2nd International Civil Engineering Conference (ICEC 2020)
Department of Civil Engineering
Federal University of Technology, Minna, Nigeria

Sustainable Use of Calcium Carbide Residue to Enhance the Strength of Cement Stabilized Clay Soil

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ABSTRACT
Clay soil collected along Gwagwalada – Garki road was characterized and classified as A-7-6 soil according to American Association of State Highway and Transportation Officers (AASHTO) soil classification system. The clay was treated with 0, 2, 4 and 6% cement which was admixed with 0, 3, 6, 9, 12 and 15% calcium carbide residue (CCR). Unconfined compressive strength (UCS) test was used as evaluation criteria to measure the effect of CCR on cement stabilized clay soil. Results showed significant increase in UCS with increase in cement and CCR. In the absence of cement, the UCS was observed to increase from 71kN/m2 at 0% CCR to 602KN/m^2 at 15% CCR and 90 days curing. At 6% cement mixture, the UCS increased from 473kN/m^2 at 0% CCR to 3589kN/m^2 at 15% CCR and 90 days curing. This UCS strength has satisfied the strength required for a soil material to be used as base course for high trafficked road bases. It was also observed that 12 – 15% CCR is the optimal CCR required for efficient stabilization of clay soils.

Keywords: Calcium Carbide Residue; Cement; Clay Soil; Microstructure; Stabilization; Unconfined Comprehensive Strenght.

1. INTRODUCTION

Clay soils are common for swelling, shrinkage and other forms of weaknesses which make it difficult as materials to support civil engineering structures or to be used in construction of some civil engineering structures including pavements. In a region where clay soils are the dominant soil materials available, stabilization of the clay soil to meet the requirements is inevitable. Many researchers (Khajuria and Chopra, 2019; Abdullah et-al, 2017; Du et al, 2019; Xiao et al, 2019; Pourakbar et al, 2016) have used different additives to improve the strength and durability of weak clay soils.

Lime such as quick lime or slaked lime is one of the major constituent in formation of cementitious compounds. This has been attributed to the presence of Calcium ion in lime which can actively substitute many other ions around clay particles to form agglomeration of smaller particles to bigger ones. This reaction will reduce the plasticity of the clay soils and increase their workability. The use of lime and other Pozzolanic materials to stabilize weak and expansive clay soils have been studied extensively.

The earlier work of Sharma (2012) depicts the use of lime and Pozzolanic fly ash to stabilize expansive clay soil. Though, the author concentrated on the microstructural behaviour of weak clays when treated with lime and fly ash as against the use of strength characteristics, X-ray diffraction (XRD) tests, scanning electron microscopy (SEM) tests coupled with Electron dispersive spectroscopy (EDS) tests and Thermal gravimetric analysis were used as evaluation criteria. The author confirmed the breaking down of montmorillonite structures on addition of lime and fly ash. The author also concluded that during stabilization process, Pozzolanic reaction dominated over cation exchange capacity. The work of Muntohar et al (2013) is a similar research but admixed with rice husk ash and waste plastic fiber. The researcher used compressive, California bearing ratio (CBR), tensile and shear strength tests as evaluation criteria to measure the effect of lime, rice husk ash (RHA) and waste plastic fiber on the strength and durability of silty clay soil. It was concluded that the addition of lime and RHA increased the compressive and tensile strength by 4 times and 5 times respectively. The CBR was observed to increase by 3.6 times on addition of lime and RHA. However, addition of waste plastic fiber to this mixture increased the CBR by 8.7 times. Effect of bagasse ash on lime stabilized lateritic soil was studied extensively (Sadeeq et al, 2015). The lateritic soil used by the author classified as clay of low plasticity (CL) based on unified soil classification system (USCS). The laterite was treated with 0, 2, 4, 6 and 8% bagasse ash and lime each. The maximum UCS and CBR values of 698kN/m^2 and

43% respectively for the laterite soil treated with 8% lime and 6% bagasse ash.

Kang et al (2015) worked on stabilization of clay soil using class C fly ash and lime kiln dust (LKD) for subgrade use. The researcher used UCS and resilient modulus as evaluation criteria to measure the effect of fly ash and LKD on the engineering properties of clay soil. It was concluded that addition of fly ash and LKD improve the UCS and resilient modulus of the clay tremendously. The author also developed a relationship between UCS and resilient modulus. The study by James and Pandian (2016) is also a contribution to the use of lime and Pozzolanic (ceramic dust) material for stabilization of clay soils. Addition of ceramic dust was observed to give negative result at early stabilization age but gave increased strength of about 12-14%. The microstructural analysis revealed that there is formation of dense and compact microstructure.

Calcium carbide residue (CCR) contains large amount of lime and is a major waste from acetylene factory which constitutes serious nuisance to environment (Horpibulsuk et al, 2013). In developing countries like Nigeria, a lot of local welding exercises by individuals and few group of people are very common. This action has led to generation of wastes calcium carbide residue. Various researchers have worked on the utilization of CCR in addition to Pozzolanic materials to stabilize deficient soils. The study by Du et al (2016) was a good presentation of the potential of CCR for use as material for subgrade stabilization of weak clay soil. Field CBR, plate load test, Benkelman beam deflection test and dynamic cone penetration (DCP) tests were used as evaluation criteria to evaluate the potential of CCR for stabilization of weak subgrade clay soil. Results showed that treatment of soft subgrade with CCR increased the value of CBR and resilient modulus and resulted in to a low construction cost. Binary blending of CCR and palm oil fuel ash were used to stabilize fine grained soils (Majeed et al, 2018). Atterberg limits and UCS strength were used to evaluate the effect of CCR and palm oil fuel ash on the fine grained soils. It was concluded that UCS showed very high increase for clay treated with binary mixtures compared to those treated with CCR only. The work of Vichan and Rachan (2013) investigated the amount of CCR and biomass ash (BA) required to cause Pozzolanic reaction. The author used SEM and XRD to elucidate the Pozzolanic reaction going on in the clay after addition of CCR and BA. High increase in UCS strength was recorded due to Pozzolanic reaction between the binders and the clay.

Clay of intermediate plasticity (CI) and clay of high plasticity (CH) were both treated with CCR and Cocoanut shell ash (CSA) to improve their strength and stability (Isah and Sharmila, 2015). 4% CCR and 6% CCR were mixed with the (CI) and CH respectively, which were in turn admixed with 4, 9, 14 and 19% CSA each. The MDD was observed to decrease with increase in CSA while the OMC decreased in the same order. The UCS values of the CI clay recorded 11.38 times the value of the untreated clay soil while the CH clay recorded 6.03 times the value of the untreated clay soil. The study by Akinwumi et al (2019) focused on the potential use of CCR to stabilize tropical sands for pavement structures. The researcher used Atterberg limits, UCS and CBR as evaluation criteria to determine the effect of CCR on tropical sandy soil. The UCS values increased from 220kN/m^2 for untreated clay soil to 420kN/m^2 on addition of 16% CCR while the CBR increased from 54% for untreated clay to 66% on addition of 16% CCR. The study on the effect of cement and CCR on the engineering properties of residual lateritic soil was carried out by Joel and Edeh (2014). 2 – 10% cement and 2 – 10% CCR were each used to stabilize Ikpayongo laterite to determine the effect of cement and CCR on the geotechnical properties of the lateritic soil. The author concluded that the UCS and CBR values increased from 534kN/m^2 and 28% for untreated soil respectively to 3157kN/m^2 and 180% respectively for clay stabilized with combination of 10% cement and 10% CCR. The use of two industrial wastes (ground granulated blast furnace slag and CCR), to stabilize soil was investigated (Bandyopadhyay et al, 2016). Addition of these two additives improved the permeability, UCS and CBR of the soil thereby reducing the thickness of pavements.

Application of CCR as stabilizer to treat waste sludge was investigated (Liu et al, 2018). The author used direct shear test and UCS tests as evaluation criteria to determine the effect of CCR on the strength of remolded sludge. 10-15% CCR was observed to be the optimum CCR required to give maximum strength to the remolded sludge. A blend of CCR and hydrated lime was used to stabilize lateritic soil by replacing CCR with hydrated lime in 2% incremental order to 100% (Joel and Edeh, 2016). UCS test, durability test and CBR test were used as evaluation criteria to evaluate the effect of replacement of CCR with hydrated lime on the strength and durability of lateritic soil. Results showed that 70% replacement of CCR with hydrated lime was recommended for use to stabilize lateritic soil. The parametric study of soil stabilized with sugarcane bagasse ash (SBA) and CCR was carried out by Hatmoko and Suryadharma (2018). Due to short time reaction, the maximum stiffness occurs at moisture content below optimum while after 28 days curing period, the maximum stiffness occurred at optimum moisture content.

2. EXPERIMENTAL MATERIALS AND METHOD

2.1 MATERIALS

The materials used for this research include clay soil, cement, calcium carbide residue and distilled water. The clay was collected from Bako village, a site proposed for T. Y. Danjuma University along Gwagwalada-Garki road. The clay soil was collected at depth of between 0.5m – 1.5m using the method of disturbed sampling. The clay soil was then air-dried and pulverized according to the method highlighted in part 1 of BS1377 (1992). The cement used was a Portland cement purchased locally in a commercial market and kept in a dried place to avoid moisturization of the cement.

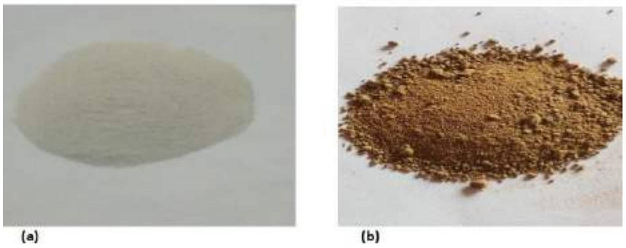


Figure 1: (a) Calcium carbide residue; (b) Clay soil

The CCR used was collected from local welders at Keteren-Gwari mechanic site, Minna, Niger State, Nigeria. This area contains a lot of calcium carbide residue waste which is usually disposed indiscriminately. The CCR sludge was air-dried, crushed and passed through sieve 0.075mm before used for the test. The distilled water was purchased from a medical shop opposite General Hospital, Minna, Niger State, Nigeria. These materials are shown in Figure 1.

2.2 METHODS

The air-dried clay soil sample was characterized through the determination of its index properties in Civil Engineering Laboratory, Federal University of Technology, Minna, Nigeria, using the method highlighted in BS 1377 (1992). X-Ray Diffraction (XRD) and X-Ray fluorescence (XRF) tests were also carried out on the clay soil. The tests were conducted in Ithemba Laboratory, Somerset West, South Africa and Electron Microscope Unit, University of Western Cape, Cape Town, South Africa. Phase characterization of the minerals and estimate of the average crystallite size of the various synthesized materials were conducted on a Bruker AXS D8 XRD system.

Scanning Electron Microscopy (SEM) test was also carried out by placing 0.05 mg of the synthesized materials, sprinkled on a sample holder, covered with carbon adhesive tape and wire sputter coated with Au-Pd using Quorum T15OT for 5 minutes prior to analysis. The sputter coated samples were characterized using Zeiss Auriga HRSEM. The SEM, which visualizes morphology and microstructure of the synthesized products were analyzed using Zeiss Auriga HRSEM. This was carried out to determine the structure of the mineral particles contained in the clay. The clay was then mixed with 0, 2, 4 and 6% cement which in turn is mixed with 0, 3, 6, 9, 12 and 15% CCR each. The idea behind 15% maximum CCR derived from the works of (Horpibulsuk et al, 2013; Isah and Sharmila, 2015 and Akinwumi et al, 2019) whose optimal percentage of CCR used for soil stabilization ranges from 9% to 16%. The clay soil and clay mixed with varied proportions of cement and CCR were compacted at standard proctor compaction energy level to obtain the maximum dry density (MDD) and optimum moisture content (OMC) of the mixtures. The predetermined MDD and OMC were then used to prepare specimen for UCS test.

Figure 2: Unconfined Compressive Strength Test Equipment

The UCS specimen of 38mm diameter and 76mm height was molded at standard proctor compaction energy level. The specimen was wax-cured for 7, 14, 28, 60 and 90 days before UCS test as shown in figure 2. The test was carried out in Civil Engineering Department, Federal University of Technology, Minna at speed of 1.2mm/min.

3. RESULTS AND DISCUSSIONS

The results of the experiments are hereby presented and discussed.

3.1 INDEX PROPERTIES TESTS

The result of the index properties of the clay soil is shown on table 2 while the grain size analysis graph of the clay is presented in figure 3. From table 2, the clay classified as A-7-6 according to AASHTO soil classification system and clay of high plasticity (CH) according to Unified Soil Classification System. This is an indication that the clay cannot be used as material for road pavement structure and cannot also be used to support pavement structures. It therefore requires stabilization to improve its strength and durability.

Table 2: Summary of Index Properties of the clay

Description	**Quantity**
Sand	18.4
Silt	28.9
Clay	53.0
Liquid limit	64.3
Plasticity Index	35.9
Specific Gravity	2.66
MDD (Standard Proctor compaction)	1.634
OMC (Standard Proctor compaction)	24.5
AASHTO soil classification	A-7-6
Unified Soil classification	CH

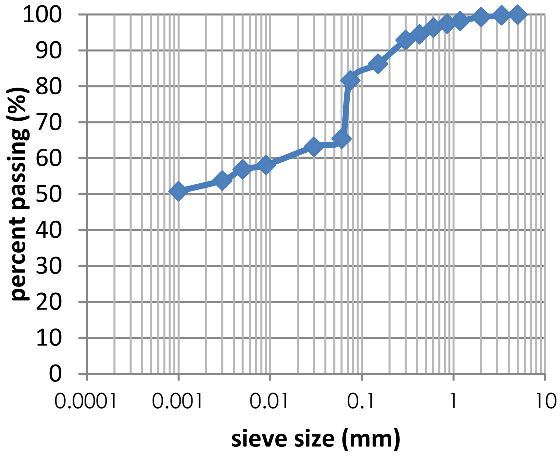


Figure 3: Grain size analysis of clay

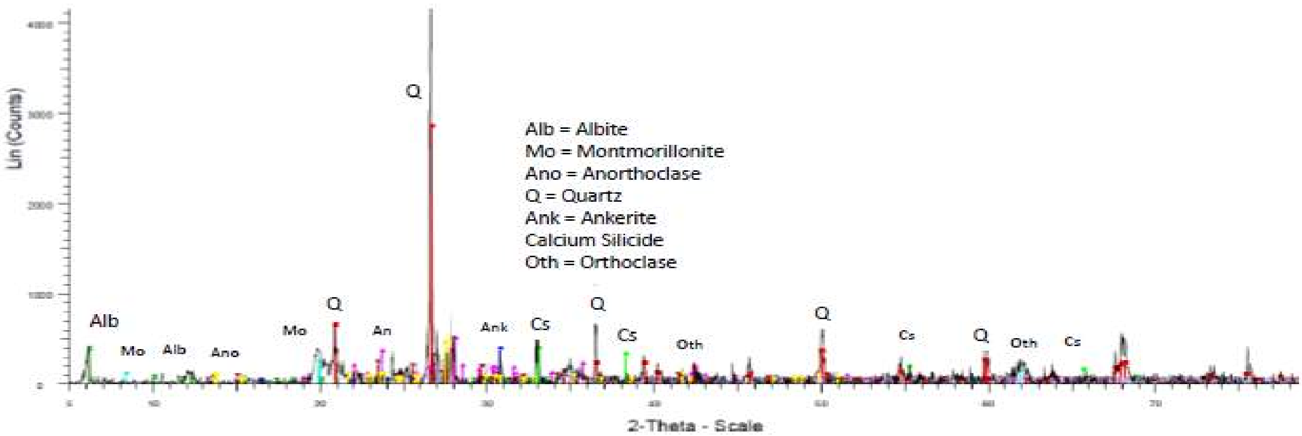


Figure 4: Graph of XRD Result

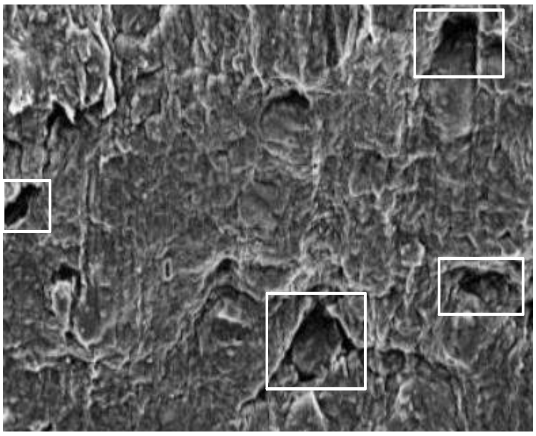


Figure 5: Result of SEM Test

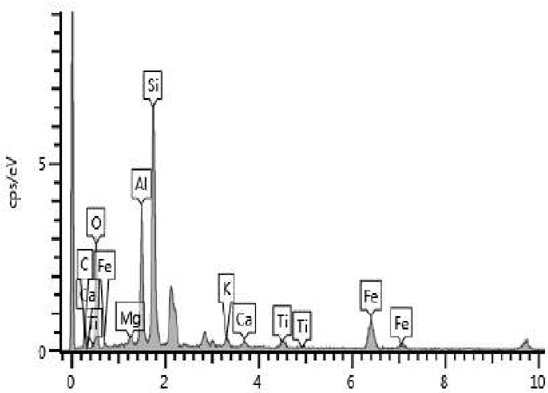


Figure 6: Result of EDS test

3.2 MICROSTRUCTURAL ANALYSIS OF THE CLAY SOIL

The result of the microstructural analysis of the clay soil are shown from XRD, SEM and EDS results are as shown in Figures 4, 5 and 6.

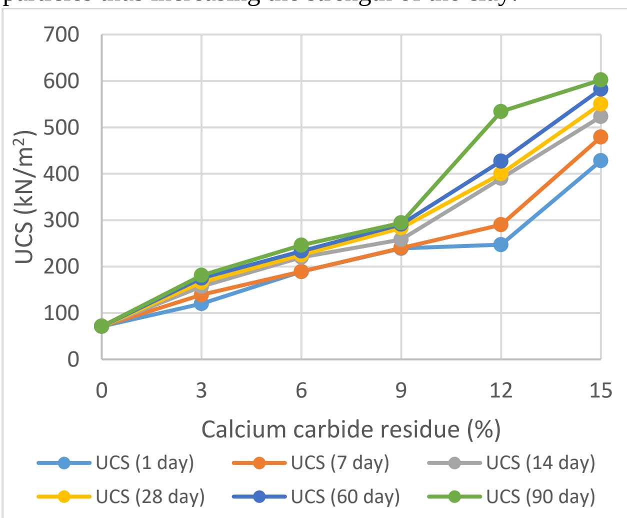
Result of Scanning Electron Microscopy (SEM) and Electron Dispersion Spectroscopy (EDS) are shown in Figures 5 and 6. The EDS result showed 24.9% carbon, 39.8% oxygen, 0.76% magnesium, 9.8% Aluminium, 17.4% silicon, 0.59% potassium, 0.54% calcium, 0.36% titanium and 5.6% iron. The silicon-aluminium ratio of1.78 confirms the presence of montmorillonite mineral. The SEM image of the soil, remolded at standard Proctor compaction energy level (Figure 4), revealed occasional presence of air voids (as highlighted in the figure) and dense fabric of flecky clay particles similar to those reported by Zang *et al.* (2013), Jaiswal and Lal (2016) and Abdullah *et al.* (2017).

Figure 4 present result of XRD test on the clay soil. The result indicates the presence of substantial composition of minerals, including montmorillonite, ankerite, calcium silicide, anorthite, anothoclase and orthoclase minerals. The presence of a peak at 8.96^0 also confirms the presence of montmorillonite mineral (Sharma et al, 2012). These are both primary and secondary minerals. Montmorillonite minerals can increase activity, and hence the consistency of the clay soil. The MDD and OMC of the clay soil, compacted at Standard Proctor energy level was observed to be 1.634 g/cm^3 and 18.5% respectively.

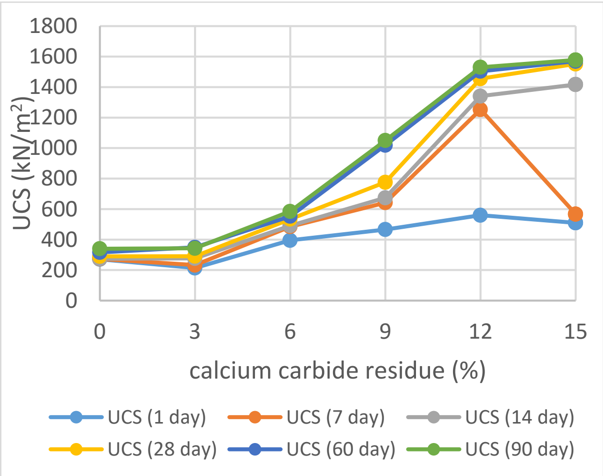
3.3 EFFECT OF CCR ON CEMENT STABILIZED CLAY

The effect of UCS with varied composition of CCR for 0, 2, 4 and 6 percentages of cement is shown in figures 7a, 7b, 7c and 7d respectively. Variation of UCS with varied percentage of CCR and 0% cement after 90 days of curing, is shown in figure 7a. The result revealed continuous increase in UCS with increase in CCR. The values increased from 71kN/m^2 at 0% CCR to 181, 246, 294, 534 and 602kN/m^2 at 3, 6, 9, 12 and 15% CCR respectively. Addition of 15% CCR therefore, represent 7.5 times increase in UCS of the clay.

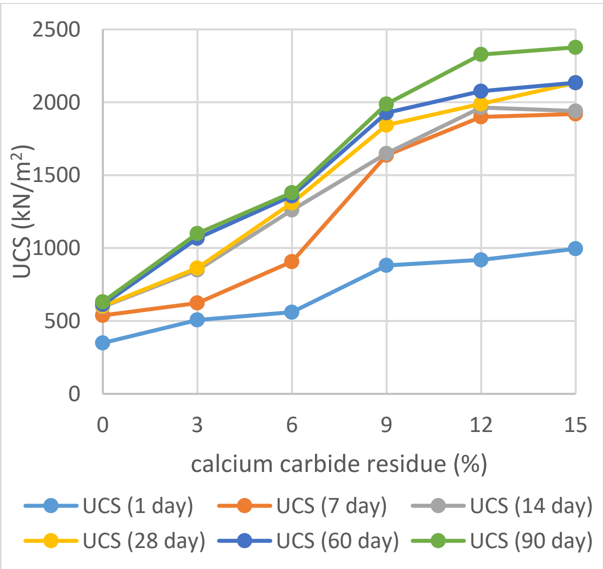
The optimal percentage CCR to give the maximum strength occur between 12% and 15% for 2% cement, 4% cement and 6% cement. For 2% cement after 28 days of curing, the UCS increased from 290kN/m^2 at 0% CCR to maximum of 1552kN/m^2 at 15% CCR. The increase must have resulted from the reaction between the calcium ions contained in the CCR which exchanges with ions present in the clay to form coagulation of clay particles thus increasing the strength of the clay.



(a)



(b)



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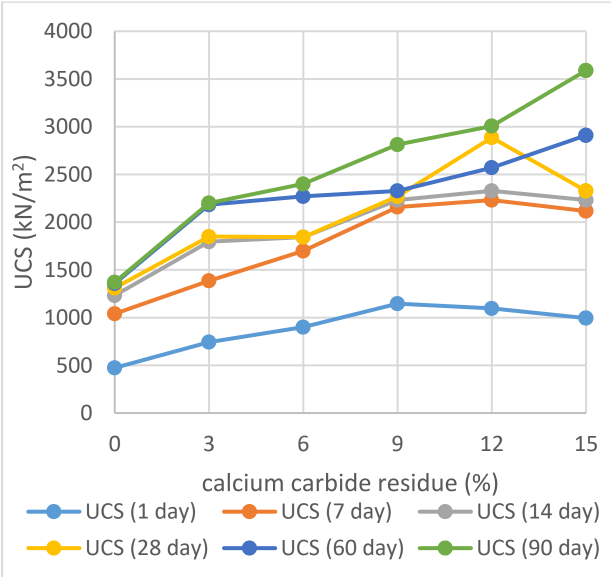


(d)

Figure 7: Variation of UCS with CCR for (a) 0% cement, (b) 2% cement, (c) 4% cement, (d) 6% cement

The UCS strength showed tendency to decrease in value beyond 12% CCR which is probably due to higher byproduct of calcium hydroxide which form unreactive whitish solids that reduces the strength of the specimen. For 6% cement after 90 days of curing, the UCS increased from 1370kN/m^2 at 0% CCR to maximum of 3589kN/m^2 at 15% CCR. This value is beyond the 3000kN/m2 recommended for soil materials to be used as base course for highly trafficked roads based on Nigerian General Specification for Roads and Bridges, 1992.

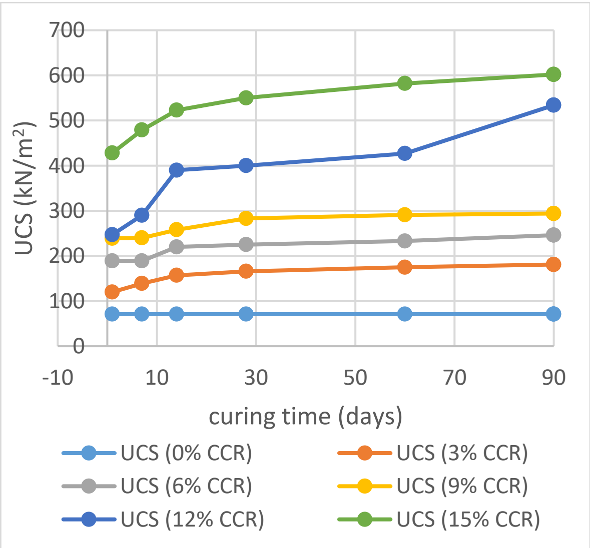
3.4 EFFECT OF CURING TIME ON CEMENT AND CCR STABILIZATION OF CLAY

The effect of curing time on the UCS of CCR stabilized clay soil at varied cement compositions are shown in figures 8a, 8b, 8c and 8d for 0, 2, 4 and 6% cement respectively. For 0% cement shown in figure 8a, the strength for 0% CCR was observed to be constant at 71kN/m^2 throughout the duration of curing. Addition of 3% CCR gave gradual increase in UCS from 120kN/m^2 after 1day curing to 181kN/m^2 after 90 days of curing which represents 51% increase in strength.

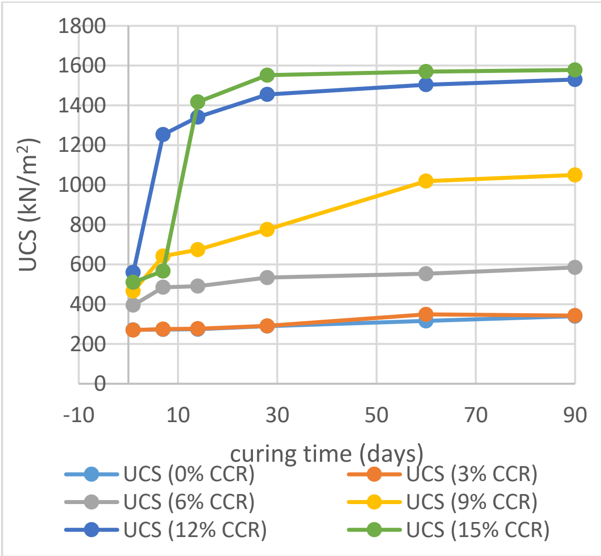
At 0% cement and 15% CCR, the UCS increased from 428kN/m2 after 1day curing to 602kN/m2 after 90 days curing which also represents 41% increase in UCS. This increase in strength must have resulted from the reaction between calcium contained in CCR and the ions surrounding the clay minerals. Figure 8b showed the variation in UCS with addition of CCR at 2% cement. Addition of 12% CCR was observed to stand out with UCS increasing from 560kN/m^2 after 1day curing to 1530kN/m^2 after 90 days curing which represents 17.3% increase in strength of the clay.

The maximum strength obtained on addition of 6% cement with varied composition of CCR occurred at 15% CCR which gave UCS of 995kN/m^2 after 1day curing to 3589kN/m^2 after 90 days curing which represents 260% increase in strength of the clay.

Figure 8a which deals with addition of CCR without cement, revealed gentle slope or gentle rate of increase in strength with increase in curing days except for 15% CCR which gave high rate of increase in strength during the first 28 days of curing after which the slope flattened. Figures 8b, 8c and 8d which composes of 2%, 4% and 6% cements with varied compositions of CCR, all showed faster rate of strength increase from 1 to 28 days after which the slope flattened out.



(a)



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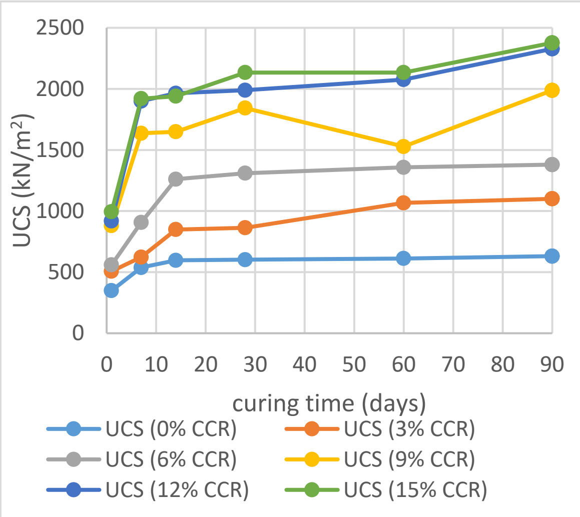

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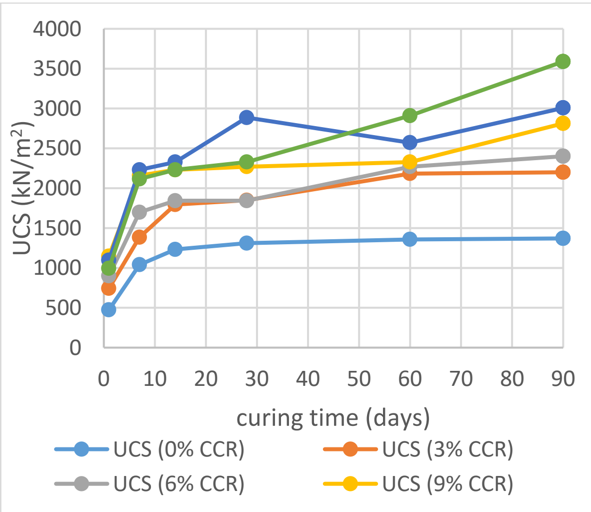

(d)

Figure 8: Variation of UCS with curing days for (a) 0% cement, (b) 2% cement, (c) 4% cement, (d) 6% cement

4. CONCLUSIONS

From the experiment and analysis carried out in this study, the following conclusions can be drawn:

The clay soil studied falls under clay of high plasticity (CH) based on Unified Soil Classification System (USCS) which cannot be used in its natural state for any component of flexible pavement structure.

Microstructural analysis of the clay using XRD and SEM revealed that the clay consists of both primary and secondary minerals including montmorillonite. The SEM showed the morphology of the compacted clay as flaky in nature with pore spaces.

Maximum UCS of 3589kN/m^2 which satisfy a soil material to be used as base course material for highly trafficked road bases. This was achieved at 6% cement and 15% CCR.

The optimal CCR required for effective stabilization of clay soil lies between 12 to 15% for clays with varied cement content.

The UCS obtained for clay stabilized with CCR only increased by 8.5 times the strength of the natural clay while the UCS at 6% cement increased by 280% at 15% CCR addition.

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