. (1997). Evaluation of cement and phosphatic waste admixture on tropical black clay road foundation. *Proceedings of 4th International Conference on Structural Engineering Analysis and Modeling (SEAM 4)*, Kumasi, Ghana, 9-11 July, Vol. 2, pp. 297-307.

Osinubi, K. J. & Stephen, T. A. (2006). Effect of bagasse ash content on particle size distribution and plasticity characteristics of black cotton soil.' *Proceedings of the 5th Nigerian Materials Congress "NIMACON 2006"*, Abuja, Nigeria, 17-19 November. pp. 214 - 220.

Osinubi, K. J., Eberemu, A. O. & Oyelakin, M. A. (2011). Improvement of black cotton soil with ordinary Portland cement - locust bean waste ash blend. *Electronic Journal of Geotechnical Engineering*, 16, 619 – 627.

Ramzi, T., Amer, A., Ali, A. & Hilia A. (2001). "*Use of Cement Kiln Dust in Soil Stabilization*". EJUQ. 14, .61-76.

Sadeeq, J. A., Ochepo, J. & Salahudeen, A. B. (2014 a). "Effect of used oil contamination on the volumetric shrinkage of lateritic soils." *Proceedings of the Third International Conference on Engineering and Technology Research*, Ladoke Akintola University of Technology , Ogbomoso, Nigeria Volume 3, pp 167-175.

Sadeeq, J. A., Ochepo, J. & Salahudeen, A. B. (2014 b). "Assessment of bagasse ash effect on the volumetric shrinkage of lateritic soils for flexible pavements." *Proceedings of the Nigerian Engineering Conference*, Ahmadu Bello University, Zaria, Nigeria, pp 241-248.

Sadeeq, J. A., Ochepo, J. & Salahudeen, A. B. (2014 c). Effect of bagasse ash on consolidation settlement characteristics of lateritic soils. *Proceedings of the national conference on "Bridging the gap between academia and industry in Nigeria-Refocosing the engineering discipline*. Faculty of Engineering, Bayero University, Kano, Nigeria, pp 573 – 587.

Sadeeq, J. A., Ochepo, J., Salahudeen, A. B. & Tijjani, S. T. (2015). Effect of bagasse ash on lime stabilized lateritic soil. *Jordan Journal of Civil Engineering* (JJCE), Vol. 9(2), 203 – 213.

Sadeeq, J. A. & Salahudeen, A. B. (2017). Strength characterization of foundation soils at Federal University Lokoja based on standard penetration tests data. *Nigerian Journal of Technology (NIJOTECH)*, 36(3), 671 – 676.

Salahudeen, A. B. (2014). Stabilization of black cotton soil with cement kiln dust. Unpublished M.Sc. thesis, *Department of Civil Engineering*, Ahmadu Bello University, Zaria.

Salahudeen, A. B. & Akiije, I. (2014). Stabilization of highway expansive soils with high loss on ignition content kiln dust. *Nigerian journal of technology (NIJOTECH)*, (332), 141 – 148.

Salahudeen, A. B., Eberemu O. A. & Osinubi, K. J. (2014). Assessment of cement kiln dust-treated expansive soil for the construction of flexible pavements. *Geotechnical and Geological Engineering*, (324), 923-931.

Salahudeen, A. B. & Ochepo, J. (2015). Effect of bagasse ash on some engineering properties of lateritic soil. *Jordan Journal of Civil Engineering* (JJCE), (94), 468 – 476.

Salahudeen, A. B. & Sadeeq, J. A. (2016a). Effect of rice husk ash on the index properties and hydraulic conductivity of lateritic soils for flexible pavement construction. *Proceedings of the International Conference and Nigerian Material Congress 2016 (NIMACON 2016), Material Science and Technology Society of Nigeria (MSN)*, Ahmadu Bello University, Zaria, pp. 1 – 6.

Salahudeen, A. B. & Sadeeq, J. A. (2016b). Strength characteristics of lateritic soils treated with rice husk ash for earth road construction. *Proceedings* *of the International Conference and Nigerian Material Congress 2016 (NIMACON 2016), Material Science and Technology Society of Nigeria (MSN),* Ahmadu Bello University, Zaria, pp. 7 – 11.

Salahudeen, A. B. (2017). "Prediction of foundation settlement based on standard penetration test results using empirical and numerical techniques." Unpublished PhD thesis, Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria. Pp 70 – 77.

Sherwood, P.T. (1993). Soil Stabilization with Cement and Lime: A State-of-The-ArtReview . Department of Transport, Transport Research Laboratory, United Kingdom.

Suhail, A.A.A., Khawla, A.K.A. and Ibrahaim, M.A.A. (2008). Strength Durability And Hydraulic Properties Of Clayey Soil Stabilized With Lime And Industrial Waste Lime". *Al-Rafidain Engineering*. (161), 102-116.

Venkaramuthyalu, P., Ramu, K., & Prasada, R.G.V.R. (2012). Study on performance of chemically stabilized expansive soil. *International Journal of Advances in Engineering and Technology (IJAET)*, 2 (1), 139-148.