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Sustainable Use of Calcium Carbide Residue admixed with Zeolite for Stabilization of Clay Soil Using Unconfined Compressive Strength (UCS) as Evaluation Criteria

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ABSTRACT

Wastes that have cementitious properties can become a useful source of cheap materials for soil improvement, thereby reducing the cost of construction projects on sites that have unsuitable soils. This research work investigated the sustainable use of calcium carbide residue (CCR) admixed with zeolite to a stabilize clay soil. Tests to determine the index properties and unconfined compressive strength (UCS) of the natural soil and its stabilization with varying percentages of CCR and Zeolite were carried out. The outcome showed that the clay mixed with zeolite alone resulted in to gradual increase in UCS after 1-day curing from 54kN/m2 at 0% zeolite to 94kN/m2 at 6% zeolite. This represents 74% increase in strength. With addition of 5% CCR after 1 day curing, the UCS increased from 378kN/m2 at 0% zeolite to maximum of 579kN/m2 at 2% zeolite after which the values reduced to 371kN/m2 at 6% zeolite. This also represents 53% increase in strength which must have been generated from the reaction between zeolite and CCR and clay soil. On variation of the CCR and Zeolite percentages, the UCS increase was maximum at 146, 873 and 1460kN/m2 for 0, 5 and 10% CCR respectively with the optimal zeolite occurring at 4% zeolite. This shows that addition of CCR and Zeolite are viable additives for stabilization of clay soils.

Keyword: Calcium Carbide Residual, Soil Stabilization; Unconfined Compressive Strength; Waste materials; Zeolite.

1 INTRODUCTION

The increasing population of the world, especially developing nations has led to increasing demand for roadways, railways, housing facilities and other infrastructures (Isah and Sharmila, 2015). Soil with higher stability is required to bear the weight of these structures; generally speaking, the stability of any construction related structure indirectly or directly depends on the soil stability. Expansive soils swell or increase in volume in monsoon seasons on imbibition of water, and shrink or reduce in volume because of evaporation of water in dry seasons. As a result of the alternate swelling and shrinkage of expansive soils, structures such as foundations, pavements and residential buildings etc. constructed on it experienced severe damage. The objective of expansive soil stabilization may be to stabilize volume change characteristics, modify plasticity and improve workability, or modify plasticity and volume change characteristics while substantially improving strength. Generally, engineers aim to achieve the last one because the subgrade layer must not only be volumetrically stable, but must also support traffic or building loads. Targeting strength gain is also one of the reasons why a particular method of soil improvement is adopted. Unlike manufactured products, some soils have to be improved to meet the engineering specifications for the intended use, this is because they come with some deficiencies due to geologic processes the soil have undergone during the formation (Jayanthi and singh, 2016). The issue then becomes what method to be used to achieve stabilization and how to validate stabilization in clay soils. Chemical stabilization as an extensively used soil improvement technique for expansive soil has the advantage of achieving adequate strength over a short period of time. For the past several years, researchers have recognized the use of locally available materials which are cost effective, available from industrial and agricultural wastes to improve the properties of expansive soils with the aim to reduce stabilization costs. The most effective chemical for soil stabilization was identified to be cement. However, the cost of its production and emission of carbon dioxide related to its production made it expensive for use as stabilizer for soils. Waste materials, such as fly ash, rice husk ash, sawdust ash, sugarcane straw ash, and coconut shell ash etc has been widely applied in practice in addition to cement and lime (Horpibulsuk et al., 2011). $Ca(OH)_2$ rich waste material like CCR together with pozzolanic materials such as Fly ash, rice husk ash, biomass ash etc have been widely used to completely replace cement in stabilization of expansive soils (Kampala *et al*, 2013). Calcium carbide residue (CCR) is a by-product of the acetylene production process that contains mainly calcium hydroxide $Ca(OH)_2$. When compared to hydrated lime, CCR has similar chemical and mineralogical compositions.

Several researches have been conducted to evaluate the potential of CCR for stabilization of 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.

Zeolite has also been used as pozzolana to prolong the strength increase in stabilized soils. The work of Shi (2013), Salamatpoor *et al.*, (2018), Yadav and Kushwaha (2018), Turkoz and Vural (2013) and Mola-Abasi and Shooshpasha (2016) are clear indications that zeolite has the potential to be used as pozzolana which can only form cementitious compounds in the presence of another chemical.

From equation (1) 64g of calcium carbide (CaC_2) provides 26g of acetylene gas (C_2H2) and 74g of CCR in terms of $Ca(OH)_2$. The study of soil stabilization with a mixture of CCR and pozzolana (e.g. zeolite) materials is an engineering, economic, and environmental challenge for geotechnical engineers and researchers. Pozzolanic reaction, which is time dependent, involves interactions between soil silica and/or alumina and cement to form various types of cementitious products, thus enhancing the strength. A pozzolan is a siliceous or siliceous/aluminous material that, when mixed with cement and water, forms a cementitious compound. Zeolites as a pozzolan are aqueous aluminum silicates containing alkali and alkaline earth elements. Their structure is made up of a framework of SiO_4 and AlO_4 tetrahedrons linked to each other's corners by sharing oxygen atoms. The substitution of Si^{4+} by Al^{3+} in tetrahedral sites results in more negative charges and a high cation exchange capacity (Akbar, 1999). The use of natural zeolites in industrial processes dates back to the 1940s. Zeolites have been used in many applications because they can function as a molecular sieve owing to their ion-exchange ability, adsorption and absorption properties, crystal structure (Mier et al., 2001) and silica content, as well as their lightweight, porous structures (Guney and Koyuncu , 2002).

This study focused on the sustainable use of Calcium carbide residue admixed with Zeolite for stabilization of clay soil using Unconfined compressive strength (UCS) as evaluation criteria.

2 MATERIALS AND METHODS

2.1 MATERIALS

Soil sample: The soil sample used in this study is clay collected behind the Library complex of Niger State Polytechnic, Zungeru of Niger State, Nigeria. The clay soil was air-dried and pulverized as specified in BS 1377 (1992).

Calcium carbide residue: The CCR used in this study was collected from local welders at

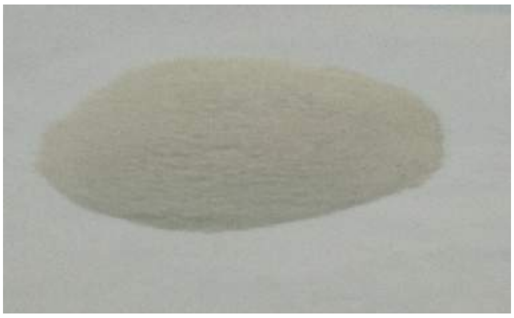

Figure 1: Calcium carbide residue

Keteren-Gwari mechanic site, Minna, Nigeria. The sludge was then air-dried, crushed and sieved through British Standard sieve with 0.075mm aperture before use.

Zeolite: The zeolite used in this study was purchased from a commercial market in Kaduna in Kaduna State of Nigeria.

Figure 2: Zeolite sample

The zeolite was observed to be powdered smooth and was used as supplied.

2.2 METHODOLOGY

The method used in this study involves characterizing the untreated clay soil by determining its index properties. Atterberg limit tests were conducted on the clay mixed with 0, 5 and 10% CCR which was admixed with 0, 2, 4 and 6% zeolite. This is to evaluate the effect of zeolite on the Atterberg limits of the CCR modified clay soil. These mixtures were then compacted at standard proctor compaction energy level to determine the effect of zeolite on the compaction characteristics of CCR modified clay soil. All tests on the untreated clay soil was carried out according to the method highlighted in BS 1377 (1992). Meanwhile, for all these tests, appropriate amount of water was mixed with the clay mixed with appropriate chemicals, kept in a polythene leather and allowed for 24 hours before conducting the tests.

Figure 3: Compaction test on the clay soil

3 RESULT AND DISCUSSIONS

Index Properties

The result of the index properties of the untreated clay soil is shown on table 1.

Table 1: Summary of Index Properties of the clay

Description	Quantity
Sand	32.2
Silt	29.2
Clay	38.6
Liquid limit	44.8
Plasticity Index	19.4
Specific Gravity	2.76
MDD (Standard Proctor compaction)	1.815
OMC (Standard Proctor compaction)	18.8
AASHTO soil classification	A-7-6
Unified Soil classification	CL

From the table above, the clay soil classified under clay of low plasticity (CL) according to unified soil classification system. This clay can only be used for any component of a road structure when modified to increase its workability.

Effect of Zeolite on UCS of CCR Stabilized Clay

The effect of zeolite on CCR stabilized clay soil is shown in figures 4 and 5 for 1 day and 7 days curing. The clay mixed with zeolite alone resulted in to gradual increase in UCS after 1-day curing from 54kN/m2 at 0% zeolite to 94kN/m2 at 6% zeolite. This represents 74% increase in strength. With addition of 5% CCR after 1 day curing, the UCS increased from 378kN/m2 at 0% zeolite to maximum of 579kN/m2 at 2% zeolite after which the values reduced to 371kN/m2 at 6% zeolite. This also represents 53% increase in strength which must have been generated from the reaction between zeolite and CCR and clay soil.

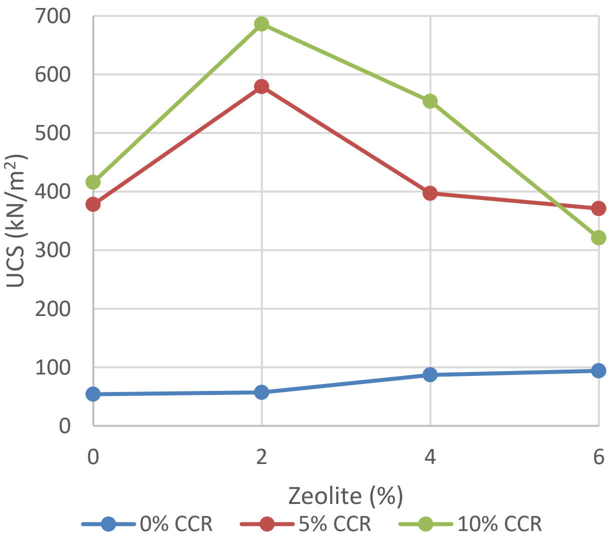

Figure 4: variation of UCS with zeolite for 1 day curing

At 10% CCR, the UCS increased from 416kN/m2 at 0% zeolite to maximum of 686kN/m2 at 2% zeolite after which the values reduced to 321kN/m2 at 6% zeolite which represents 65% increase in strength. The optimal zeolite that gave the highest UCS occurred at 2% zeolite addition.

For 7 days curing with 0% CCR, the UCS increased from 54kN/m2 at 0% zeolite to 146kN/m2 at 6% zeolite which represents 170% increase in strength. The result of UCS on addition of 5% CCR revealed that the values increased from 398kN/m2 at 0% zeolite to maximum of 873kN/m2 at 4% zeolite after which the values reduced to 606kN/m2 at 6% zeolite. This represents 119% increase in UCS. The UCS results on addition of 10% CCR showed that the UCS increased from 340kN/m2 at 0% zeolite to maximum of 1460kN/m2 at 4% zeolite after which the values reduced 1043kN/m2.

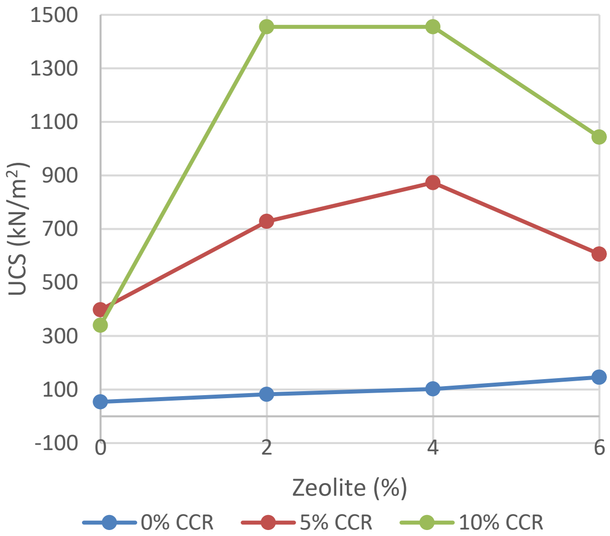

Figure 5: variation of UCS with zeolite for 7 days curing

These values represent 329% increase in strength with optimal zeolite occurring at 4% zeolite addition.

3 CONCLUSION

The clay used in this study classified as clay of low plasticity based on unified soil classification system.

For 1 day curing, the UCS increased to maximum of 94, 579 and 686kN/m2 for 0, 5 and 10% CCR respectively with the optimal zeolite occurring at 2% zeolite addition.

For 7 days curing however, The UCS increased to maximum of 146, 873 and 1460kN/m2 for 0, 5 and 10% CCR respectively with the optimal zeolite occurring at 4% zeolite.

Addition of CCR and Zeolite are viable additives for stabilization of clay soils.

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