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CORN-COB ASH AS PARTIAL REPLACEMENT OF CEMENT FOR STABILIZATION OF LATERITE SOIL

Oluniyi Oyedeji Popoola, Jonathan Segun Adekanmi* and Omolade Regina Olulope
Department of Civil Engineering, The Federal Polytechnic, Ado-Ekiti, Ekiti State, Nigeria

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*Corresponding author's email: adekanmi_js@fedpolyado.edu.ng
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Abstract — Properties of underlying soils and borrowed soil samples are some of the key factors that determine the performance rate of roads. Most of the underlying soils possess some characteristics that make them unsuitable for use. There are available agricultural waste products in most rural settlements which can be used to treat unsuitable soils. This research examined the use of corn cob ash (CCA) as an admixture to cement on some selected geotechnical properties of laterite soil. The choice of the A-7-5 class of laterite soil is due to its general rating as poor material for subgrade and other layers of road pavement by the classification system of the American Association of State Highway and Transportation Officials (AASHTO). Cement was gradually added to the soil sample in steps of 2% from 0% to 10% by weight of the soil sample and its effect on the plasticity of the sample was examined. The addition of cement performed optimally on the soil's plasticity at 4% which was used to form different mixtures of cement and CCA having a total sum not exceeding 4%. The additives were added to the soil sample which was subjected to laboratory tests such as compaction, California bearing ratio (CBR) and unconfined compressive strength (UCS) compacted with the efforts of 596kN/m^2 and 1192kN/m^2. The combination of 2% cement and 2% CCA on the soil sample improved the plasticity index and UCS properties of the soil to its optimal level while 3-1 and 4-0 cement-CCA performed optimally for CBR and compaction respectively. Thus, it was concluded that CCA performed optimally with cement at a ratio varying between 4:0 to 3:1 total percentage not exceeding 4% of the weight of the soil sample.

Keywords: corn cob ash, compaction effort, cement, subgrade, plasticity index

1.0 INTRODUCTION

Soil is one of the commonly used materials in the construction industry which are of varying properties from a location to another. Owing to the inability of most of the soil samples to perform optimally as a result of deficiency in their properties, either in grain size, strength or density, it is important to stabilize the soil. Soil stabilization is any process by which properties of soil in its natural state can be altered without adding any other material, altered with the addition of other materials, or altered by providing reinforcement to achieve the desired engineering properties [1–3].

The recent development in the use of agricultural waste ashes as stabilizer is encouraging, due to some of the disadvantages observed in the use of conventional materials such as cement. Aribisala [4] opined that as important as cement is to the construction industry, the cost of acquiring it and the global threat of the CO_2 released into the atmosphere during its production placed it at a disadvantage. Scholars are studying the use of CCA as a stabilizer, admixture or as pozzolanic material on soil and concrete. Its use as a whole or in partial replacement of lime and cement was observed by multiple scholars such as [5–14]. While other studies examined the effect of CCA as partial replacement in percentages, this study examined the effects of CCA blended with cement at varying ratios, on the geotechnical properties of poor (A-7-5) soil.

2.0 MATERIALS AND METHODS

Materials used for this research work were lateritic soil, corn cob, cement and water. Samples of lateritic soil used were collected in a disturbed state from a borrow pit located along new Iyin road, Ado Ekiti, Ekiti State Nigeria, located on Latitude 7°38'22.8"N and Longitude 5°12'01"E. The corn cob was collected from the farm settlement of the Federal Polytechnic Ado Ekiti (7°35'07"N and 5°17'55"E). The cobs were sun-dried for an average of two weeks to remove the moisture and later burnt to ash in a metallic drum under atmospheric temperature and pressure. The corn cob ash was sieved with a 600µm aperture size.

The laboratory tests conducted on the soil samples were natural moisture content, specific gravity, grain size analysis, Atterberg limits, compaction, California bearing ratio and unconfined compressive strength. Cement was added to the soil sample by weight from 0 to 10% in steps of 2% and the mixture of cement and CCA was also added at varying percentages of 3:1, 2:2, 1:3 and 0:4 for cement: CCA. The choice of 4% was adopted because the lowest value of plasticity index (PI) was obtained at 4% cement for the soil sample. Two different compaction efforts [596kN/m^2 - British Standard Light (BSL) and 1192kN/m^2 - West African Standard (WAS)] derived using Equation 1 were employed for compacting soil sample used for compaction, CBR and UCS tests. The tests conducted on natural and stabilized samples were carried out in conformity with British Standards [15, 16].

$$Compaction\ effort\ (kN/m^2), E = \frac{\left[\begin{pmatrix} Number\ of \\ blows\ per\ layer \end{pmatrix} \times \begin{pmatrix} Number\ of \\ layers \end{pmatrix} \times \begin{pmatrix} Weight\ of \\ Rammer \end{pmatrix} \times \begin{pmatrix} Height\ of \\ drop \end{pmatrix}\right]}{Volume\ of\ mould} \quad (1)$$

2.1. Natural Moisture Content

Specimen of soil samples collected was subjected to laboratory test to determine the natural moisture content. The weight of specimen tested was recorded before drying in an oven at the temperature of 105°C for 18 hours, after which the weight was measured at a dry state and recorded. The moisture content was determined using Equation 2.

$$\text{Moisture Content} = \frac{M_2 - M_3}{M_3 - M_1} \times 100\% \quad (2)$$

M_1 is Mass of empty can, M_2 is mass of can and weight soil and, M_3 is the mass of can and dry soil.

2.2. Specific Gravity

The specific gravity, which is a measure of the particle density of a substance, was determined for CCA and soil samples using 50ml density bottles. The ratio of the mass of the substances tested to the mass of an equal volume of water at standard temperature gives the specific gravity of the substances. The value was calculated using the formula shown in Equation 3.

$$\text{Specific gravity} = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \quad (3)$$

2.3. Grain Size Analysis

A 500g dry soil sample was soaked for 24hours to facilitate the easy removal of fines glued to soil particles. The soaked samples were washed with BS sieve number 200. The residue was dried and then poured into a set of sieves which were agitated on a mechanical sieve shaker for 10 minutes. The percentage of particles passing through each sieve was calculated, and the distribution was plotted on a semi-logarithmic graph.

2.4. Compaction Characteristics

A compaction test was conducted to determine the maximum dry density and optimum moisture content of the soil samples. The test was performed using the energies of BSL (British Standard Light) and WAS (West African Standard) in accordance with the British Standard [15]. For the BSL method, 3000g of soil was compacted in three layers using a 2.5kg rammer. Each layer underwent 25 blows from the rammer falling through a height of 300mm. For the WAS method, a 4.5kg rammer falling through a height of 450mm was utilized to compact a 6000g soil sample with five layers, subjecting it to 27 blows. The weight of the soil and moisture content were determined through various trials until the weight of the soil dropped. A graph of dry density was then plotted against moisture content.

2.5. California Bearing Ratio (CBR)

Soil samples, compacted with 55 blows of a 4.5kg rammer at 5 layers using the optimum moisture content, underwent strength testing on a standard California Bearing Ratio (CBR) machine with a known proving ring. The CBR was calculated as the percentage ratio of the test load to the standard load.

2.6. Unconfined Compression Strength (UCS)

Pulverized soil samples, after remolding, were compacted in two layers using a sand compacting apparatus (see Figure 1). The apparatus included a rammer weighing 6.6kg, falling through a height of 5 cm into an attached mould with a volume of 197 cm^3. The soil sample, mixed with the optimum moisture content determined for each mix, received 18 and 32 blows of the falling rammer per layer for the energies of BSL and WAS, respectively. The specimens, prepared in accordance with Part 7 of British Standard [15], were oven-dried at 70ºC for 24 hours and cured for 28 days by covering them with polythene nylon, following Method A14 of the materials manual [17]. UCS values of the soil samples, calculated using Equation 4, were determined by subjecting the average of three specimens representing each additive content to unconfined pressure using a compressive machine with a known proving ring factor.

$$UCS = \frac{Failure\ Load}{Corrected\ Surface\ Area\ of\ Specimen} \tag{4}$$

Figure 1 Sand compacting apparatus

3.0 RESULTS AND DISCUSSION

3.1. Index Properties of Soil at Natural and Stabilized States

3.1.1. Specific gravity

The specific gravity of the CCA was determined using density bottles, and the results are presented in Table 1. The average value obtained, 2.17, falls within the recommended range of 2.10 to 2.40 specified by ASTM C618 [18] for pulverized fuel ash. Additionally, laboratory tests were conducted to determine various engineering properties of the soil sample in its natural state, and the summarized results are presented in Table 2. The soil sample is classified as A-7-5(1) and SM using the AASHTO and USCS methods of the soil classification system, respectively [19–21].

Table 1 Specific gravity result of CCA

Trial	**1**	**2**	**3**
Weight of bottle (g)	27.65	26.70	27.52
Weight of bottle + CCA (g)	39.42	40.12	38.93
Weight of bottle + CCA + water (g)	67.40	71.03	69.52
Weight of bottle + water (g)	61.09	63.81	63.34
Specific Gravity	2.16	2.16	2.18
Average Specific Gravity		**2.17**	

Table 2 Results of engineering tests conducted on the natural soil sample

Soil Properties		**Values**
Natural Moisture Content		17.10%
Percentage Passing Sieve	4.75mm	86.64%
	2.00mm	78.20%
	0.60mm	56.00%
	0.425mm	49.12%
	0.075mm	35.34%
Atterberg Limits	Plastic Limit	37.00%
	Liquid limit	54.50%
	Plasticity Index	17.50%
	Linear Shrinkage	5.71%
Compaction Characteristics	MDD (596 kN/m^2)	1736Kg/m^3
	OMC	15.30%
	MDD (1192 kN/m^2)	1874Kg/m^3
	OMC	12.00%
California Bearing Ratio	596 kN/m^2	15.64%
	1192 kN/m^2	17.36%
Soil Classification	AASHTO	A-7-5(1)
	USCS	SM

3.1.2. Grain size analysis

The particle size distribution of the soil sample is illustrated in Figure 2. The graph indicates a poorly graded soil, with a percentage finer than the 0.075mm sieve aperture slightly exceeding 35%. In accordance with the recommendation of a maximum of 35% for soil suitability in road pavement layers, as specified in the General Specifications for Roads and Bridges by the Federal Ministry of Works and Housing [22], it is concluded that the soil is not suitable based on its grain size.

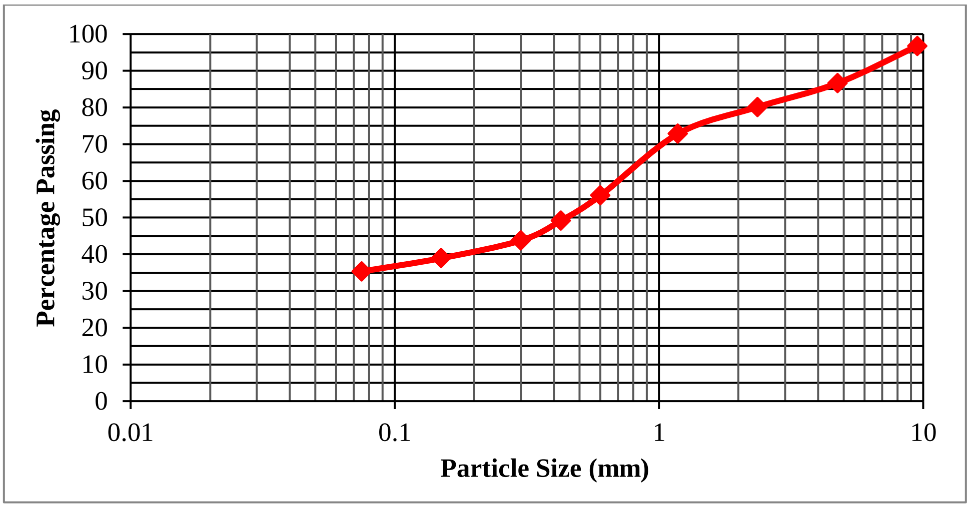
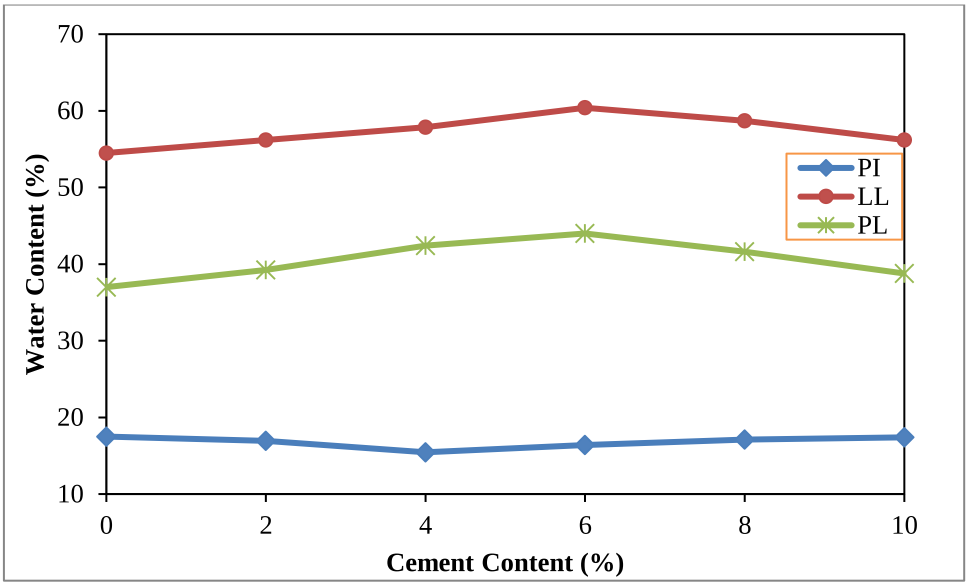


Figure 2 Particle size distribution curve for natural soil sample

3.1.3. Atterberg limits

The soil, tested at its natural state, had plastic and liquid limits of 37% and 54.5%, respectively. This indicates that the clay mineral present was kaolinite [23, 24]. The soil sample, as described by Casagrande [25], is an inorganic silt of high compressibility. The plasticity index of less than 20% means that the sample is of medium plasticity [26]. As shown in Figures 3, addition of cement, cement and CCA reduced the plasticity index of the soil throughout the runs, with optimal performance observed at 4% cement and 2-2 Cement- CCA, respectively.



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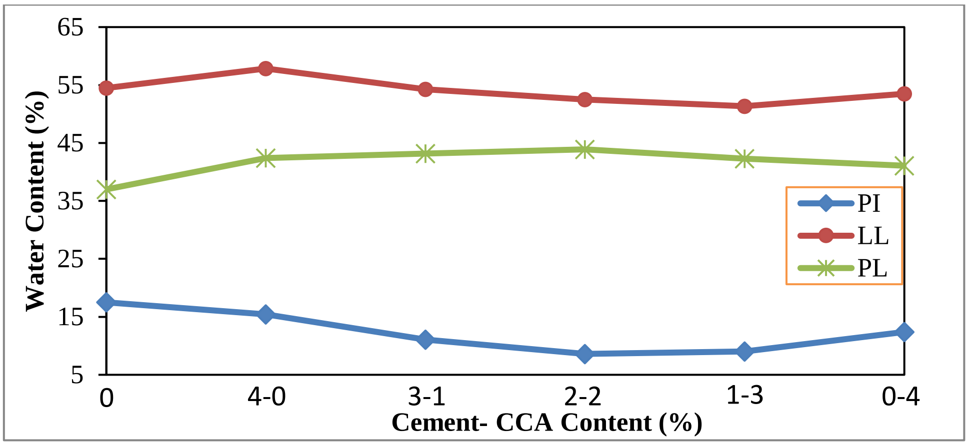


(b)

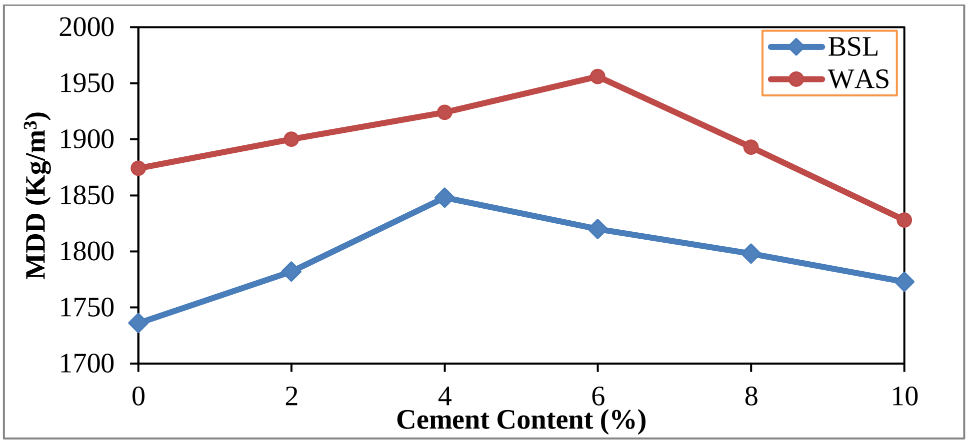
Figure 3 Atterberg limits against (a) cement content and (b) cement-CCA content

3.2. Soil Density Test at Natural and Stabilized States

3.2.1. Compaction

The compaction characteristics of the soil sample treated with cement and a mixture of cement and CCA were examined using compaction efforts of 596kN/m2 and 1192kN/m2. Graphs depicting the reaction between the soil and the additives are presented in Figures 4 and Figure 5. The increase in compaction efforts resulted in an increase in the maximum dry density (MDD) and a reduction in the optimum moisture content (OMC) of the soil, regardless of the dosage of additives, which aligns with the findings of Ogundipe et al. [27]. It was observed that increase in

CCA content in the mixture of cement-CCA, reduces the MDDs and increases the OMCs of the soil sample which was found to be consistent with the findings of Nnochiri and Adetayo [9].



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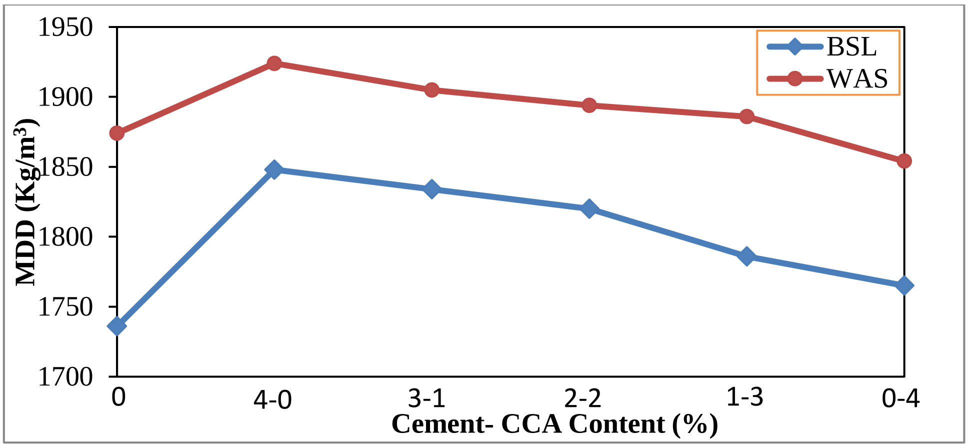

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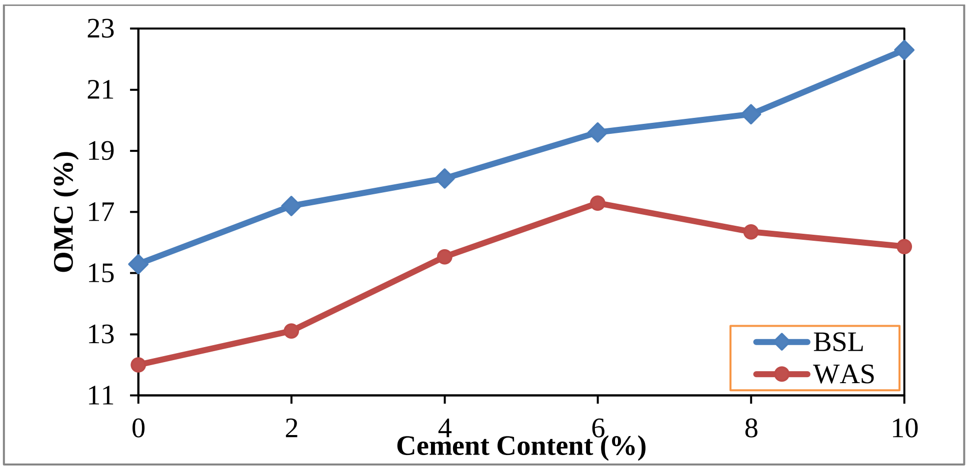
Figure 4 Graph of MDDs against (a) Cement contents (b)Cement-CCA contents



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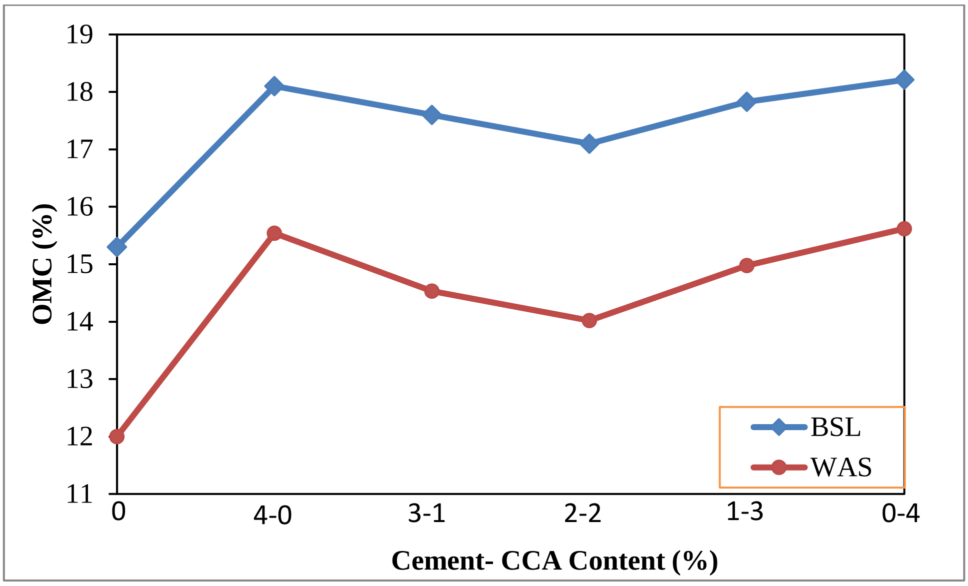


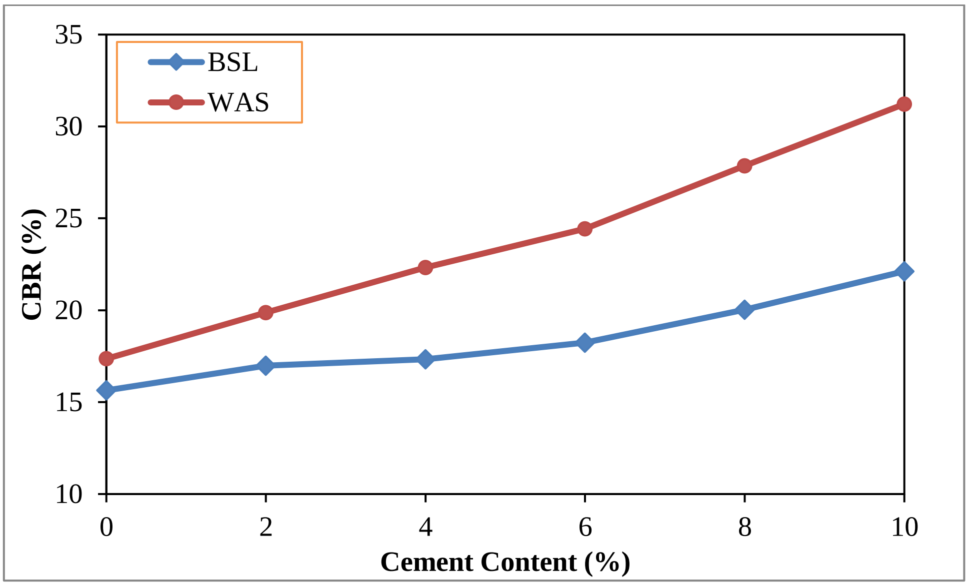
(b)

Figure 5 Graph of OMCs against (a) Cement contents (b) Cement-CCA contents

3.3. Soil Strength Test at Natural and Stabilized States

3.3.1. California bearing ratio (CBR)

The strength of the soil for pavement layers was assessed by conducting CBR tests on both natural and stabilized soil in an unsoaked state. The CBR values of 15.64% and 17.36% for the natural soil sample at 596kN/m2 and 1192kN/m2, respectively, indicate that the soil sample was poor and did not meet the specified requirements for sub-base and base course according to the general specifications [22]. The CBR values, as depicted in Figure 6(a), increase with a corresponding increase in cement contents. The trend was similar to the findings of Ogundipe and Adekanmi [28]. The addition of CCA and cement, as shown in Figure 6(b), enhances the CBR value of the soil. Although the soil's strength when stabilized with the mixture was found lesser than that of cement stabilized soil, the addition of CCA to the soil still improved the strength more than the natural soil. The trend corroborates the findings of Nnochiri and Adetayo [9].



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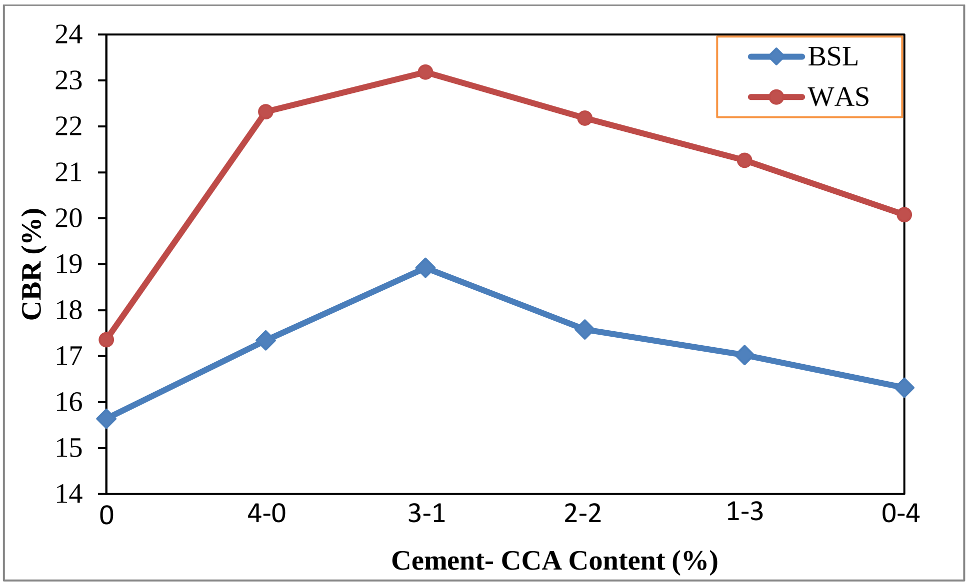
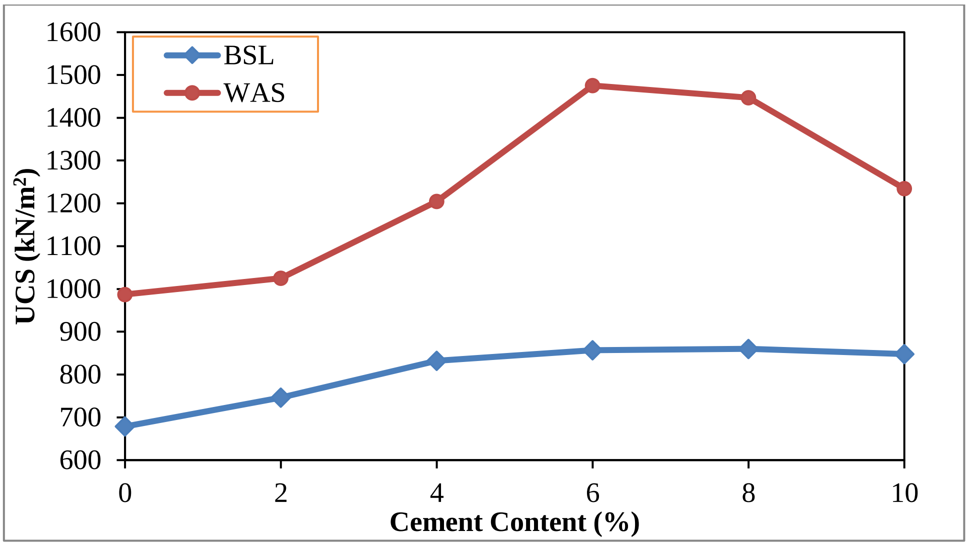


(b)

Figure 6 Graph of CBR against (a) Cement contents (b) Cement-CCA contents

3.3.2. Unconfined compressive strength

Unconfined compressive strength (UCS) test was conducted on the soil samples cured for 28 days. The strength increased with corresponding increase in compaction effort at every dosage of additives, as shown in Figures 7. The UCS values increased from 678.54kN/m^2 to 860.04kN/m^2 and 987.12kN/m^2 to 1475.32kN/m^2 at 8% and 6% cement contents for the efforts of 596kN/m^2 and 1192kN/m^{2,} respectively. The Cement-CCA reaction performed optimally at 3-1 ration on the soil sample.



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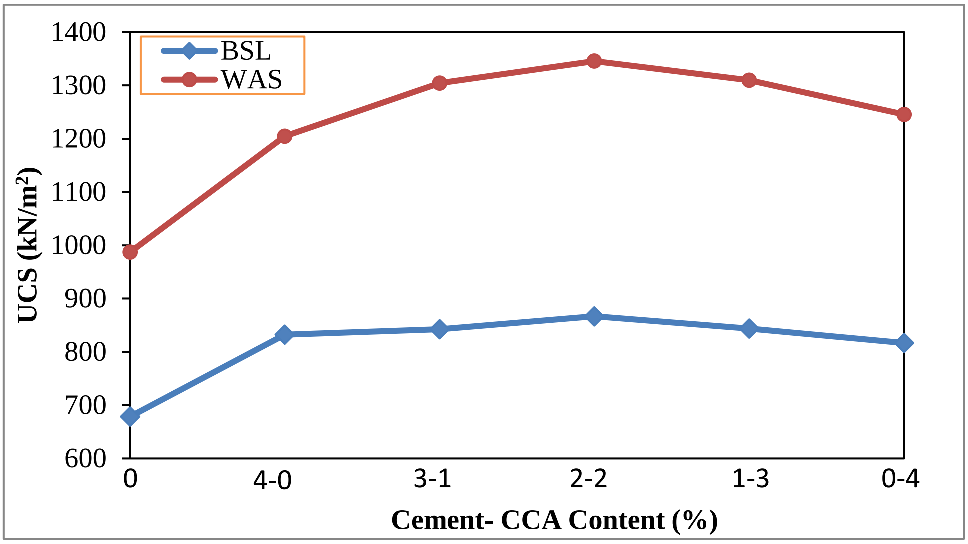

(b)

Figure 7 Graph of UCS against (a) Cement contents (b) Cement-CCA content

3.4. Statistical Analysis

Regression analysis was done with Excel software to predict relationships between MDD-OMC and soaked CBR-MDD for stabilized soil with the blended cement-CCA compacted with two different energies. The model with coefficients of determination 0.5659 and 0.7536 for MDD-OMC and CBR-MDD of soil compacted with the energy of British Standard Light, as shown in Equations 6 and 8, demonstrates a moderate dependence of the variables. However, values less than 0.5, as observed with the energy of West African Standard, indicate a weak dependence of the variables. Statistical analysis was carried out with ANNOVA to examine the relationship between the additive and CBR, as shown in Table 3. The P-value which is less than α-value (0.05) shows that the model is statistically significant. The error bar for the CBR, depicted in Figure 8 with a confidence interval of 95%, illustrates the goodness of fit of the function.

$$MDD = -5.6357OMC^2 + 159.04OMC + 776.56 \qquad R^2 = 0.1508 \qquad (5)$$

$$MDD = -26.015OMC^2 + 892.35OMC - 594.1 \qquad R^2 = 0.5659 \qquad (6)$$

$$CBR_{Soaked} = 7E^{-05MDD^2} - 0.1973MDD + 152.25 \qquad R^2 = 0.4578 \qquad (7)$$

$$CBR_{Soaked} = -0.0002MDD^2 + 0.66MDD - 594.1 \qquad R^2 = 0.7536 \qquad (8)$$

Table 3 Analysis of Variance

Source	Type III Sum of Squares	df	Mean Square	F	P-Value
Corrected Model	115.467[a]	6	19.245	12.515	0.007
Intercept	4893.652	1	4893.652	3182.336	0.000
Additive	44.754	5	8.951	5.821	0.038
CBR	70.713	1	70.713	45.985	0.001
Error	7.689	5	1.538		
Total	5016.808	12			
Corrected Total	123.156	11			

a. R Squared = 0.938 (Adjusted R Squared = 0.863)

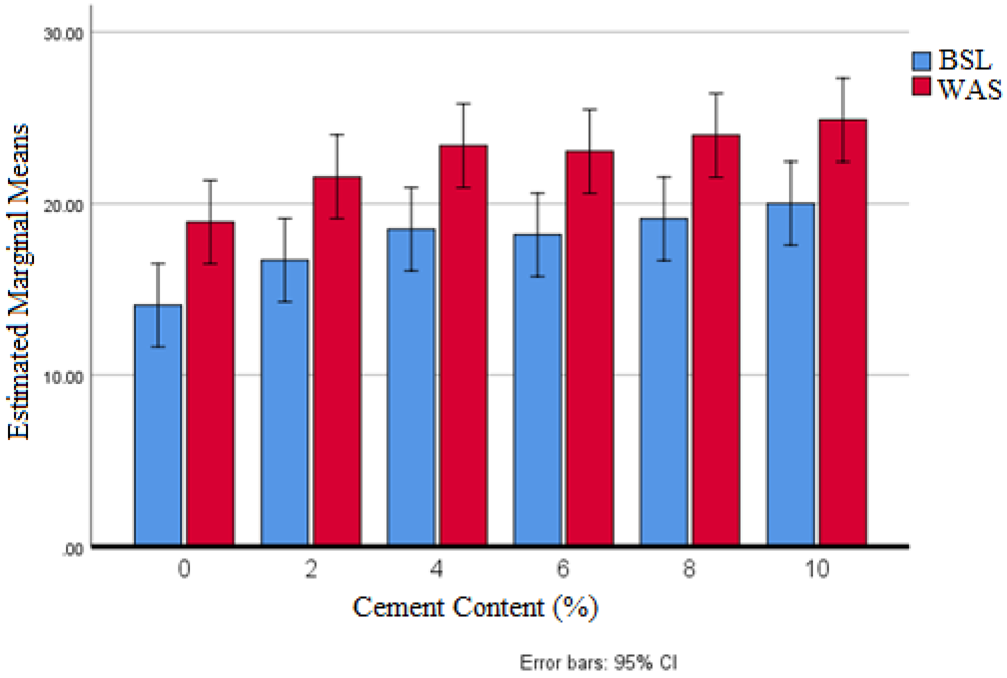

Figure 8 Error bars showing the estimated marginal means for the CBR

4.0 CONCLUSION

The soil sample, initially classified as A-7-5 soil, underwent laboratory tests in both natural and stabilized states following British standards. Several geotechnical properties of the soil exhibited improvement when stabilized with CCA as an admixture to cement, compared to the natural soil samples. The following findings were observed:

i. There was a reduction in the plasticity index and optimum moisture content (OMC) of the soil as CCA replaced cement, with the optimum result observed at a 2:2 ratio of Cement: CCA.
ii. The CBR value exhibited an increase, with the optimum value observed at a 3:1 ratio of Cement: CCA.
iii. There was an increase in the UCS value with a corresponding rise in CCA content, reaching the optimum value at a 2:2 ratio of Cement: CCA.

In summary, the optimal results were achieved with an average of 4% cement by the weight of dry soil and a mixture of cement and CCA blended at a 2:2 ratio. This suggests that CCA serves as a beneficial admixture to cement in soil stabilization, improving various tested soil properties.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

[1] Thagesen, B. (1996). Highway and Traffic Engineering in Developing Countries. (B. Thagesen, Ed.) Related books from E & FN Spon. Abingdon, UK: Taylor & Francis. https://doi.org/10.4324/9780203223673

[2] Garber, N. J., Hoel, L. A., & Sarkar, R. (2002). Traffic and highway engineering.

[3] Nicholson, P. G. (2014). Soil improvement and ground modification methods. Butterworth-Heinemann.

[4] Aribisala, O. A. (1989). Sourcing of local raw materials and investment opportunity in building/construction industrial sector. In Proceedings of the National Workshop held at Central Hotel, Kano (pp. 23–37).

[5] Jimoh, Y. A., & 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), 1–10.

[6] Apampa, O. A. (2019). Environmental benefits of corn cob ash in lateritic soil cement stabilization for road works. African Journal of Science, Technology, Innovation and Development, 11(4), 427–431. https://doi.org/10.1080/20421338.2017.1399533

[7] Oluborode, K. D., & Olofintuyi, I. O. (2015). Strength Evaluation of Corn cob ash in a blended Portland cement. International Journal of Engineering and Innovative Technology (IJEIT), 4(12).

[8] Nnochiri, E. S. (2018). Effects of corn cob ash on lime stabilized lateritic soil. Selected Scientific Papers - Journal of Civil Engineering, 13(s1), 73–85. https://doi.org/10.1515/sspjce-2018-0007

[9] Nnochiri, E. S., & Adetayo, O. A. (2019). Geotechnical properties of lateritic soil stabilized with corn cob ash. Acta Technica Corviniensis-Bulletin of Engineering, 12(1), 73–76.

[10] Adedokun, S. I., & Oluremi, J. R. (2019). A Review of the Stabilization of Lateritic Soils With Some Agricultural Waste Products. Acta Technica Corviniensis-Bulletin of Engineering, 12(2).

[11] Olofintuyi I. O., Oluborode K. D., & Oladapo S. A. (2022). Effects of corn cob ash (CCA) on strength and microstructural characteristics of laterized concrete. Europian Modern Studies Journal, 6(3), 100–109.

[12] Yifru, W., Getu, N., Kifile, D., Mesfin, A., Sewunet, A., & Tamene, M. (2022). Effects of Corn Cob Ash as Partial Replacement of Cement for Stabilization of an Expansive Clay. Advances in Civil Engineering, 2022. https://doi.org/10.1155.2022/6788120

[13] Singh, K., Singh, J., & Kumar, S. (2018). A Sustainable Environmental Study on Corn Cob Ash Subjected To Elevated Temperature. Current World Environment, 13(1), 144–150. https://doi.org/10.12944/CWE.13.1.13

[14] Apampa, O. A., Jimoh, Y. A., & Olonade, K. A. (2015). Modeling of Compaction Curves for Corn Cob Ash-Cement Stabilized Lateritic Soils. International Journal of Civil and Environmental Engineering, 9(6), 763–766.

[15] Institution, B. S. (1990). *British standard methods of test for soils for civil engineering purposes*. British Standards Institution. https://doi.org/10.3403/00793481

[16] 1924-2, B. S. (1990). Methods of Test for Cement-Stabilized and Lime-Stabilized Materials. British Standards Institution London, England. https://doi.org/10.3403/00224744

[17] WCPA. (2006). UCS stabilised materials (1sted.). Materials Manual, Western Cape Provincial Administration, Transport and Public Works Department.

[18] American Society of Testing and Materials ASTM C618. (2005). Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. West Conshohocken.

[19] American Association of State Highway and Transportation Officials (AASHTO). (1986). Standard Specification for Transportation Materials and Methods of Sampling and Testing. USA: Washington DC.

[20] Casagrande, A. (1948). Classification and Identification of Soils. Transactions of the American Society of Civil Engineers, 113(1), 901–930. https://doi.org/10.1061/TACEAT.0006109

[21] American Society for Testing and Materials. (2007). Annual Book of ASTM Standards, Section 4 (Vol. 04(08)). West Conshohoken, Pa.

[22] Federal Ministry of Works and Housing (FMWH). (1997). General Specification (Roads and Bridges). Revised edition (Volume II). Nigeria, Abuja.

[23] Mitchell, J. K. (1976). Fundamentals of Soil Behavior, John Wiley and Sons, Inc., New York.

[24] Skempton, A. W. (1953). The colloidal activity of clays. Selected papers on soil mechanics, 1, 57–61.

[25] Casagrande, A. (1932). Research of Atterberg Limits of Soils. Public Roads, 13(8), 121–136.

[26] Burmister, D. M. (1949). Principles and techniques of soil identification. In Proceedings of Annual Highway Research Board Meeting. National Research Council. Washington, DC (Vol. 29, pp. 402–434).

[27] Ogundipe, O. M., Adekanmi, J. S., Akinkurolere, O. O., & Ale, P. O. (2019). Effect of Compactive Efforts on Strength of Laterites Stabilized with Sawdust Ash. Civil Engineering Journal, 5(11), 2502–2514. https://doi.org/10.28991/cej-2019-03091428

[28] Ogundipe, O. M., & Adekanmi, J. S. (2019). Assessment of the Effects of Lime and Cement on Geotechnical Properties of Laterites. FUOYE Journal of Engineering and Technology, 4(2). https://doi.org/10.46792/fuoyejet.v4i2.387