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Influence of Calcium Carbide Residue on Corn Stalk Ash Stabilized Lateritic Soil for Highway Pavement Construction

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Abstract

The most common binder used for roads and buildings is cement, and its annual production rate is rising at an unprecedented rate, which has significant negative effects on the environment. This research investigated the effect of a varying percentage of Calcium Carbide Residue (CCR) and Corn Stalk Ash (CSA) samples on lateritic soils. A total of 25 mixture samples of CCR and CSA were prepared and mixed with lateritic soils to evaluate the mechanical and strength properties according to the Standard for transportation materials and methods of sampling and testing, AASHTO. The results showed that CCR has the property that reacts with CSA which is a good pozzolana yielding a product similar to the cement hydration process. Particle size analysis, Atterberg limits, Specific gravity, Compaction, and California Bearing Ratio were developed for each test sample, and the corresponding optimum mixtures were determined for the general specification for roads and bridges. Tests showed that in comparison to the control sample, there is an increase in the Atterberg limits properties with a decrease in the compaction properties and an increase in the CBR values upon the addition of 8% CCR and 2.5% CSA mixture before soaking and after soaking for 24 hours respectively which falls within the guidelines of the Nigerian Federal Ministry of Highways and Transportation (1997). Similarly, CCR was found to be advantageous for use as an activator with CSA to stabilized soil as a sub-base material in Highway Pavement Construction.

Keywords: Industrial waste, Highway pavement, Cement, Strength, Sub-base material

Introduction

Lateritic soil is extensively used for road construction in Nigeria. Lateritic soils in their natural state generally have low bearing capacity and low strength which is due to the presence of high clay content. Alhassan, 2008 and Oluremi *et al.*, 2018 suggested that the presence of high clay content in lateritic soil reduces its ability to be stable and withstand strength under load with the presence of moisture. In this tropical part of the world, lateritic soils are used as a road-making material and they form the subgrade of most tropical roads, they are used as a sub-base for low-cost roads and these carry low to medium traffic. Most tropical lateritic soils are composed predominantly of Kaolinite minerals with some quartz (Oluremi *et al.,* 2016).

Soil stabilization is the process of improving the shear strength parameters of soil and thus increasing the bearing capacity of the soil. It is required when the soil available for construction is not suitable to carry a structural load. It may also be defined as the alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of soil. This increases the shear strength of soil and controls the shrink-swell properties of soil which improves the load-bearing capacity of a subgrade to support pavements and foundations (Habiba, 2017). Cement is the most common binder used in the road and construction industry, and the annual production rate of cement is increasing at a ground-breaking pace. In 2015, cement manufacturers produced 4.6 billion tons worldwide which is estimated to reach 4.83 billion tons by 2030 (Miraki *et al.*, 2022). Cement production accelerates the depletion of natural resources resulting in consumption of about 1.5 tonnes of limestone and clay per ton of cement (Miraki *et al.*, 2022).

Corn stalk is a waste product obtained from corn, a major cereal crop produced in Sub-Saharan Africa. According to the data released by the Food and Agriculture Organization (FAO) in the year 2000, 589 million tons of corn were produced all over the world in 2000 (FAO, 2002). According to the International Institute of Tropical Agriculture (IITA) (2002), Africa produced 7% of the world's corn and Nigeria was the second largest producer of corn in Africa after South Africa (Raheem *et al.*, 2017). Therefore, replacing the proportion of the Portland cement in soil stabilization with material like corn stalk ash will reduce the overall environmental impact of the stabilization process.

Improvement in the strength and durability of lateritic soil has therefore become imperative and this has geared up researchers toward using stabilizing materials that can be sourced locally at a very low cost. Excellent efforts have been made for the successful exploitation of the efficient use of various agricultural and industrial by-products (such as natural fibers, corn cob ash, fly ash, rice husk ash, waste wood ash; corn husk ash; foundry waste; silica fume, etc.) that have been continuously generated (Oluremi *et al.,* 2012; 2017). The reuse of these waste products will help to save the environment from pollution and severe ecological problems. This research investigated the effect of a varying percentage of Calcium Carbide Residue (CCR) and Corn Stalk Ash (CSA) samples on lateritic soils.

Materials and Methods

Materials Used

The lateritic soil used was collected as a disturbed sample from a borrow pit in LAUTECH, Ogbomoso, Oyo State, Nigeria. The corn stalk was collected from farmland on Latitude 7.42º and Longitude 3.97º in Ibadan, Oyo State, Nigeria. The collected corn stalk sample was sundried for two weeks and calcined into ashes in an open steel container to reduce its particles before being calcined to a temperature of 600℃ and allowed for about 2 hours inside the oven as suggested by Memon *et al,* 2019. The calcined stalk was further sieved through a sieve with a 75µm opening to obtain a material of fineness similar to cement. The preparation process is shown in Plate 1. CCR was collected from automobile workshops in Ibadan, Oyo State, Nigeria and water was taken from the Geotechnical Laboratory of Civil Engineering Department in LAUTECH, Ogbomoso, Oyo State, Nigeria.

Method Employed

Particle size analysis, index properties, compaction, specific gravity, and CBR were also conducted on the untreated soil and treated soil. The pozzolan (CSA) and chemical activator (CCR) were prepared at different percentages according to Table 1 for the stabilization of the lateritic soil.

The microstructure and elemental components of CCR, CSA, and soil samples procured were evaluated using scanning electron microscopy (SEM machine-Phenom ProX) and Energy Dispersive X-ray Fluorescence (EDXRF) spectrometer. The samples are prepared at varying percentages according to Table 1. Particle size analysis was carried out on the soil sample and the percentage finer of the material was calculated after it had been dried in an oven at 105℃ for 24 hours. The corn stalk ash was sieved through British Standard sieve No 200 (75µm aperture) and stored in a sealed polythene bag to be mixed with the soil specimen in appropriate percentages by dry weight of the soil. The CCR was also air-dried, pulverized, and sieved through a sieve with a 425µm opening and then mixed in appropriate percentages according to Table 1. Specific gravity is performed according to BS 4110:1986 for the soil sample, CSA, and CCR with a certain weight of the samples passing through a 0.425mm aperture. Atterberg limits test which includes liquid limit, plastic limit, and plasticity index test which is used to obtain consistency behaviour was done on the control soil sample and with varying percentages of CSA and CCR as specified in Table 1 according to British Standards 1377 and 1924 (BSI 1990).

The Maximum Dry Density (MDD) and optimum moisture content (OMC) of the un-stabilized and stabilized soils were determined using the Standard Proctor Compaction test according to ASTM D698 (2015). California Bearing Ratio (CBR) tests were conducted to assess the soil's strength. In a 2360 cm^3 mould, three layers of natural soil and soil-CCR-CSA admixtures were compacted using a 4.5 kg rammer at the OMC value determined from compaction by the required standard. A total number of 27 blows were uniformly distributed across the surface of the compacted specimens. The specimens for the various combinations were cured and sealed in polythene bags for 6 days to achieve their full strength and prevent moisture loss such that at their expiration, they were then subjected to soaking in water for 48 hours before testing. At penetrations of 2.5 mm and 5.0 mm, the CBR value is obtained and in situations where the two values differ by 10%, their average is taken as the CBR value.

a) Corn Stalk b) Controlled Calcination c) Sieved Corn Stalk Ash

Plate 1: Corn Stalk Ash preparation

a) Calcium Carbide Residue b) Soil sample-CSA-CCR

Plate 2: Appearance of calcium carbide residue after sieving and its mixture with soil sample and CSA

Table 1: Varying percentage combination scheme for the stabilized soil

CCR (%) / CSA (%)	0	2	4	6	8
0	0,0	0,2	0,4	0,6	0,8
2.5	2.5,0	2.5,2	2.5,4	2.5,6	2.5,8
5	5,0	5,2	5,4	5,6	5,8
7.5	7.5,0	7.5,2	7.5,4	7.5,6	7.5,8
10	10,0	10,2	10,4	10,6	10,8

Results and Discussion

The following are the results of the test carried out on the soil sample, Corn Stalk Ash (CSA), and Calcium Carbide Residue (CCR) during the process of laboratory work. The characteristics and properties of the soil in its natural form, before the addition of the activators, are shown in Table 2.

Particle Size Distribution

Figure 1 shows the particle size distribution for the lateritic soil sample before and after mechanical stabilization. The percentage passing sieve No. 200 (0.075 mm) is 53.17% and 24.9% for the lateritic soil before and after mechanical stabilization. According to specifications for the road by Road and Bridges Specification Revised Edition of Federal Ministry of Works, Nigeria, the limits for percentage passing sieve No. 200 mm for subgrade and subbase course are 35% and 25% maximum, which shows that the soil sample before mechanical stabilization is poor for subgrade and subbase course. The value after mechanical stabilization shows that the soil sample is good for sub-grade but poor for the sub-base course as shown in Figure 1. Hence is a need for stabilization of the soil for the subbase course. The particle size distribution curve shown in Figure 1 shows that the untreated soil has a percentage of silt and clay which has expansive properties with the addition of water and contracts when water is removed.

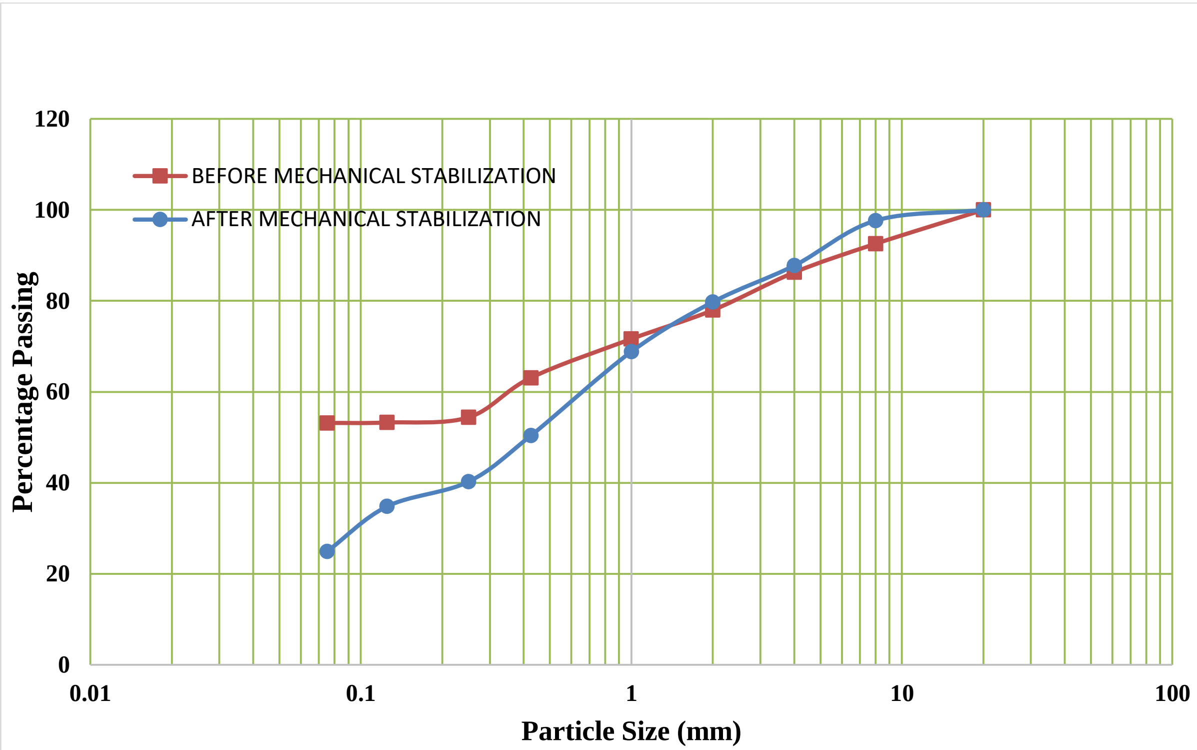

Figure 1: Particle size distribution curves for soil sample before and after mechanical stabilization

Chemical Composition

The chemical composition of CCR and CSA are presented in Table 3. The major component of CCR is 53.16% CaO, whereas the minor components are pozzolanic materials (SiO_2, Al_2O_3, and Fe_2O_3) of about 14.39% which is lesser compared to the result of Horpibulsuk *et al.*, (2014) and Phummiphan *et al.*, (2017) which might be due to the higher percentage of loss of ignition (LOI). Kampala *et al*. (2013) and Phummiphan *et al.* (2017) suggested that the high $Ca(OH)_2$ and CaO contents of the CCR indicate that it can react with CSA and produce cementitious products calcium silicate hydrate (CSH). The XRF result shows the contents of SiO_2 and Fe_2O_3 to be 12.75% and 1.63% with no evidence of Al_2O_3 but gave a higher K_2O content of 54.22%. The contents of the K_2O in the CSA are distinctively higher than in previous studies which is due to the utilization of large quantities of agricultural fertilizers used in the farmland. Meanwhile, from the XRF result, the CSA cannot be classified under any Class of pozzolanic material according to ASTM standards. Previous studies have shown that CSA can be classified under the Class F pozzolans according to ASTM standards (Raheem *et al.*, 2017 and Li *et al.*, 2021).

Table 2: Geotechnical Properties of the Soil Sample

Geotechnical Properties	Percentage Passing BS No 200 sieve (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Specific Gravity	Maximum Dry Density (g/cm^3)	Optimum Moisture Content (%)	AASHTO Classification	California Bearing Ratio (%)
Test Result	24.9	34	17	17	2.22	1.89	10.5	A-2-6 (1)	34

Table 3: Chemical composition of CCR and CSA

Chemical composition (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	P_2O_5	Cl	K_2O	TiO_2	ZnO	Ag_2O	LOI
CCR	4.215	1.902	0.127	53.157	0	0.475	0	0	0	0	0	0	40
CSA	12.754	0	1.634	0	1.895	1.245	12.771	1.612	54.223	0.121	0.317	0.13	13

Microstructural Analysis

For a better understanding of the morphology of soil sample-CSA-CCR, it was scanned under SEM equipment and analysed using Energy Dispersive X-ray (EDX) Spectroscopy. The results are shown in Figure 2 and Figure 3. The chemical composition of the soil sample-CSA-CCR was obtained using EDX analysis, which is a non-destructive test that provides information about the elemental composition of the tested materials. The surface elements verified using EDX analysis are shown in Figure 2. The elemental analysis of the soil sample-CSA-CCR as determined by EDX analysis is composed mainly of 48% Oxygen and 30.1% Silicon which when combined give Silicon dioxide (quartz) under the presence of moisture as an indication of cementitious properties.

The SEM image provides information regarding the soil sample-CSA-CCR structure such as shape. Figure 3 shows that the soil sample-CSA-CCR particles are generally irregular in shape which is in line with Phummiphan *et al*., (2017).

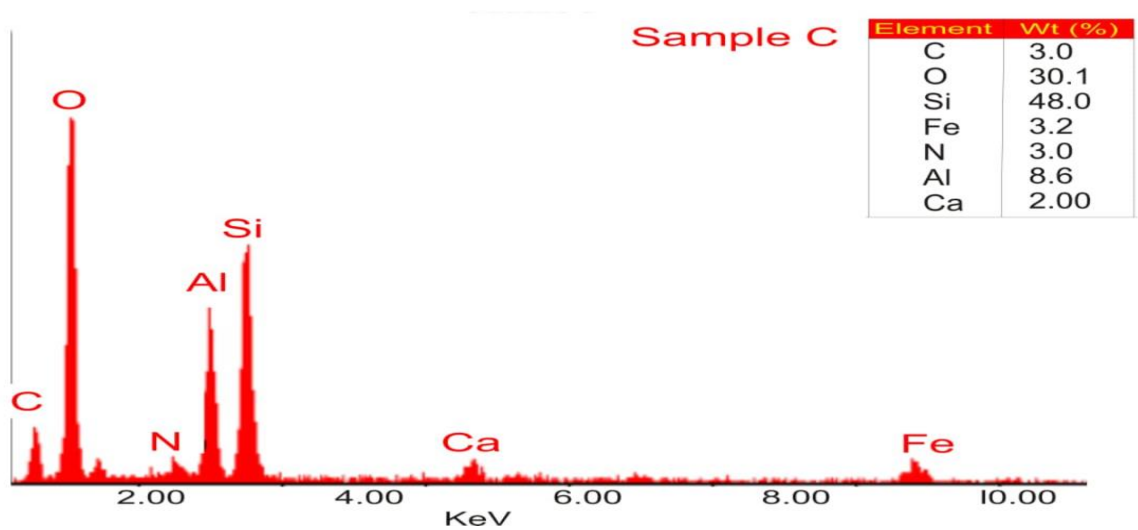

Figure 2: EDX Spectrometry of soil sample- CSA-CCR

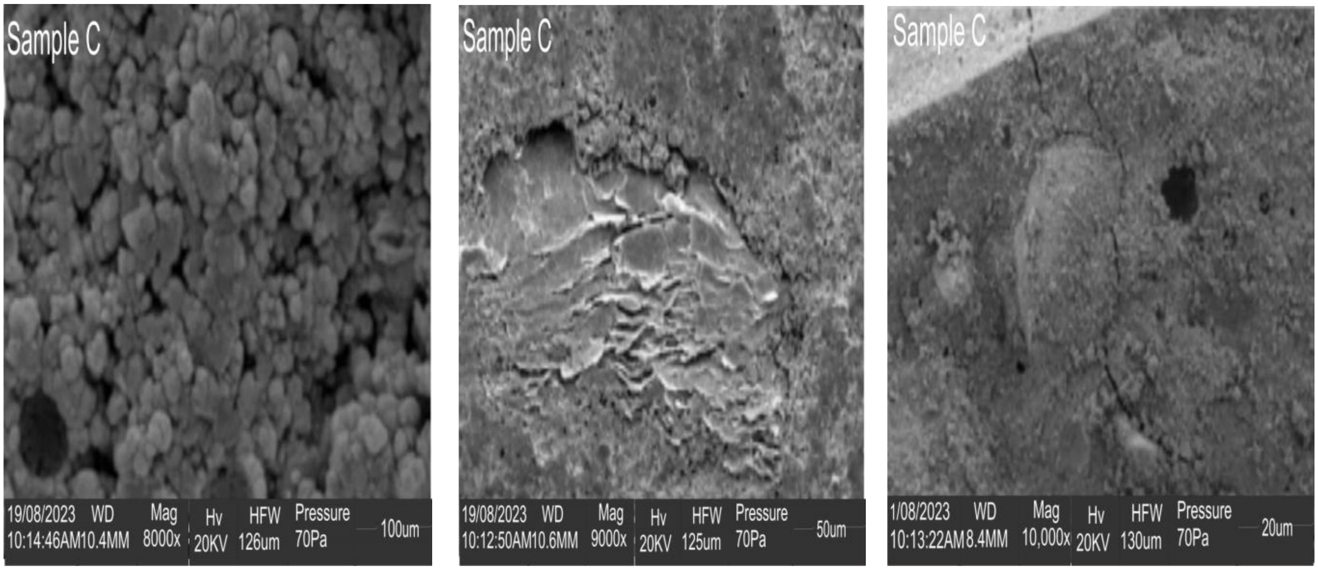

Figure 3: SEM images of soil sample-CSA -CCR

Specific Gravity Test

The specific gravity of the soil sample, Calcium Carbide Residue (CCR), and Corn Stalk Ash (CSA) gave values of 2.22, and 2.39. and 2.86 with the CSA having the highest value of 2.86 which is an indication that the soil sample unsuitable as a subbase material but can be improved with the mixture of CCR and CSA to give a denser mixture.

Atterberg Limits Test

The Atterberg limit results include the liquid limit, plastic limit, and plasticity index of the soil sample with different percentages of CSA and CCR as speculated in the methodology of this study.

Liquid limit

The result obtained from the analysis of data from the tests carried out in the laboratory is shown in Figure 4. It shows that the unstabilized soil exhibits a liquid limit of 34% and upon the addition of CCR and CSA at varying percentages, there is a decrease in the value ranging from 25-33%.

Plastic limit

The result obtained from the analysis of data obtained from the tests carried out in the laboratory is shown in Figure 5. It shows that the unstabilized soil exhibits a plastic limit of 17% and upon addition of CCR and CSA at varying percentages, the value ranges from 20% to 30% with the maximum value of 30% at 8% CCR and 2.5% CSA mixture addition.

Plasticity index

The result obtained from the analysis of data obtained from the tests carried out in the laboratory is as shown in Figure 6, It shows that the unstabilized soil exhibits a plasticity index value of 17% and upon addition of CCR and CSA at varying percentages, the value ranges from 17% to 1% with the minimum value of 1% at 8% CCR and 2.5% and 7.5% CSA mixture addition

Compaction Test

The compaction test results include the maximum dry density and optimum moisture content of the soil sample with different percentages of CSA and CCR as speculated in the methodology of this project work.

Maximum Dry Density (MDD)

The compaction behavior of the stabilized soil showed that the MDD was lowered by the addition of a varying percentage of CCR and CSA compared to the natural soil. The MDD chart showing the values generated as a result of the stabilization is shown in Figure 7. There was a general decrease in MDD with the addition of CCR and CSA. This decrease is connected to the initial simultaneous flocculation and agglomeration of clay particles caused by cation exchange leading to an increase in volume and decrease in dry density. Also, this is due to the comparatively higher specific gravity value of 2.39 and 2.86 of the CCR and CSA compared to that of the soil which is 2.22.

Optimum Moisture Content (OMC)

The compaction behavior of the stabilized soil showed that the OMC was increased by the addition of varying percentages of CCR and CSA compared to the natural soil. The OMC chart showing the values generated as a result of the stabilization is shown in Figure 8. There was a general increase in OMC with the addition of CCR and CSA treatment due to the increase in fines from the stabilizers with larger surface areas that required more water for hydration. This aligns with the works of Roy (2018) and Yadav *et al.* (2016).

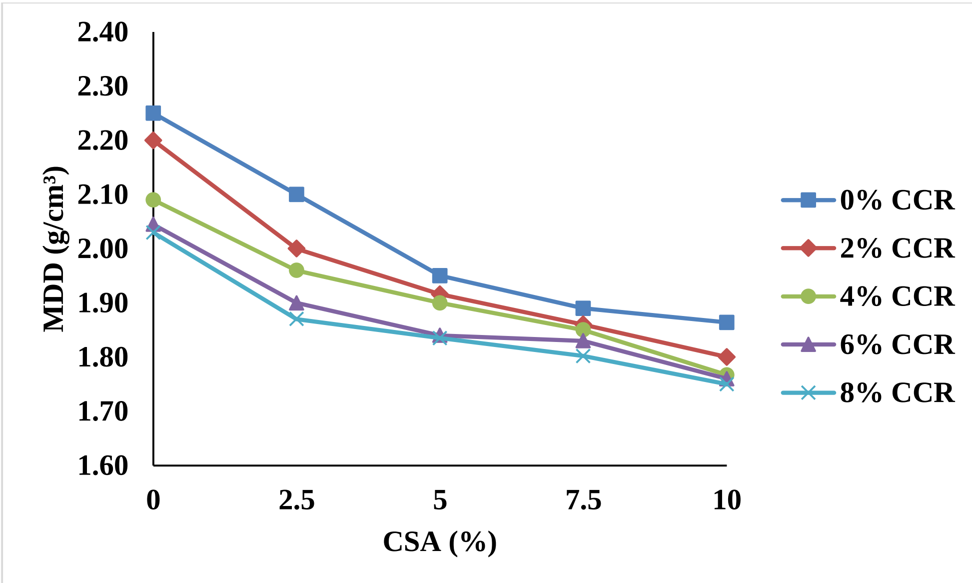

Figure 7: MDD characteristics of the stabilized soil sample

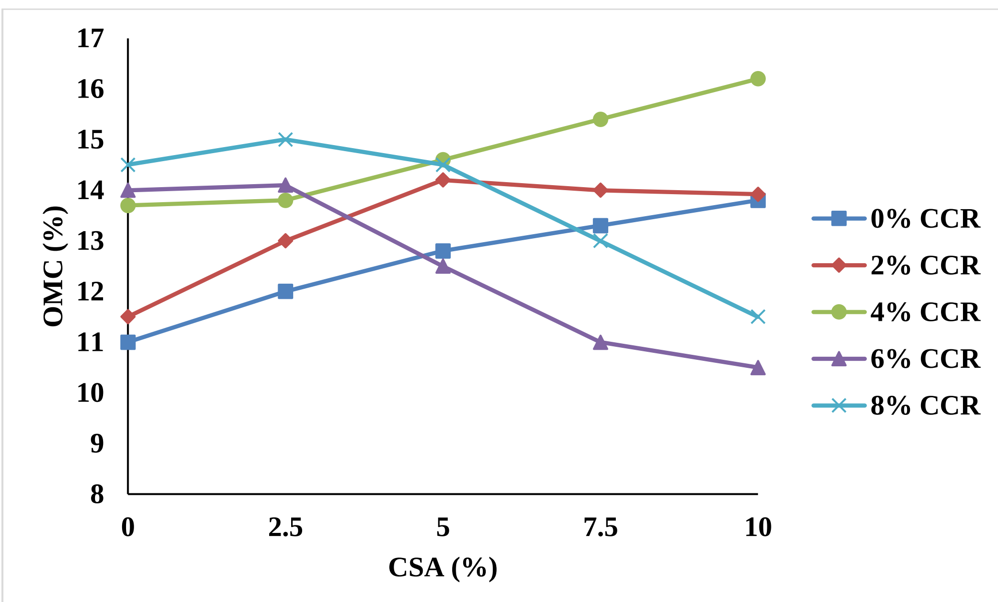

Figure 8: OMC characteristics of the stabilized soil sample

California Bearing Ratio (CBR)

Figure 9 shows the variation of the CBR with varying CCR and CSA content at both soaked and unsoaked conditions. The values of the California Bearing Ratio range between 27 and 45% for the unsoaked samples. The value of the CBR for the unstabilized lateritic soil was 34% and decreased to 30% as the CSA addition increased to 5% before it increased to 42% at 10% CSA. The maximum unsoaked CBR value of 42% was obtained at 10% CSA addition which shows that the addition of CSA decreases the CBR value of the soil sample before it increases. This shows that CSA can be effectively used to improve the CBR value of soil. Meanwhile, the addition of CCR to the soil sample decreases the CBR value to 27% at 2% CSA and increases to 41% at 8% CSA addition. Upon the addition of a mixture of CCR and CSA at varying percentages, the CBR values range from 29% to 45% with the maximum value at 45% for an 8% CCR and 2.5% CSA mixture. The maximum unsoaked CBR value of 45% was obtained at 8% CCR and 2.5% CSA mixture addition which shows that the addition of the mixture of CSA and CCR decreases the CBR value of the soil sample before it increases. Although this highest unsoaked CBR met the minimum CBR value of 30% stipulated for sub-base material according to the Federal Ministry of Works and Housing (1997) for cement stabilization. Similar results were obtained by Salahudeen and Ochepo, (2015), Sadeeq *et al.*, (2015), and Itthikorn *et al.*, (2015).

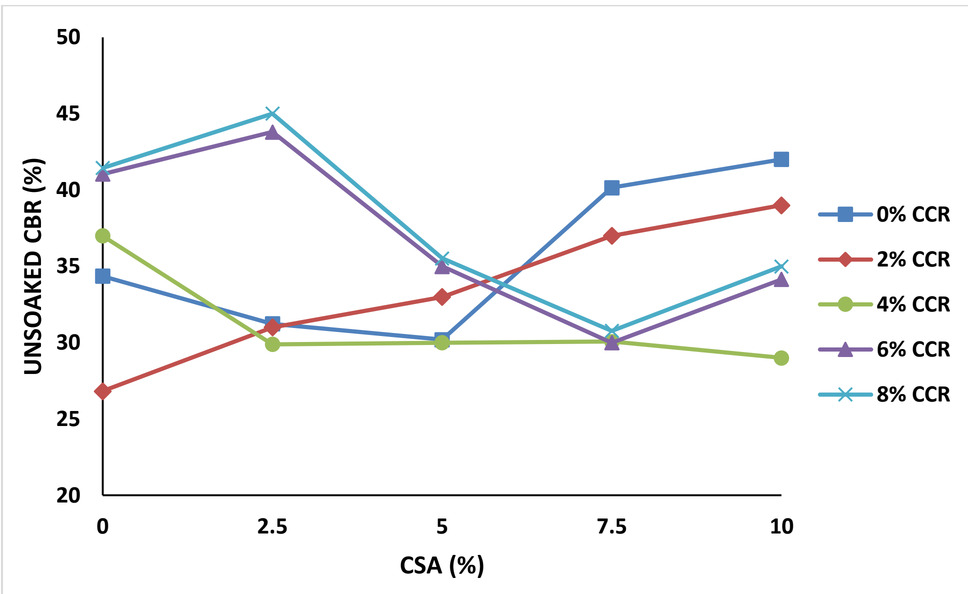

Figure 9: Unsoaked CBR characteristics of the stabilized soil sample

For soaked conditions as shown in Figure 10, the CBR values range between 8 and 85% with a maximum value of 8% obtained for unstabilized lateritic soil. The value of the CBR increased from 8 to 31% as CSA content increased from 0 to 2.5% and decreased to 29% at 5% as CSA addition which further increased from 40% to 48% at 7.5% and 10% addition of CSA. Upon the addition of CCR to the unstabilized soil sample the CBR value increases from 8% to 51% with the maximum value at 8% CSA addition. Upon the addition of a mixture of CCR and CSA at varying percentages, the CBR values range from 31% to 85% with the maximum value at 85% for 8% CCR and 2.5% CSA mixture. The maximum soaked CBR value of 45% was obtained at 8% CCR and 2.5% CSA mixture addition which shows that the effect of CCR on the CSA addition to the unstabilized sample increases the CBR value unlike when CSA is added only. The soaked CBR value of 85% obtained at 8% CCR and 2.5% CSA mixture addition met the requirement of a minimum CBR value of not less than 25% as specified by the Federal Ministry of Works specification for Road Works (1997) for sub-base materials in flexible pavement.

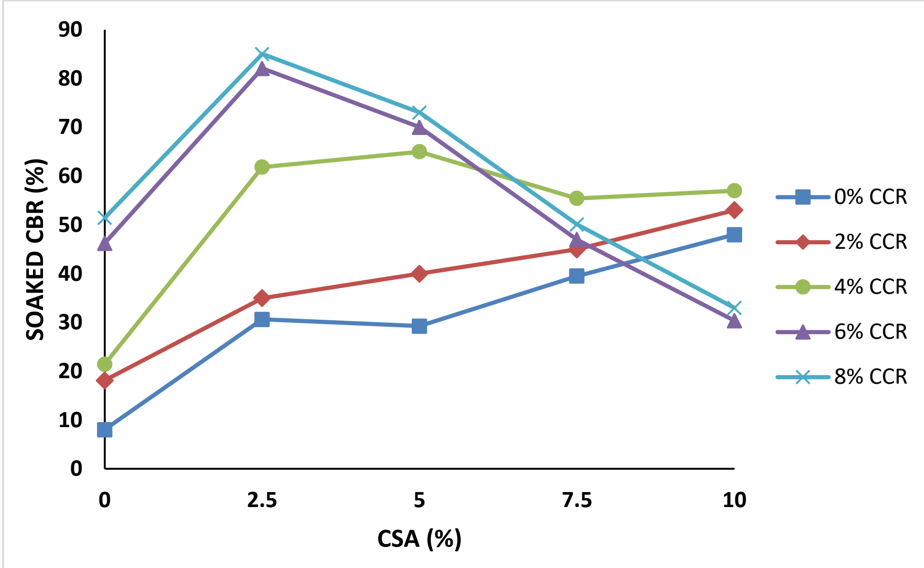

Figure 10: Soaked CBR characteristics of the stabilized soil sample

Conclusion

The study of the influence of Calcium Carbide Residue (CCR) on Corn Stalk Ash (CSA) stabilized lateritic soil for highway pavement construction was presented.

(i) The particle size distribution shows that the percentage passing the No. 200 BS sieve was 24.9% for the unstabilized laterite soil sample which is less than the specified limit of 35% according to the Federal Ministry of Works.

(ii) The liquid limit of unstabilized soil increases at 8% replacement of the CCR and decreases at 5% replacement of CSA which is evidence that the CCR is an activator and CSA is pozzolanic in nature. The optimum CSA-CCR replacement having the lowest liquid limit is found at 5% CSA, 6%, and 8% CCR.

(iii) The plasticity index value decreases tremendously to 1% upon the addition of CSA-CCR on the unstabilized soil sample. This shows the liquid limit and plasticity index values of stabilized soil fall within the guidelines of the Nigerian Federal Ministry of Highways and Transportation (1997).

(iv) The presence of CSA and CCR in the unstabilized soil decreased the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the unstabilized soil the optimum percentages of the additives and a slight increase in the OMC value at 5% CSA replacement.

(v) The California Bearing Ratio (CBR) of the soil increases upon the addition of CCR and CSA contents. Based on the results of this study, an 8% CCR and 2.5% CSA mixture yielded the best results in terms of strength increment compared to the control and is recommended to satisfactorily modify the soil.

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