STABILISATION OF TROPICAL BLACK CLAY USING CALCIUM CARBIDE RESIDUE AND COCONUT SHELL ASH

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ABSTRACT
A Tropical Black Clay (TBC), obtained by method of disturbed sampling, at a depth of between 0.5m to 1.5m, at Gwako village, Abuja, Nigeria, was treated with up to 10% each of Calcium Carbide Residue (CCR) and Coconut Shell Ash (CSA), at 2% variations. Effect of the additives was investigated with respect to compaction characteristics (Maximum Dry Density-MDD and Optimum Moisture Content-OMC) and Unconfined Compressive Strength (UCS). Results of index properties of the soil indicated that it classified under CH and A-7-5, according to Unified Soil Classification System (USCS) and American Association for Highway and Transportation Officials (AASHTO) respectively. There was a general decrease in MDD of the treated soil with increase in dosage of the additives, while the OMC increased with increase in dosage of the additives. Unconfined Compressive Strength (UCS) of the treated soil showed general increase with both increase in dosage of the additives and curing period. It was therefore, concluded that although, 1700 kN/m^2 UCS was not achieved within the composition considered, CCR and CSA indicated positive potentials for treatment of tropical black clays.

Keywords: Calcium Carbide Residue, Coconut Shell Ash, Compaction characteristics, Stabilisation, Tropical Black Clay, Unconfined Compressive Strength

INTRODUCTION

The rising cost of conventional soil stabilising additives, such as cement and lime has motivated the search for cheaper and locally available materials for improvement of deficient soils in order to make them meet geotechnical engineering requirements. Deficient soils are regarded as soils which do not meet some or all the criteria required for satisfactory performance as geotechnical structures. These could either base courses for road, embankment for dam or road, subsoil base for foundation, clay liners for containment of leachates and backfill for retaining walls (Alhassan and Alhaji, 2015).In the tropical region, deficient soils could be lateritic or tropical clays, among which include Tropical Black Clays (TBC). TBC are expansive soils that principally occur in arid and semi-arid regions of the tropical zone marked with dry and wet seasons, with low rainfall, poor drainage and exceedingly great heat (Chen, 1988; Nelson and Miller, 1992).Because of their unconventional behavior, they are problematic in geotechnical engineering practice trough exhibition of large volume changes with respect to variation of moisture content (Eberemu *et al*., 2012). They form a major soil group in North Eastern part of Nigeria, where they are commonly referred to as Black Cotton Soil (BCS). They are so named because of their colour and suitability for growing cotton. Pockets of other deposits of Black Clays (BC), with similar behavior, have also been identified in other parts of Nigeria. Tropical black clay have colours ranging from light grey to dark grey and black (Oriola and Moses, 2011). They occur in continuous stretches as superficial deposits and are typical of flat terrains with poor drainage. The absence of quartz in the clay mineralogy enhances formation of fine-grained in these soils, which poses challenges to civil engineering works because of their swelling and shrinkage characteristics. They are usually very hard when dry, but losses their strength when wet and exhibit very low bearing capacity, low permeability and high volume change due to the presence of montmorillonite and illite clay minerals in them. These properties make the soils, in their natural state, unsuitable for geotechnical engineering constructions (Das, 2007).

Various efforts have been made (Osinubi *et al*., 2009; Ola, 1983; Balogun 1991a;Balogun 1991b)to improve the engineering properties of black clays using cement, lime, admixtures and waste products (both industrial and agricultural).Improving the mechanical properties of these soils by admixing it with either conventional or nonconventional binding material, either before or during construction process has been known to have long term beneficial effect on the durability and serviceability of structures constructed on them. This process known as soil stabilization is based on the pozzolanic activities of the soil and the used admixtures, chemical state of the soil moisture (pH level) and strict adherence to the construction procedure for maximum benefit (Johnson *et al.,* 2016).

Amu *et al.*(2010) stated that soil stabilization can save cast in contrast to cutting and replacing the unstable material. Cement and lime are the major conventional admixtures used in construction industry since ancient periods (Ola, 1983; Balogun, 1991). Cement is a substance which sets and hardens independently, and therefore is considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the required stabilizing action (Sherwood, 1993). The most important use of cement is in the production of mortar and concrete (Nagarajan *et al.*, 2014). However, the relatively high cost of cement production and the negative environmental effect, associated with this production, coupled with its corrosive action when working with it in the field, has made sourcing for alternatives materials imperative. This has made researchers (Mohammedbhai and Baguant, 1990; Osinubi, 1998a, Osinubi, 1998b; Osinubi and Medubi, 1997; Medjo and Riskowiski, 2004; Osinubi *et al.,* 2009; Osinubi *et al.,* 2011; Oluremi *et al*., 2012; Oluremi *et al*., 2016) to focus on the use of industrial and agricultural by-products with pozzonalic potentials, which were initially regarded as waste, but have recently been known to have economic importance as stabilizing agents. One of these industrial and agricultural wastes is Calcium Carbide Residue (CCR) and Coconut Shell Ash (CSA) respectively.

CCR is a by-product from acetylene gas production. This gas is used around the world for welding, lighting, metal cutting and for fruit ripening. CCR is obtained from a reaction between calcium carbide and water to form acetylene gas and calcium hydroxide in a slurry form, which mainly consists of calcium hydroxide $Ca(OH)_2$ along with silicon dioxide SiO_2, $CaCO_3$ and other metal oxides. The presence of natural pozzolanic materials in clayey soil, makes calcium hydroxide [$Ca(OH)_2$] a rich material that can be used to produce high strength geo-material (Gurugubelli *et al.*, 2017). For environmental and economic impact, such a waste materials can be utilized collectively with natural pozzolanic material in clay to form cementitious material. Calcium carbide residue production is described in the following reaction equation:

$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2 \quad (1)$$

From the Equation (1), Kumrawat and Ahirwar (2014) stated that 64g of calcium carbide (CaC_2) will produce 26g of acetylene gas (C_2H_2) and 74g of Calcium carbide residue (CCR) as $Ca(OH)_2$.

Recent studies (Arulrajah *et al*. 2016; Du *et al.,* 2016; Jiang *et al*., 2015; Horpibulsuk *et al*., 2015a) have shown that CCR stabilization can improve strength characteristics, dispersibility, and reduce swelling potential of problematic soils. Horpibulsuk *et al.* (2014) studied the use of CCR as a binder to treat over-wetted clays for use as embankment material. They found that CCR-stabilized soil performed better than lime-stabilized soil. This was in agreement with results previously reported by Kampala *et al*. (2013). Furthermore, the performance of CCR has been examined in combination with other beneficial by-products such as fly ash or coal bottom ash. Jaturapitakkul and Roongreung (2003) and Horpibulsuk *et al*. (2014) used CCR, blended with pozzolanic materials such as fly ash and Rice Husk Ash as an alternative to without Ordinary Portland cement, to form cementing agent for manufacturing concrete and masonry units.

Coconut Shell Ash (CSA) has also been recently known to possess pozzolanic characteristics. According to Madakson *et al*. (2012), CSA consists of major chemical composition as silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), magnesium oxide and iron (III) oxides. SiO_2, Al_2O_3 and iron (III) oxides are known to as substances that can react with the product from cement hydration process and provide additional strength to the material being bonded. CSA is obtained from incineration of coconut shell, which is a by-product from coconut palm tree. Coconut palm (*Cocos nucifera*) is an important and useful palm in the world (Uwubanmwen *et al*., 2011). It belongs to the palm family known as *Arecaceae* and is the accepted species of genus *Cocos* (Hahn, 1997; Amu *et al.,* 2011). In Nigeria they are mostly cultivated in the coastal regions of the country. However, more than 90% of the nation's coconut belt is a continuation of the plantations or groves along the West African coast, running from Cote d'Ivoire and southeast towards Ghana, Togo and Benin to Lagos state in Nigeria. In 2013, the global land area used for cultivation of coconut was estimated at approximately 12.28 million hectares, with global production put at approximately 64.3 billion nuts (Sudarat, 2019).

Many researchers have posited that coconut shell can be used as replacement material in construction industry, where this may lead to reduction in construction material cost and reduce the environmental nuisance it dumping causes (Gunasekaran *et al*., 2013). In Nigeria, coconut shell can be a source of energy-biofuel for boilers and some quantity is also used as gravel for plantation roads maintenance

(Onyelowe, 2016). Furthermore, some researchers Gunasekaran, *et al*., (2017) have shown that coconut shell can be turned to powder form, through incineration process and then be used for activated carbon production, mosquito repellent coil and as filler in plastic. Moreover, coconut shells possess higher resistance against crushing, abrasion and impact, compared to normal crushed aggregate (Kukarni *et al*., 2013). Research (Olanipekun *et al.*, 2005) indicates that, at the same mix proportion, concrete produced using coconut shell has higher compressive strength than that made with palm kernel shell. Kambli and Mathapati (2014) showed that coconut shell can be used as lightweight aggregate.

Rashmi *et al.* (2016) studied effect of coconut shell ash on the properties of expansive soil and concluded that the ash can effectively be used to stabilize this type of soil. Segun and Oluyemisi (2017) assessed the effect of coconut shell ash on lime-stabilised lateritic soil, and concluded that CSA is a potential and effective complement for lime stabilization of lateritic soil. Athira *et al*. (2017) studied the effectiveness of coconut shell powder and lime in stabilizing the expansive soil, and found that compressive strength of the soil increased by 228% after 28 days of curing. Isah and Sharmila (2015) stabilised clay soils using CCR and CSA, and reported that 4% CCR/4% CSA improved strength of CL soil by 11.38 times after 7 days curing period. Gurugubelli *et al*. (2017) carried out laboratory study on the strength improvement of expansive soil, treated with calcium carbide residue and Fly Ash (FA), and concluded that using 6 – 8% CCR + 10% FA can improve the performance of black cotton soil as pavement structure. Neeraj and Ahirwar (2014) investigated the performance of black cotton soil, treated with CCR and stone dust, and stated that, for controlling swelling behavior, addition of equal quantities (10 and 10%) of the additives is more effective than adding them individually. This study investigated the possibility of using CSA with CCR for stabilizing tropical black clay.

MATERIALS AND METHODS

Materials

The materials used in this study were Tropical Black Clay (TBC), Calcium Carbide Residue (CCR) and Coconut Shell Ash (CSA).

Tropical black clay

The Tropical Black Clay (TBC) used in the study was obtained by method of disturbed sampling at depth of between 0.5m to 1.5m at Gwako village, along Zuba-Gwagwalada express way area of Abuja, Nigeria. The collected soil sample was preserved in polythene bags and transported to the Geotechnical laboratory of Federal University of Technology, Minna. At the laboratory,the natural soil sample was air dried and pulverized using hammer before further tests were conducted.

Calcium carbide residue

The Calcium Carbide Residue (CCR) used in the study was obtained from panel beaters in Minna. It was air dried and grinded to fine particles passing through BS sieve No. 200 (75μm) before use.

Coconut shell ash

The coconut shell was obtained from local coconut dealers in Minna, Niger State. The shells was well dried to remove moisture and burnt in open air for four hours and then allowed to cool. The burnt ash was sieved through BS No 200 (75μm) and then stored in air tight polythene bags to avoid contamination. Chemical composition of the coconut shell ash was carried out to determine its oxide composition.

Methodology

The laboratory test performed on the natural soil in order to determine its engineering properties were in accordance with BS 1377 (1990) parts 2, 4 and 7, while on the stabilized soil, the tests were conducted accordance with BS 1924 (1990). In accordance with the method used by Isah and Sharmila (2015), the soil was mixed with 0, 2, 4, 6, 8 and 10% CSA, and each was then admixed with 0, 2, 4, 6, 8 and 10% CCR. Natural moisture content, specific gravity, particle size distribution, Atterberg limits (liquid limit, plastic limit and plasticity index), compaction at Standard Proctor energy level, Unconfined Compressive Strength (UCS) were performed on the natural soil, while on the stabilized soil, compaction and UCS tests were performed. Samples for UCS test were prepared at Maximum Dry Densities (MDD) and Optimum Moisture Contents (OMC), obtained from compaction test at respective mixtures of the soil and the additives (CCR and CSA).

Results and Discussion

Properties of natural tropical black clay

The results of preliminary tests conducted on the natural soil, for identification and classification purposes, is presented on Table I. From the results, the soil is classified as CH and A-7-5according to Unified Soil Classification System (USCS) and American Association for State Highway and Transportation Officials (AASHTO) respectively. This indicates that the geotechnical properties the fall below the standards, recommended for most civil engineering construction works, especially highway (Osinubi and Medubi, 1997), and therefore need stabilization.

Table 1: Geotechnical properties of natural tropical black clay

Property	**Values**
Fraction passing BS No 200 sieve (%)	50.63
Natural moisture content (%)	13.65
Specific gravity	2.63
Liquid limit (%)	58
Plastic limit (%)	33.88
Plasticity index (%)	24.14
USCS	CH

AASHTO classification	A-7-5
MDD (g/cm³)	1.784
OMC (%)	17.0
UCS (kN/m²)	19.196

Compaction Characteristics

Variation of compaction characteristics with dosage of CSA at various percentages of CCR are presented in Figures 1 and 2 for MDD and OMC respectively. From Figure 1, it can be observed that at constant dosage of CCR, MDD of the stabilized soil decreased with increase in percentage of CSA. This can be attributed to the specific gravities of both the soil and the additives. With the soil having specific gravity of 2.63, which is typical for clay soil, as compared to that of the CSA (2.26) and CCR (2.25), increase in percentage composition of CSA in the soil will tend to reduce the net density of the composite material. This trend of MDD variation is similar to that reported by Isah and Sharmila (2015), when they treated CL and CH soils with CCR and CSA.

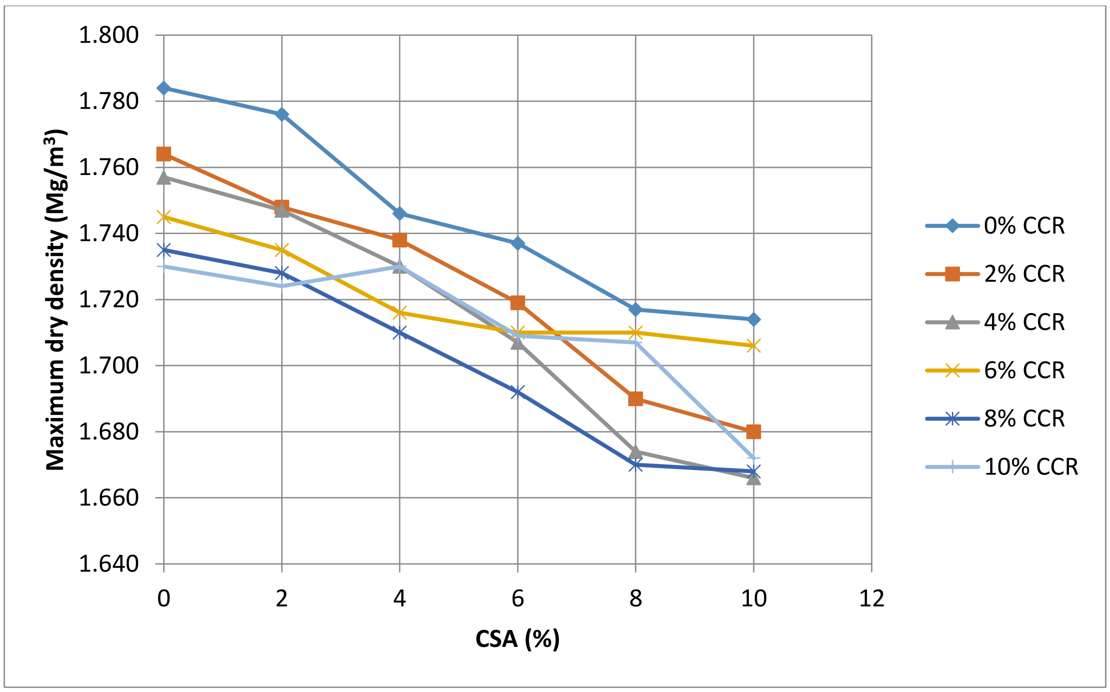

Figure 1: Variation of MDD with increase dosage of CSA and CCR

Also, from Figure 2, it can be observed that at constant dosage of CCR, OMC of the stabilized soil increased with increase in percentage of CSA. This is attributed to the reaction between the CCR and CSA in the soil. While CCR helps in flocculating the soil-typical when lime is used to improve soil, CSA react with the CCR, silica and alumina in the soil. This reaction requires water to proceed, hence increase in the OMC. This trend of OMC variation is also similar to that reported by Isah and Sharmila (2015).

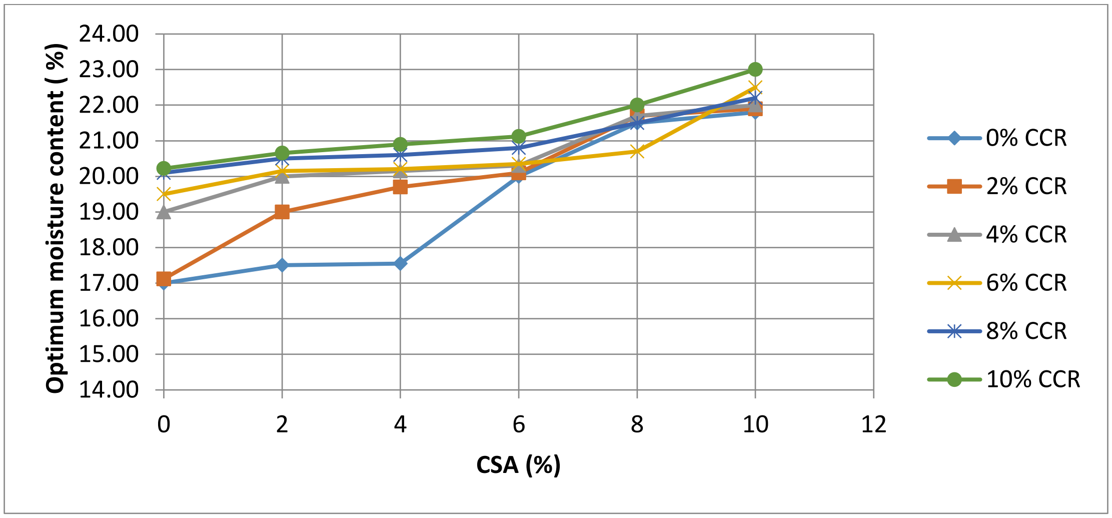

Figure 1: Variation of OMC with increase dosage of CSA and CCR

Unconfined Compressive Strength

Variations of unconfined compressive strength with various dosages of both CSA and CCR are in Figures 3, 4, 5, 6 and 7 for 1, 7, 14, 28 and 60 days curing periods respectively. From the figures, it can be observed that as the percentage composition of both CSA and CCR increased, unconfined compressive strength of the treated soil increased. Also, observation and comparison of the figures revealed that as the curing period increases, unconfined compressive strength of the treated soil also increased. This noticeable increase in unconfined compressive strength of the treated soil, with increase in curing time is attributed to the pozzolanic reaction, brought about by the CSA in the composite. Since pozzolanic reaction is relatively a time based reaction, the effect is more pronounced beyond14 days curing period, which vividly seen between 28 (Figure 6) and 60 days (Figure 7) of curing.

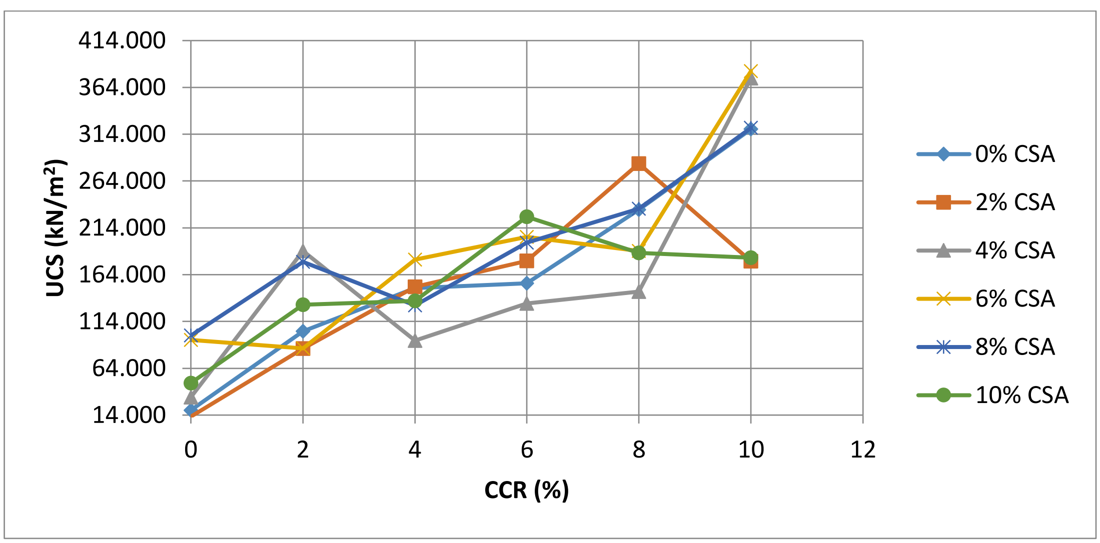

Figure 3: Variation of unconfined compressive strength with various dosages of both CSA and CCR after 1 day curing period

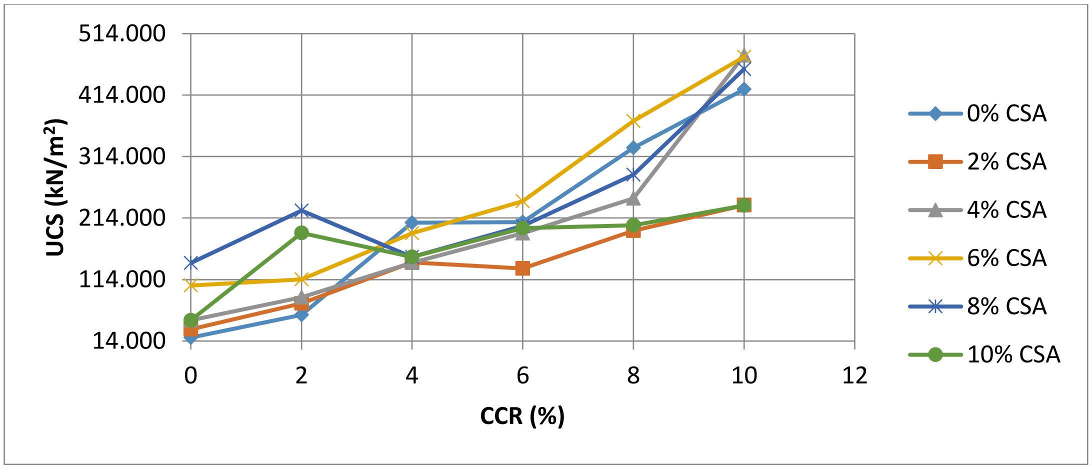

Figure 4: Variation of unconfined compressive strength with various dosages of both CSA and CCR after 7 days curing period

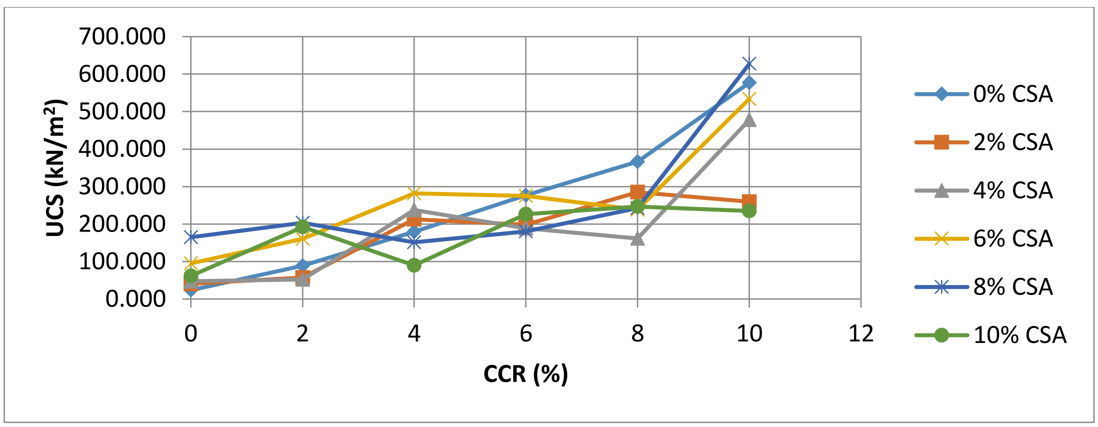

Figure 5: Variation of unconfined compressive strength with various dosages of both CSA and CCR after 14 day curing period

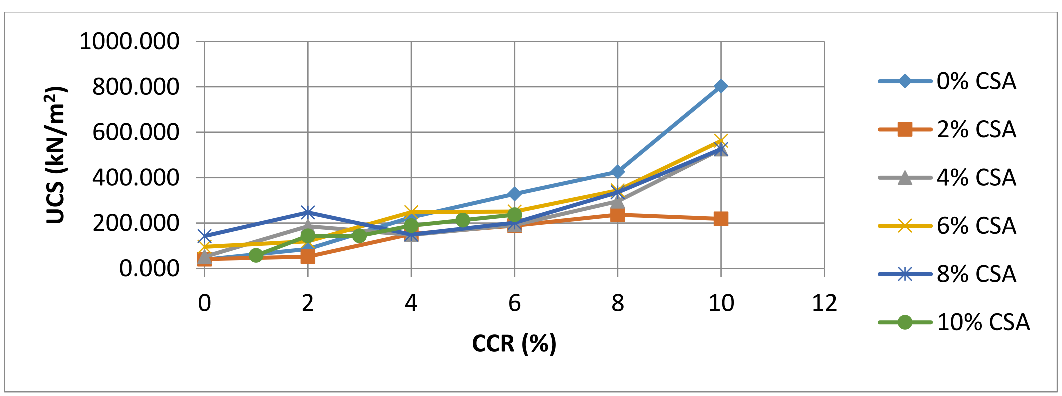

Figure 6: Variation of unconfined compressive strength with various dosages of both CSA and CCR after 28 day curing period

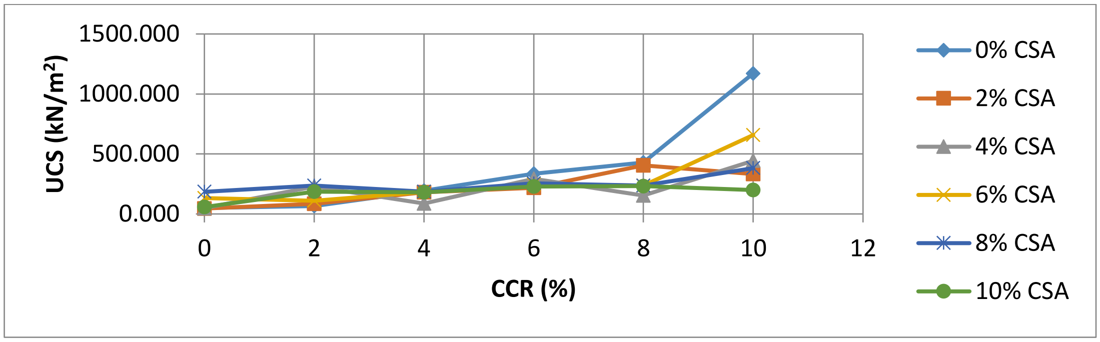

Figure 7: Variation of unconfined compressive strength with various dosages of both CSA and CCR after 60 day curing period

Conclusion

From the study, the following conclusion is drawn:

The Tropical Black Clay (TBC) classified under CH and A-7-5, according to Unified Soil Classification System (USCS) and American Association for Highway and Transportation Officials (AASHTO) respectively.

There was a general decrease in maximum dry density of the treated soil with increase in dosage of the additives.

Optimum moisture contentof the treated soil increased with increase in dosage of the additives unconfined compressive strength of the treated soil showed general increase with both increase in dosage of the additives and curing period.

Although the 1700kN/m^2 required, was not achieved within the composition considered, CCR and CSA indicated positive potentials for treatment of tropical black clays.

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