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An Evaluation of the Influence of Corn Cob Ash on the Strength Parameters of Lateritic Soils

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Abstract
This paper reports the investigation of Corn Cob Ash as a pozzolan and a stabilizing agent for lateritic soils in road pavement construction. Corn cob feedstock was obtained from Maya, a rural community in the derived savannah agro-ecological zone of South-Western Nigeria, and burnt to ashes of pozzolanic quality. Reddish brown silty clayey sand material, characterized as an A-2-6(3) material and locally recognized as laterites was obtained from a borrow pit in Abeokuta, South-Western Nigeria and subjected to physical characterization tests according to BS 1377: 2000. The soil was subsequently mixed with CCA in varying percentages of 0%, 1.5%, 3%, 4.5%, 6% and 7.5% and the influence of CCA on the soil was determined for Liquid Limit, Plastic Limit, Compaction Characteristics, CBR and the Unconfined Compression Test. These tests were repeated on laterite-CCA-cement mix and laterite-cement mix respectively in order to detect any pozzolanicity in CCA when it combines with Portland cement and to compare results with a known soil stabilizing agent. The result shows a similarity in the compaction characteristics of soil-cement, soil-CCA and soil-CCA-cement, in that with increasing addition of binder from 1.5% to 7.5%, Maximum Dry Density progressively declined while the OMC steadily increased. In terms of the strength parameters, the maximum positive impact was observed at 1.5% CCA addition for soil-CCA with a CBR value of 84% and a UCS value of 1.0MN/m2, compared with the control values of 65% and 0.4MN/m2 respectively. For the soil-CCA-cement mix, the strength parameters CBR and UCS continued to increase with increasing binder addition within the tested range for the ratios 1:2 and 1:1 and 2:1 CCA:cement. Significantly, the results from the soil-CCA-cement mix, indicate the pozzolanicity of CCA in that UCS values were higher by at least 14% for the 1:1 ratio, than was attained with the addition of only the corresponding quantity of cement.
Keywords: Corn Cob Ash, pozzolan, CBR, UCS, biomass waste, road pavement.

1.0 Introduction

1.1 Background

A number of biomass waste ashes are increasingly being reported as pozzolans. These include Rice Husk Ash (Chungsangunsit et al, 2007), Bamboo Leaf Ash (Dwiveldi et al, 2006), Palm Fruit Ash (Olonode, 2010), Locust Bean Pod Ash (Adama and Jimoh, 2011), Cement Cassava Peel Ash (Salau et al, 2012), Corn Husk Ash (Raheem et al, 2012) and Corn Cob Ash (Adesanya and Raheem, 2009). The use of these waste ashes as pozzolans in concrete works has widely dominated the literature while their application as soil stabilizing agents is scanty and in some cases non-existent in spite of the fact that the mechanism for lime-soil stabilization includes a pozzolanic phase (O'Flaherty, 2002). Of particular instance is the complete absence of work on CCA as a stabilizing agent for road works. Producing at an annual rate of 9.2million tones (FAOSTAT, 2011), Nigeria ranks 8th among the corn producing countries of the world, with a corresponding generation of waste cobs across the country. Finding further use for biomass wastes will have a salutary effect on the environment, particularly in a developing country like Nigeria, where waste collection tends to be low and these wastes often constitute a menace to the environmnent. Furthermore, cohesive soils which fall within the band of soils that could be modified abound in Nigeria and are routinely used as sub-base and base course materials in pavement construction, which in some cases do have to be improved or modified with the addition of cement in order to raise the strength parameter to the expected standard. A further advantage to the environment is that partial or total replacement of cement in soil stabilization with a biomass waste will reduce the overall green house gas emission from the construction industry. This is because while emissions from CCA production is carbon neutral (Chungsangunsit et al, 2007), approximately 1tonne of CO_2 is generated for every tonne of cement produced (OEE, 2001; USDoE, 2003)

1.2 Aims and Objectives

The aim of the research work therefore, was to further find use for corn cob ash as a replacement for cement in the stabilization of soils in pavement construction in the belief that the more use that is found for biomass wastes like corn cob, the less they will constitute an environmental hazard. The specific objective of this work is to investigate the influence of corn cob ash on the geotechnical properties of locally available lateritic soil namely; Atterberg Limits, Compaction Characteristics, California Bearing Ratio and the Unconfined Compression Strength.

2.0 Materials and Methods

2.1 Materials

Corn Cob Ash

Corn cobs were obtained from the heaps of waste cobs which abound in *Maya* (7.29°N, 3.19°E) a major corn producing rural community in the *Derived Savannah* Agro-ecological zone of Oyo State in Southwestern Nigeria. The corn cob was gathered in an open heap and set afire until it turned to ash after a period of about 5 hours. Burning temperature was monitored and limited to a maximum of 650°C using a digital pyrometer. The ash was allowed to cool, gathered and passed through a 212micron sieve. Useful ash was taken as that finer than the 212micron sieve.

Laterite and Lateritic Soils

Ola (1983) defines lateritic soils as all products of tropical weathering with red, reddish brown or dark brown colour, with or without nodules or concretions and generally found below hardened ferruginous crusts or hard pan. The reference goes on to distinguish between laterite and lateritic soils using the ratio of silica to sesquioxide represented by $SiO_2/(Fe_2O_3 + Al_2O_3)$ as a critierion. Those less than 1.33 are indicative of laterites, those between 1.33 and 2 are lateritic soils, while those greater than 2 are non lateritic.

The Abeokuta formation is composed essentially of lithologies which vary from basal conglomerate through sand to clay-shale facies . The lateritic zone of the Abeokuta formation is known to lie just below the top soil, with Fe_2O_3 as the predominant mineral (Ehinola, et al; 2009) giving it the characteristic reddish brown colour. Reddish gravelly sand material commonly locally recognized as laterite was obtained from six locations at a borrow pit site in the Kobape area of Abeokuta (7.1°N, 3.3°E) South-West Nigeria, as disturbed samples and taken to the civil engineering laboratory of the University of Lagos, Nigeria for physical characterization and geotechnical properties tests in accordance with BS 1377:2000.

2.2 Test Methods

2.2.1 Physical and Chemical Analysis of the Corn Cob Ash

Corn Cob ash passing the 212 micron sieve was sent to the analytical laboratory of Lafarge-WAPCO Cement Factory in Ewekoro, Ogun State Nigeria for chemical analysis by the X-Ray Flourescence (XRF) technique using the Thermo Fisher Model ARL 9900. The result is presented in Table 1 alongside the requirements of ASTM C618-12 (1994) for identification and classification as a pozzolan.

2.2.2 Soil Tests

The parameters investigated in pursuit of the objective of this study were particle size distribution, Atterberg Limts, Specific Gravity, Compaction Characteristics, CBR tests and the Unconfined Compression Strength tests. Two controls were established for this study; the soil sample without any binder, and the soil sample with increasing additions of Portland cement – an established soil stabilizing agent. These provided a framework within which to observe the relative behaviour soil-CCA and soil-CCA-cement samples subjected to the same tests under similar conditions. All tests were carried out in the civil engineering laboratory of the University of Lagos Nigeria, in accordance with the standard procedures of BS 1377: 2000.

3.0 Results and Discussion

3.1 Control Tests on Lateritic Soil

The control tests on the physical characterization of the lateritic soil sample are as presented in Table 2, while Table 3 presents the control values for compaction characteristics, CBR and the Unconfined Compression Strength tests. The soil is a reddish brown silty clayey sand material with A-2-6(3) AASHTO classification. These type of soils are known to be good borrow pit materials for road works and very suitable for stabilization (Ola, 1983). Furthermore, the soaked CBR value of 65% makes it suitable as a sub-base material, but probably less suitable as a base course material for major highways where the minimum CBR is specified as 80% (FMWH, 1973). Therefore in locations where this material is predominant, the engineer often has to make a decision to either use a crushed stone base course or to enhance the strength parameters of the lateritic soil through admixture stabilization.

3.2 Control Tests on Laterite-Cement Mix

In order to establish a basis for the evaluation of the influence of CCA on the lateritic soil, the laterite-cement mix was subjected to the same set of physical characterization and strength parameter tests that the laterite-CCA mix would be subjected to, on the basis that cement is an established soil stabilizing agent (Ola, 1983). The results are as presented in Table 4. As expected, the addition of cement to the lateritic soil significantly boosted its CBR and UCS values, rising from 65% and 403kN/m2 respectively to 105% and 1459kN/m2 respectively upon the addition of 1.5% cement, and continues to rise but at a much slower rate with further addition of cement up to 7.5%.

3.3 Tests on Laterite-CCA mix

Table 5 gives the test results of laterite-CCA mix, and it indicates a similar trend with laterite-cement mix. The variation of the various parameters with increasing CCA content is discussed in detail thus:

3.3.1 Atterberg Limits

The Atterberg limits for soil-cement and soil-CCA as shown in Figures 1 and 2 are very similar, and almost flat, except for the section between 0 and 1.5% binder addition indicating that these parameters are hardly affected by the addition of either cement or CCA, beyond the limit of 1.5%. Liquid limit increased from the control value of 42 to 47.1 percent at 7.5 percent CCA while for cement addition, liquid limit increased to 45.4 percent at 7.5 percent cement. It has been recognised that the type of mineral present in a soil type determines its cation exchange capacity and hence, the effect the addition of soil stabilizers will have on the Atterberg Limits (Ola, 1983; O'Flaherty, 2002; Daita, 2005). According to the quoted references, montmorillonite clay will be much more dramatically affected by the addition of lime than kaolinite clay. Therefore the almost flat curve of the liquid limit and plastic limit can be explained by the predominance of kaolinite, with its low cation exchange capacity in the laterite soil of Southwest Nigeria as reported by Alao (1983).

3.3.2 Compaction Characteristics

The graphical representation of the compaction test results are as presented in Figures 3 – 6

A close similarity can be observed in the compaction characteristics of soil-CCA and soil-cement, in that the Maximum Dry Density decreased sharply from the control value of 1.905g/cm3 to 1.849g/cm3 at 1.5% CCA and decreased steadily therafter to a value of 1.827g/cm3 at a CCA content of 7.5%. The Optimum Moisture Content increased as the binder content was progressively increased from 0% to 7.5%. These are in line with established trend for stabilization of laterite with cement and lime respectively (Ola, 1983), laterite with rice husk ash (Alhassan, 2008), laterite with bamboo leaf ash (Amu et al, 2010) and South Chicago Clay with lime kiln dust (Daita and Kim, 2005). This has been expained for lime and fine grained soils in terms of the flocculation and agglomeration of the soil which form larger particles with subsequent increase in air voids giving rise to reduced dry densities (Ola, 1983). This explanation is considered to hold true for CCA given the K_2O and CaO content of the ash which add up to 11.92% could combine with any naturally occuring CaO in the lateritic soil (Alao, 1983) to initiate cation exchange, flocculation and agglomeration of the soil, in a manner similar to the effect of lime stabilization (Daita et al, 2005). Another explanation for this observation could be the replacement of the higher specific gravity soil (2.65) with ash of lower specific gravity (2.50) which leads to a higher volume mix requiring more water added, leading to more reduction in density since water has an even lower specific gravity. This phenomenon of sand-CCA mix requiring more water to form a workable mix has been reported in research work on CCA-cement blends in concrete works (Adesanya and Raheem, 2009).

3.3.3 California Bearing Ratio

The soaked CBR results for soil-cement and soil-CCA are as presented in Tables 4 and 5 and Figure 7. These show that for the soil soil-CCA there was an initial increase in CBR from the control value of 65% to 84% at 1.5% CCA followed by a decline at increasing levels of CCA additions. For the soil-cement mix, though the CBR continued to increase with increasing cement content, a graph in Figure exhibits a noticeable turning point at 1.5% CCA. This phenomenon can be explained from the understanding of the two phases expected in soil-cement stabilzation – the pozzolanic phase and the cement hydration reaction phase. The pozzolanic reaction phase ceases upon the completion of all reaction with the available soil minerals, while the cement hydration reaction continues (Daita, 2005; Ola, 1983). This explains why for the soil-cement, the graph exhibits a noticeable point of inflexion at 1.5% probably representing the termination of pozzolanic phase. Further strength increases beyond this point is attributable to the cement hydration reaction. Whereas the CCA- soil mix being only capable of pozzolanic reaction as explained in 3.5, exhibits an increase in CBR up to 1.5% CCA, considered to be the cation exchange capacity of the lateritic soil. Further additions of CCA beyond this level only goes to increase the water demand of the mix, lowering the dry density without any chemical reaction capable of increasing any strength parameter. This upper limit of 1.5% is in contrast with the range of 3 – 6% recommended in the Federal Ministry of Works Specification (FMW, 1997) for cement stabilization of A-2 soil group to which the studied soil belongs.

3.3.4 Unconfined Compression Strength

Figure 8 presents the Influence of CCA and cement respectively on the Unconfined Compression Strength of the lateritic soil sample. As with the CBR results, the UCS increased significantly (from 403 to 992KN/m2) at 1.5% CCA addition but decreased steadily thereafter with increasing addition of CCA. With cement stabilization however, the UCS continued to increase though at a slower rate beyond 1.5% cement. Again a point of inflexion can be observed at 1.5%, suggesting the termination of one of the factors contributing to strength development. This is thought to be the pozzolanic phase, which ceases upon the attainment of the cation exchange capacity of the laterite soil as explained in section 3.6

3.4 Tests on Laterite – CCA – Cement mix

Figure 9 is a graphical representation of the test results of the laterite – CCA – Cement mix. The UCS values depicted in this figure indicate the pozzolanicity of CCA in that at 7.5% binder addition (3.75% cement content at CCA: Cement ration 1:1). UCS value is 1987kN/m2, which is higher by 14% than the 1742kN/m2 deducible by interpolation for the same soil stabilized with cement only at 3.75%. These results follow trend reported for

Lime-Fly ash stabilization (Beeghly, 2003) and other reported works on Lime soil stabilization (Little, 1999; Jacobson, 2002). The significance of this result is further underscored by the fact that in adding CCA to Portland cement, not only is the price of the CCA cement blend expected to be cheaper (Adepegba, 1990; Olonode 2010), also the CO_2 trail of the blend will be friendlier to the environment (Jimoh and Apampa, 2013). In other words, the possibility of CCA-cement blend as a commercial product for stabilization of soils with cost advantage and significant added benefits to the environment is strongly indicated. This analogy is true for the CCA-cement blend in the ratio 1:1 as it is in varying degrees for the 1:2 and 2:1 blends.

4.0 Conclusion and Recommendation

4.1 Conclusion

In line with the aims and objectives of this research work to investigate the influence of the CCA as a stabilizing agent in lateritic soils and based on the foregoing results, the following conclusions can be reached:

a) The behavior of CCA in the stabilization of the A-2-6(3) lateritic soil sample is similar to the established trend in the lime and cement stabilization of A-2 lateritic soils in many respects, particularly regarding the Atterberg limits and the compaction characteristics.
b) The Maximum Dry Density decreased sharply from the control value of 1.905g/cm3 to 1.849g/cm3 at 1.5% CCA and decreased steadily therafter to a value of 1.827g/cm3 at a CCA content of 7.5%. The Optimum Moisture Content increased as the binder content was progressively increased from 0% to 7.5%.
c) The observation in (b) above is indicative of the value of CCA in the stabilization of soils that might ordinarily be considered too wet for compaction, since the higher moisture content is in fact the requirement for the attainment of MDD upon CCA addition.
d) For the CBR test, there was an initial increase from the control value of 65% to 84% at 1.5% CCA. This was followed by a decline at increasing levels of CCA additions.
e) For the Unconfined Compression Strength test, there was also an initial increase from the control value of 403kN/m2 to 992kN/m2 at 1.5% CCA, followed by a decline at increasing levels of CCA.
f) From (b), (c) and (d) above, it can be posited that the cation exchange capacity of the A-2-6(3) lateritic soil is reached upon addition of up to 1.5% CCA, at which point the pozzolanic reaction ceases, and further addition of CCA becomes detrimental to the strength of the stabilized soil.
g) For the soil-CCA-cement mix, the shape of the UCS-binder curve follows the trend soil as for soil-cement, with UCS increasing with increased binder addition. However, The UCS results from the soil-CCA-cement mix (1:1 CCA:cement) further go to establish the pozzolanicity of CCA in that UCS results were higher by 14% than would normally be attained with the addition of only the corresponding quantity of cement.
h) Points (f) and (g) above point to the commercial viability of a CCA and CCA-cement blends as a soil stabilization additive. This is further reinforced by the fact that CCA and CCA-cement blends have been established by Jimoh and Apampa (2013) as being more environmentally friendly than ordinary Portland cement.

4.2 Recommendation

This investigation set out to establish whether corn cob ash has any influence on the strength parameters of soils, using lateritic soil from Abeokuta as case study. The results clearly show that CCA does indeed influence positively the CBR and UCS values of the tested soil. Furthermore the activation of pozzolanic reaction upon the blending of ordinary Portland cement with CCA was demonstrated by the UCS values being higher than the corresponding value for only cement addition. In the light of this, it is herewith recommended that CCA can be made commercially available in its pure form or as CCA-cement blends and promoted as a stabilizing agent for soils in pavement construction. This would help in alleviating extreme poverty among the rural poor, enhance agro-waste management reduce net CO_2 contribution of the construction industry to the environment and reduce the cost of stabilizing soils for pavement construction.

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Table 1: Chemical Analysis of Corn Cob Ash

	Open Air Burning	ASTM C618-12 Requirement
SiO_2	63.60	$SiO_2+Al_2O_3+Fe_2O_3 \geq 70\%$
Al_2O_3	5.85	
Fe_2O_3	2.95	
CaO	3.50	
MgO	2.11	
SO_3	1.14	
K_2O	8.42	
Na_2O	0.45	
Mn_2O_3	0.06	
P_2O_5	2.42	
TiO_2	0.60	
LOI	8.55	10% max for Classes N and F, 6% max for Class C
Total	99.65	
Residue (45 micron)	34.32	35% max
Residue (90 micron)	11.78	
Specific Gravity	2.50	

Table 2: Physical Characterization of Lateritic Soil Sample

Parameter	%Passing Sieve No 200 (75µm)	Specific Gravity	Liquid Limit	Plastic Limit	Plasticity Index	Group Index GI= $0.01(F_{200}-15)(PI-10)$	AASHTO Classification
Value	31%	2.65	42%	15%	27	3	A-2-6(3)

Table 3: Strength Properties of Lateritic Soil Sample

Parameter	MDD g/cm3	OMC %	CBR (unsoaked) %	CBR (soaked) %	UCS (28days)kN/m2
Value	1.905	9.1	138	65	403

Table 4: Geotechnical Properties of Soil Sample with Cement

Parameter	**1.5% Cement**	**3% Cement**	**4.5% Cement**	**6% Cement**	**7.5% Cement**
Liquid Limit	43.0	43.5	44	44.7	45.4
Plastic Limit	15.1	15.3	15.4	16	16.2
Plasticity Index	27.9	28.2	28.6	28.7	29.2
Maximum Dry Density	1.852	1.847	1.841	1.835	1.830
Optimum Moist Cont	12.6	12.9	13.5	14.3	15.2
CBR 7 days (unsoaked)	182	193	204	209	207
CBR 7 days (soaked)	105	117	120	125	127
Unconfined Compression Strength(KN/m2)	1459	1525	1958	2161	2295

Table 5: Geotechnical Properties of Soil Sample with CCA

Parameter	0% CCA	1.5% CCA	3% CCA	4.5% CCA	6% CCA	7.5% CCA
Liquid Limit	42.0	45.4	45.8	46.2	46.7	47.1
Plastic Limit	15.0	16	16	16.3	16.3	16.4
Plasticity Index	27.0	29.4	29.8	29.9	30.4	30.7
Maximum Dry Density (g/cm3)	1.905	1.849	1.835	1.832	1.829	1.827
Optimum Moist Cont	9.1	12.5	13.0	13.3	14.0	14.9
CBR 7 days (unsoaked)	138	164	139	126	99	88
CBR 7 days (soaked)	65	84	68	60	55	49
Unconfined Compression Strength(KN/m2)	403	992	842	647	352	320

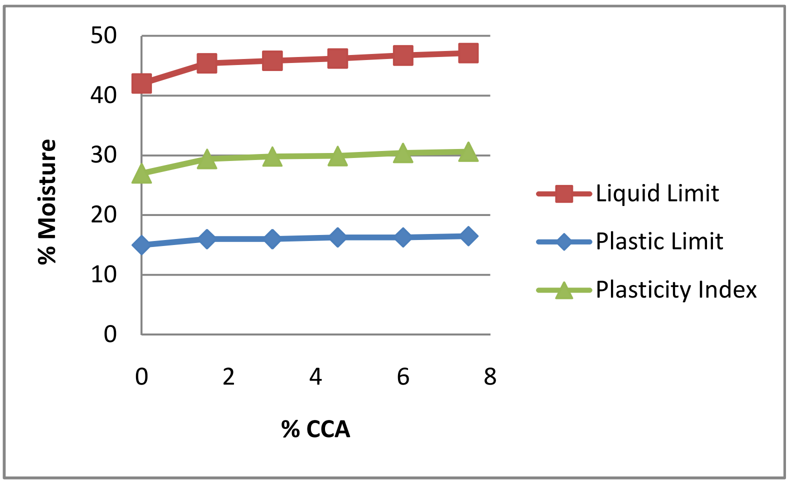

Figure 1: Influence of CCA on the Atterberg Limits of Lateritic Soil

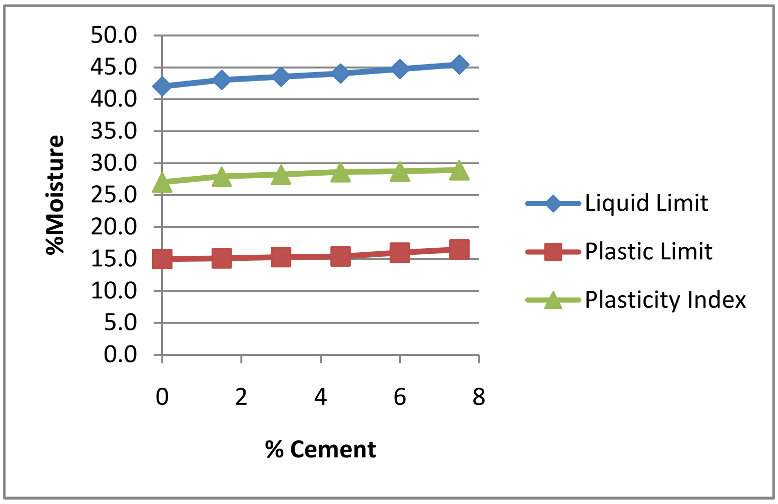

Figure 2: Influence of Portland Cement on the Atterberg Limits of Lateritic Soil

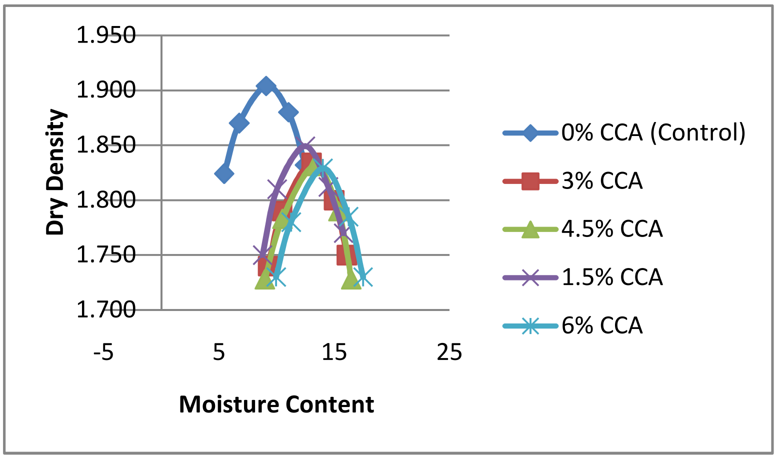

Figure 3: Dry Density vs Moisture Content, Soil-CCA

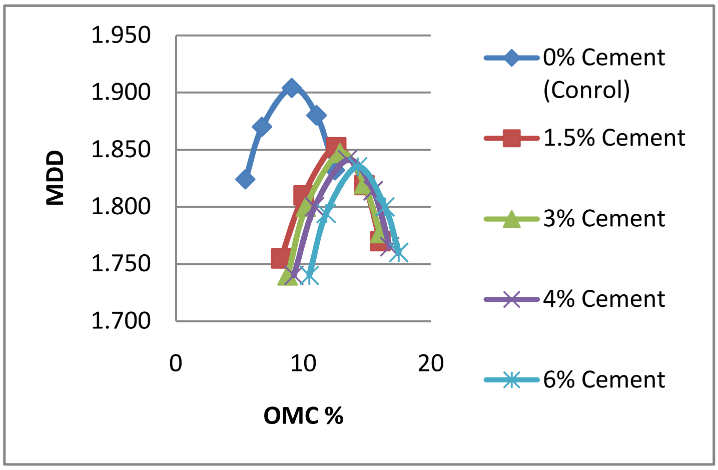

Figure 4: Dry Density vs Moisture Content, Soil-Cement

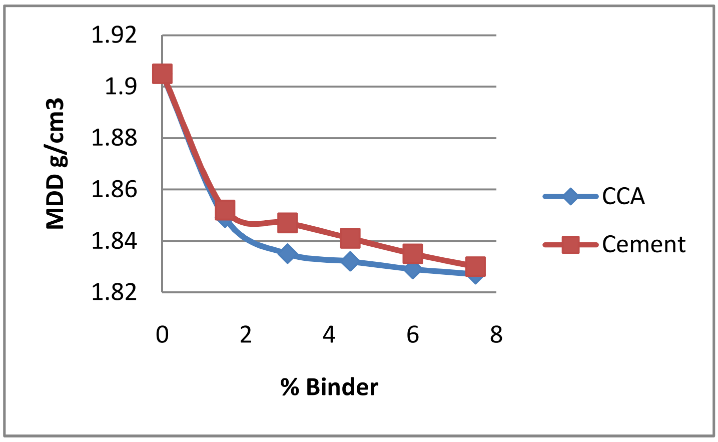

Figure 5: Maximum Dry Density vs Binder Content

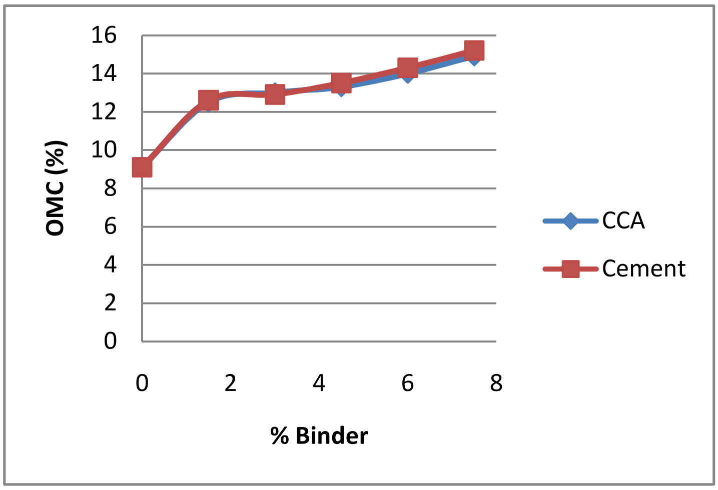

Figure 6: Optimum Moisture Content vs Binder Content

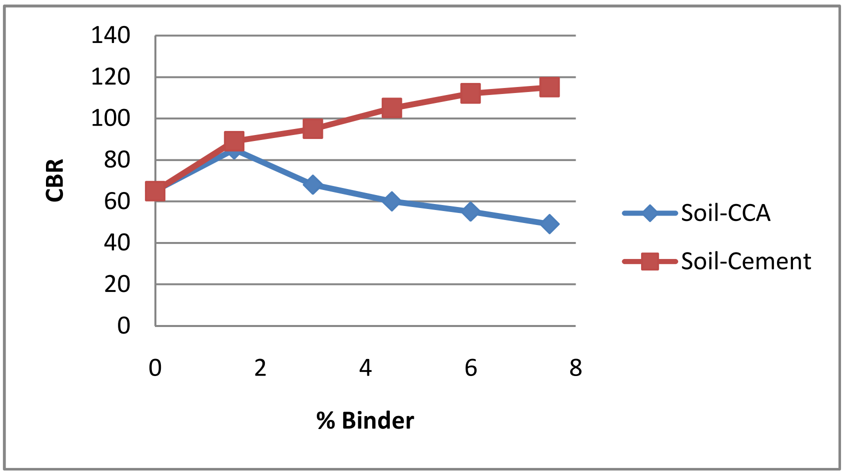

Figure 7: Influence of Varying Percentages of CCA and Cement Respectively on CBR of Lateritic Soil

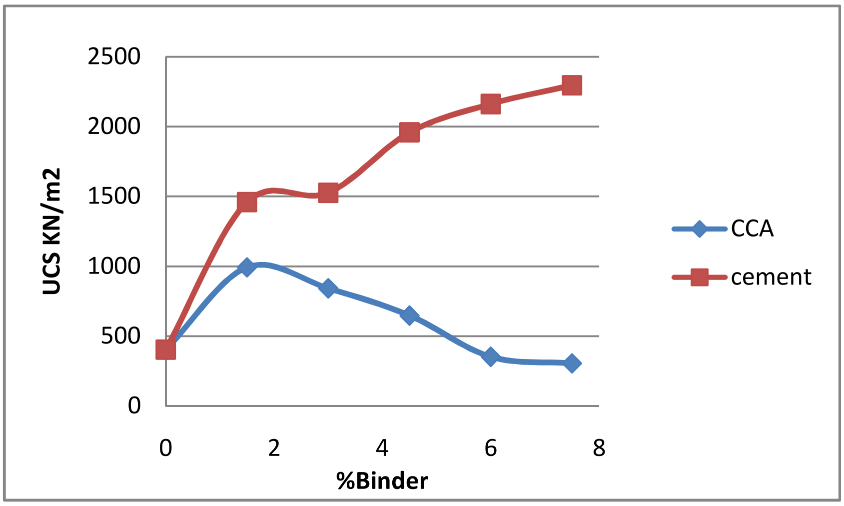

Figure 8: Influence of Varying Percentages of CCA and Cement Respectively on UCS values.

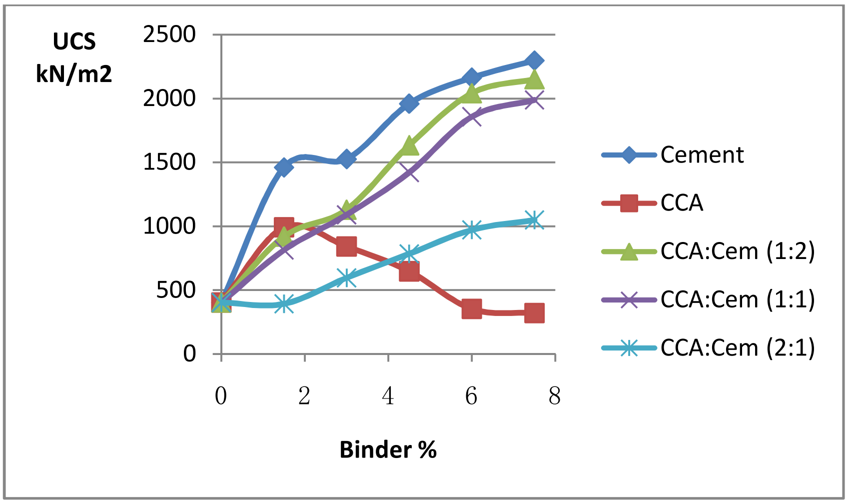

Figure 9: Variation of UCS with % binder for varying Binder Compositions