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Improvement of Deficient Laterite Soil using Cement and Calcium Carbide Residue

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ABSTRACT

Lateritic soil, obtained from a borrow pit at Lapan Gwari, Minna, Niger State was stabilized with up to 6 and 8% (at 2% variations) of cement and Calcium Carbide Residue (CCR) respectively.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 CL and A-6, according to Unified Soil Classification System (USCS) and American Association for Highway and Transportation Officials (AASHTO) respectively. There was a general increase in both MDD and OMC of the treated soil with increase in dosage of cement, while at constant cement content, the MDD and OMC of the mixtures was observed to decrease and increase respectively, with increase in CCR content. UCS was observed to increase as cement content increase, while at constant cement content, the UCS increased to their maximum values at 4% CCR content, after which the strength decreased, indicating 4% CCR content as the optimal. Results of the study showed that 2 and 4% cement and CCR respectively, satisfied the 1710 or 1750 kN/m^2recommended in the literature, as criteria for design cement content, which is considered adequate for soil-cement (and now soil-cement-CCR) composite as base course material for highway pavements with light to medium traffic.

Keywords: *Calcium carbide residue, Cement, deficient soil, Laterite, Stabilization*.

1 INTRODUCTION

The rising cost of conventional soil improving additives (cement and lime) has necessitated the search for less costly and locally available materials for treatment of deficient soils in order to make them meet the desired geotechnical requirements (Suleiman, 2020). Deficient soils are regarded as soils which do not meet some or all the criteria, required for satisfactory performance as geotechnical structures. According to Alhassan and Alhaji (2015), these structures could either be base courses for road, embankment for dam or road, subsoil base for foundation, clay liners for containment of leachates and backfill for retaining walls. In the tropical region, deficient soils could be lateritic soils or other tropical clays.

Lateritic soil is the dominant soil material available for construction of bases for pavements in Nigeria and other countries in the tropical region of the world. The rate at which deposits of good lateritic soil are depleting has become a concern. Good lateritic soil deposits were initially thought to be inexhaustible, but their current situation, especially in Minna, the capital city of Niger state and its environs,have proved otherwise (Saidu*et al.*, 2020). This, coupled with the ever rising cost of cement, which is the most popular soil stabilizing agent, has further necessitated the search for less costly additives that can be used for stabilization of the available deficient lateritic soils.

Cement and lime are the major conventional admixtures used in construction industry since ancient periods (Ola, 1983). However, the relative high cost of cement production and the negative environmental effect, associated with the production, coupled with its corrosive action when handling it in the field, has made sourcing for alternatives materials imperative. This has prompted researches into possible use of industrial and agricultural by-products that have cementitious and pozzonalic potentials, and which were initially regarded as waste, but have recently been known to have economic importance as stabilizing agents. One of these industrial wastes is Calcium Carbide Residue (CCR).

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:

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

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 $(OH)_2$.

2 MATERIALS AND METHOIDS

MATERIALS

The materials used in this study were lateritic soil, Portland cement and Calcium Carbide Residue (CCR).

Lateritic soil

The lateritic soil used in this study was collected using method of disturbed sampling from a borrow pit at LapaiGwari village, a suburb of Minna. 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 before further tests were conducted.

Cement

The Portland cement used for the study was procured from a cement vendor at Minna building materials market. The cement was properly stored under dry condition.

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. Table 1 presents chemical composition of cement and CCR used in the study.

Elemental Oxide	Percentage composition (%)	
	CCR	cement
CaO	61.41	64
MgO	0.80	1.94
Al_2O_3	1.78	5.75
Fe_2O_3	0.17	2.50
SiO_2	2.69	20.40
SO_3	0.36	2.75
LOI	32.51	1.20

Figure 1: Chemical composition of the CCR and cement

METHODOLOGY

In order to determine engineering properties of the natural soil, laboratory tests were performed in accordance with BS 1377 (1990) parts 2, 4 and 7, while on the stabilized soil, the tests were carried out in accordance with BS 1924 (1990). Considering the results of studies by Isah and Sharmila (2015), Marathe*et al*. (2015), Roy (2014), Afolayan (2017), Olutaiwo and Ariyo (2016), Ogunribido (2018), Todingrara*et al*. (2017), Onyelowe (2016), Jaritngam*et al*. (2014), Elsharief*et al*. (2013), and Joel and Agbede (2011), the soil was mixed with 0, 2, 4 and 6% cement, and each was then admixed with 0, 2, 4, 6 and 8% 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. The compaction test was carried out using British Standard Light (BSL) compaction energy, otherwise known as Standard Proctor energy level. This was because, of the three compaction energy levels, Standard Proctor gives the highest OMC, and since cement hydration reaction requires much water, hence the choice. Samples for UCS test were prepared at MDD and OMC, obtained from the compaction test at respective composition of the soil and additives (cement and CCR). The UCS samples were cured for 1, 7, 14, 28 and 60 days before testing.

3 RESULTS AND DISCUSSION

PROPERTIES OF NATURAL SOIL

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 CL and A-6 according to Unified Soil Classification System (USCS) and American Association for State Highway and Transportation Officials (AASHTO) respectively. The result indicates that the geotechnical properties of the soil fall below the standards, recommended for most civil engineering construction works, especially pavement structures (Osinubi and Medubi, 1997) and therefore need stabilization.

Table I: Geotechnical properties of natural soil

Property	Quantity
Fraction passing BS No 200 sieve (%)	48
Natural Moisture Content (%)	6.90
Specific Gravity	2.69
Liquid Limit, (%)	39
Plastic Limit (%)	16
Plasticity Index (%)	23
AASHTO Classification	A-6
USCS Classification	CL
MDD (Mg/m^3)	1.86
OMC (%)	12
UCS (kN/m^2)	57.92
24hr soaked CBR (%)	28
Colour	Reddish brown

COMPACTION CHARACTERISTICS

Variations of compaction characteristics with increase in dosage of CCR at various percentages of cement are presented in Figures 1 and 2 for MDD and OMC respectively. From Figure 1, it can be observed that MDD increase with increase in cement content. This is as a result of the relative higher density (specific gravity of 3.14) of cement as compared to that of the soil (2.69). At constant percentage dosage of cement, MDD of the stabilized soil decreased with increase in percentage of the CCR. This again, can be attributed to the relatively lower specific gravity of the additive (CCR) as compared to those of the soil and cement. With the soil and cement having specific gravities of 2.69 and 3.14, as compared to that of the CCR (2.25), increase in percentage composition of CCR in the soil-cement mixture will result to reduction in the net density of the composite material. This trend of MDD variation is similar to that reported by Isah and Sharmila (2015), when CL soil was treated with CCR. Results similar to this were also reported by Alhassan and Alhaji (2007), Joel and Agbede (2011), Elsharief*et al*. (2013), Roy (2014), Horpibulsuk*et al*. (2014), Ige and Ajamu (2015), Ogunribido (2018) and Pereira *et al*. (2018).

From Figure 2, it is observed that OMC increase with increase in percentage composition of cement, which as a result of the need for water for hydration of cement. At constant dosage of cement, OMC is also observed to increase with increase in percentage of CCR. This again is attributed to the reaction between the soil-cement and CCR. While CCR helps in flocculating clay particles in the soil, a phenomenon typical, when lime is used to improve soil, cement hydration produces cementatious materials, binding the soil-additives mass. These reactions require water to proceed, hence increase in the OMC. This trend of OMC variation is also similar to that reported by Isah and Sharmila (2015), Alhassan and Alhaji (2007), Joel and Agbede (2011), Elsharief*et al*. (2013), Roy (2014), Horpibulsuk*et al*. (2014), Ige and Ajamu (2015), Ogunribido (2018), Pereira *et al*. (2018) and Akinwumi*et al*. (2019).

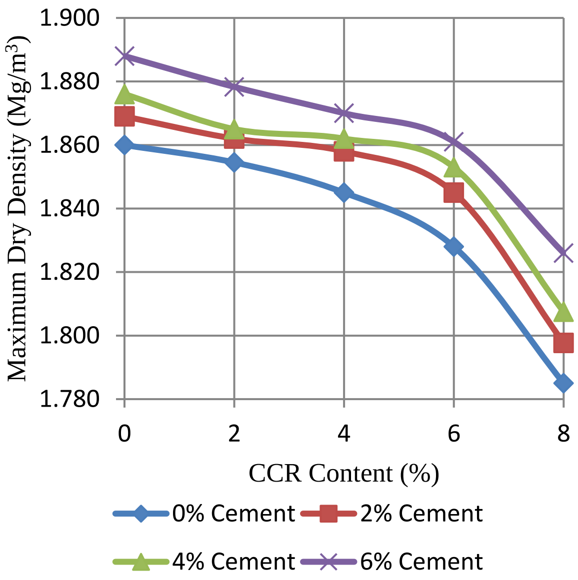

Figure 1: Variation of MDD with increase dosage of cement and CCR

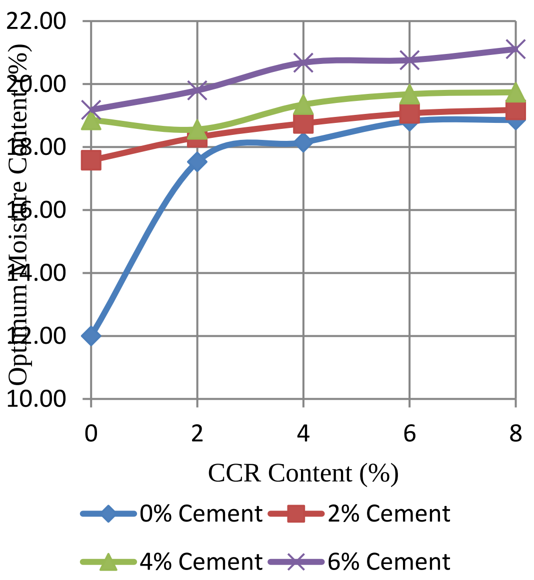

Figure 2: Variation of OMC with increase dosage of cement and CCR

Unconfined Compressive Strength

Variations of Unconfined Compressive Strength (UCS) with percentage dosage of both cement and CCR are presented in Figures 3, 4, 5, 6 and 7 for 1, 7, 14, 28 and 60 days curing periods respectively. From the figures, it is observed that as cement content increase, UCS of the treated soil increased. At constant percent content of cement, UCS increased to their maximum values at 4% CCR content. Also, observation and comparison of the figures revealed that as the curing period increases, unconfined compressive strength of the treated soil increased. This noticeable increase in unconfined compressive strength of the treated soil, with increase in curing time is attributed

to the progress in hydration reaction of cement. Addition of CCR initially increased the UCS, because of the modification effect of Ca(OH), which is a typical process when lime is used to treat clayey soil. This modification process manifests itself by flocculating the clay particles in the soil to make them behave as granular once.Since cement hydration proceed, better in granular soil than soil, this flocculation, coupled with cementation by products of hydration, results to increase in strength (UCS). The drop in strength after 4% CCR content can be attributed to excessiveness in mixtures of Ca(OH), from the CCR and that liberated by cement hydration reaction. This excessive Ca(OH) within the mass of the mixtures create barrier that hinders bonding of the soil particles by the formed cementitious materials, resulting to decrease in strength.

Since cement hydration reaction is relatively a time based reaction, the strength of the mixtures increased with curing period. It can be observed that after 1 day curing period (Figure 3), only mixtures with 4 and 6% cement at 4% CCR recorded UCS values above the 1710 kN/m^2 recommended by TRRL (1977) and 1750 kN/m^2 reported by Khanna and Justo (2011), as criteria for design cement content, considered adequate for soil-cement composite as base course material for highway pavements with light to medium traffic. After 7 days curing period (Figure 4), mixture with 2% cement met this requirement at 4% CCR. Although, mixtures with higher cement contents also satisfied this criteria, even at relatively earlier curing period, mixture with 2 and 4% cement and CCR respectively, will be more cost effective. Saidu*et al*. (2020) also reported this combination (2 and 4% cement and CCR contents respectively), as optimal for treatment of full depth reclaimed surface-dressed pavement for road base.

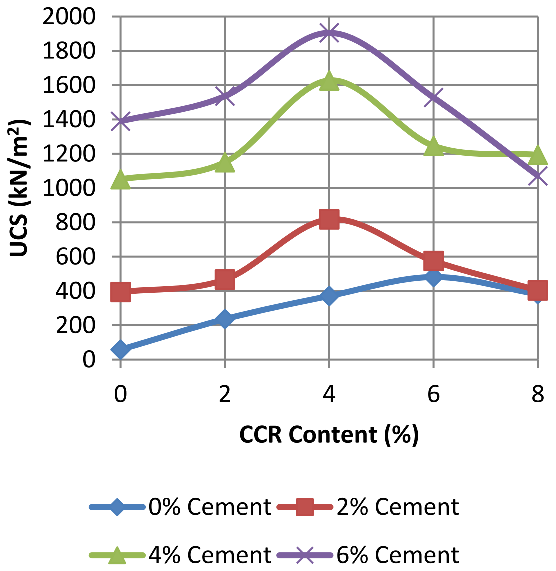

Figure 3: Variation of unconfined compressive strength with various dosages of cement and CCR after 1 day curing period

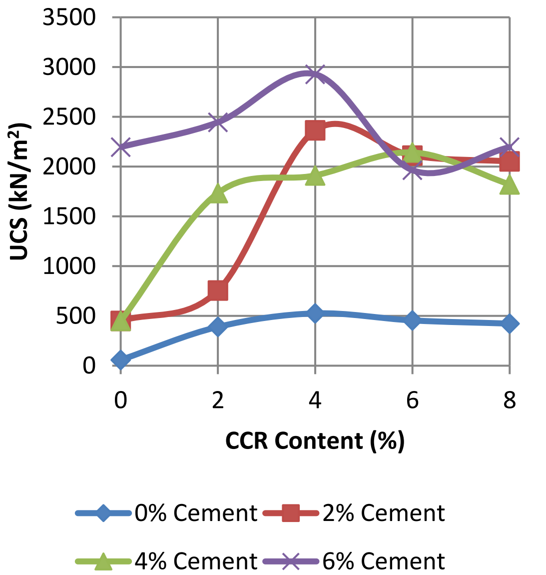

Figure 4: Variation of unconfined compressive strength with various dosages of cement and CCR after 7 days curing period

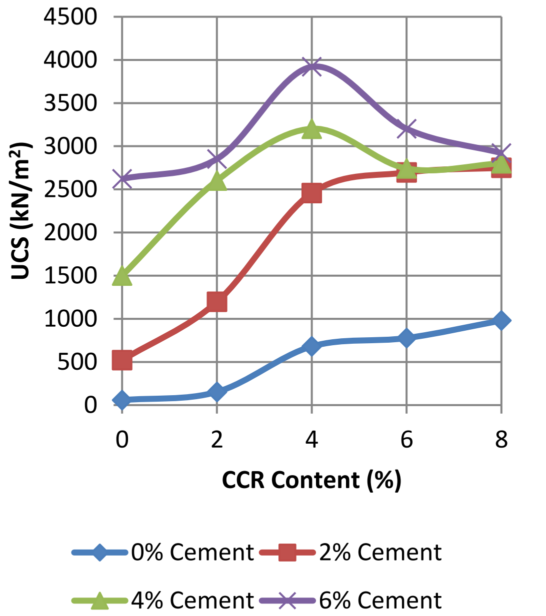

Figure 5: Variation of unconfined compressive strength with various dosages of cement and CCR after 14 days curing period

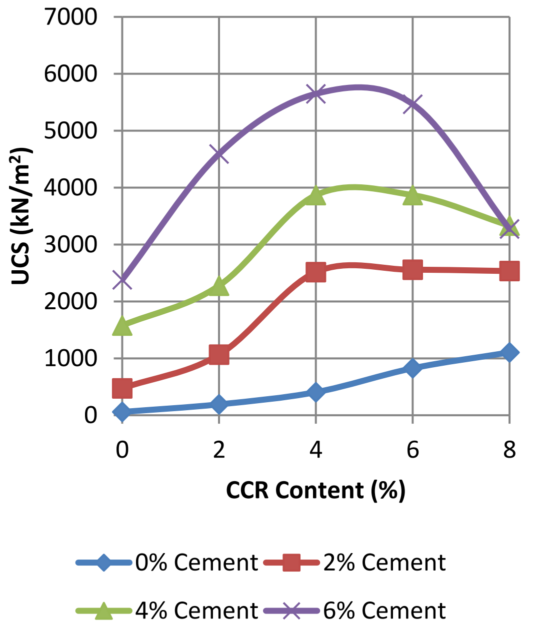

Figure 6: Variation of unconfined compressive strength with various dosages of cement and CCR after 28 days curing period

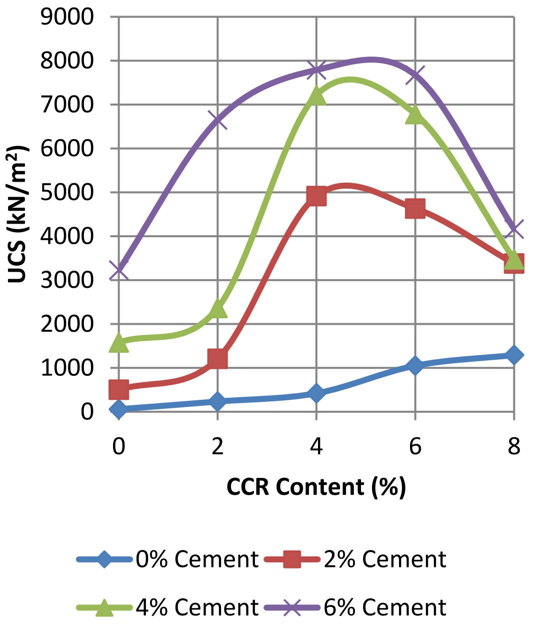

Figure 7: Variation of unconfined compressive strength with various dosages of cement and CCR after 60 days curing period

4 CONCLUSION

From the study, the following conclusion is drawn:

The lateritic soilwas classified under CL and A-6, according to Unified Soil Classification System (USCS) and American Association for Highway and Transportation Officials (AASHTO) respectively.

There was a general increase in maximum dry density of the treated soil with increase in dosage of cement, while at constant cement content, the maximum dry density of the mixtures was observed to decrease with increase in CCR content.

Optimum moisture contentof the treated soil increased with increase in dosage of both cement and CCR.

Unconfined compressive strength was observed to increase as cement content increase, while at constant cement content, UCS increased to their maximum values at 4% CCR content, after which the strength decreased. This indicates that 4% CCR content is the optimal.

After 7 days curing period, mixture with 2 and 4% cement and CCR respectively, satisfied the 1710 kN/m^2recommended by TRRL (1977) and 1750kN/m^2 reported by Khanna and Justo (2011), as criteria for design cement content, considered adequate for soil-cement composite as base course material for highway pavements with light to medium traffic.

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