1st International Civil Engineering Conference (ICEC 2018)
Department of Civil Engineering
Federal University of Technology, Minna, Nigeria

CEMENT STABILIZATION OF BLACK COTTON SOIL USING RICE HUSKASH AND PROMOTER

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ABSTRACT

Black cotton soils exhibit high swelling and shrinkage on the absorption or depletion of moisture and are the main cause of the many problems such as pavement failure, foundation cracks, and excessive settlement associated with the soil. Although poor and undesirable for engineering purposes, black cotton soil could be improved to meet engineering specifications by stabilization processes. The aim of this paper is to evaluate the effect of RHA and promoter on the compressive strength of black cotton soil. Natural black cotton soil was stabilized with 0% cement, 0% RHA, 0% promoter; 0% cement, 1% RHA, 0.3% promoter; 0% cement; 2% RHA, 0.6% promoter; 0% cement, 3% RHA, 1% promoter continuously up to 1% and 2% cement replacement and cured for a period of 1, 7, 14, 28, and 60 days. To evaluate the strength of the natural soil, various tests were carried out in the laboratory such as moisture content, sieve analysis, Atterberg limit, specific gravity and compaction (OMC and MDD).
The experimental results showed that unconfined compressive strength (UCS) values increased with higher compactive effort, RHA and promoter content. The UCS increased from 340KN/m2 to a maximum strength value of 582kN/m2 at 3% cement, 3% RHA and 1% promoter for specimens compacted at the West Africa Standard energy level at 60 days curing period, which implies that stabilization of black cotton soil can be improved with increased amount of RHA and promoter.

Keywords: Black Cotton Soil, Promoter, Rice Husk Ash, Stabilization, Unconfined Compressive Strength.

1.0 INTRODUCTION

Black cotton soils are expansive and inorganic clays of medium to high compressibility characterized by high shrinkage and swelling properties which form a major soil group in Nigeria (Adeniji, 1999). They exist majorly in arid and semi-arid regions of the tropical/temperate zones marked with dry and wet seasons; and with low rainfall, poor drainage and exceedingly great heat. The name black cotton is derived from the fact that cotton plant thrives on it.

In Nigeria, black cotton soils are vastly available in the North-Eastern part lying within the Lake Chad Basin and the upper Benue trough which covers a wide area extending North-East of the Jos Plateau. They are problematic soils (Adesunloye, 1987).

a. Dry state b. Wet state
Plate I: Black cotton soil in different forms

Black cotton soils are susceptible to detrimental moisture and appear firm in its dry state and demonstrate tremendous swelling when wet. Cracks measuring about 70 mm wide and over 1 m deep have been observed and may extend up to 3 m or more in cases of high deposits (Adeniji, 1999).

Plate II: Horizontal crack on a pavement constructed on black cotton soil

Black cotton soils are greyish to blackish in colour, possess pure clay particles with about 85-100% passing through sieve 75µm and are rich in montmorillonite which is responsible for their shrink-swell behaviour (Adesunloye, 1987). The high shrinkage and swelling of these soils are especially troublesome to pavement subgrades and has also caused a lot of problems for engineering works such as foundation cracks, severe structural damage, heaving and cracking of sidewalk (Osinubi, 1997). Although poor and undesirable for engineering applications, black cotton soil can be improved to meet standard specification by stabilization processes (Ola, 1983).

Soil stabilization is the improvement of the original soil properties to meet specific engineering requirements (Arora, 2011). Objectives of soil stabilization include: improvement of the strength of the soil and bearing capacity, reduction of compressibility and volume instability, decrease permeability and water absorption, and to increase the durability under varying moisture content. Soil stabilization can be mechanical or chemical. Mechanical stabilization is achieved by altering the properties of a soil and includes controlled grading of the coarse aggregate, fine aggregate, silt and clay correctly proportioned and fully compacted. Chemical stabilization depends on the chemical reaction between stabilizers such as cement, lime, bitumen, Rice Husk Ash or other agents and soil minerals to achieve the desired result. Brooks (2009) stabilized black cotton soil with rice and husk ash and fly ash and concluded that unconfined compressive strength increase by 97% with increase Rice Husk Ash.

For decades, the stabilization of soil with cement, lime and bitumen have successfully been experimented and used extensively in the USA, Europe, India and Africa. However, chemical conditions of black cotton soil inhibits the normal hardening of cement, lead to loss of durability and high construction cost, while bitumen and lime have significant effect on vegetation and the environment (IRC, 1973). This phenomenon has led to the growing research on the use of cheap and readily available industrial and agricultural waste materials such as rice husk ash and promoter for the stabilization of soils.

In Nigeria, about 2 million tons of rice is produced while about 96, 600 tons was produced in Niger State in the year 2000 alone (Oyetola and Abdullahi, 2006). The rice husk generated does not degrade easily and their disposal has had a devastating effect on the natural environment. Rice Husk Ash (RHA) is an agro-waste obtained from burning the protecting outer cover of rice husk which is about one-fifth (20%) by weight of the harvested rice. It contains about 50% cellulose, 25-30% lignin, and 85-90% of silica which makes it a superb replacement of silica because they contain lime-pozzolana particles (Aparna, 2014). The high angularity and friction angle (up to 530) of RHA contribute to excellent stability and load bearing capacity (Raj, 2016). When rice husk is burnt, rice husk ash is generated. Rice husk ash when used for cement-based stabilization increases calcium silicate hydroxide and decreases calcium hydroxide which leads to high strength, reduced efflorescence, reduced sulphate and chemical attacks. Promoters are chemical additives that speed up the rate of chemical reaction in the stabilization process and lead to improvement of mechanical strength. In other to improve the strength, durability and other engineering properties of soil-cement, small quantities of promoter have always been used. The addition of 1% to 4% by weight of hydroxides and various salts would greatly increase compressive strength (Lambe and Moh 1958). It is worthy to note that most promoters and agricultural wastes posses pozzolanic properties, that is, having cementitious tendencies on exposure to moisture (O'Flaherty, 1988). Pozzolanas are, therefore, siliceous and aluminous material which themselves possess little or no cementitious value but, will, in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties (Robert, 1993). Sodium silicate has often been used as a pozzolana for replacement of rice husk ash. However, sodium silicate is expensive and difficult to handle which is why a cheap and easy to handle promoter (calcium chloride and sodium hydroxide) was explored in this research as replacement for rice husk ash chemically react with calcium hydroxide at ordinary temperature, to form compounds possessing cementitious properties. Sodium silicate has often been used as a pozzolana for replacement of RHA. However, sodium silicate is expensive and difficult to handle, which is why a cheap and easy to handle promoter (calcium chloride and sodium hydroxide) sorted and used in this research as replacement for RHA.

2.0 MATERIALS AND METHODOLOGY

2.1 Materials

The materials used in this research are black cotton soil, rice husk ash, promoter (calcium chloride and sodium hydroxide) and distilled water

2.1.1 Black Cotton Soil

The black cotton soil sample was collected from a borrow pit in Gwagwalada, FCT, Abuja. Gwagwalada is located at an elevation of 210m above sea level and has a latitude of 8°56'29" N and a longitude of 7° 5'31" E on the Nigerian geographic map (FCDA, 2015). It was collected by method of disturbed sampling in conformity with BS 1377 (1992) using the hand carved method at depths of 0.50 to 1.0m below the ground surface to avoid organic matter. The sample was then wrapped in polythene bags to avoid loss of moisture and transported to the Civil Engineering Laboratory, Federal University of Technology, Minna. At the laboratory the natural soil sample was air–dried and pulverized using a hammer and classification tests such as natural moisture content, sieve analysis, Atterberg limit and compaction were conducted.

2.1.2 Rice Husk Ash

The Rice Husk Ash was obtained locally from Minna town. Raw husk of parboiled rice was collected from local milling plants and burnt for 7 days in an open place without the control of heat (mass burning and ashing). The ash was then transported to the laboratory and sieved through sieve 75µm size and then stored in air-tight polythene bags to avoid any form of hydration. Dangote cement brand of grade 32.5 was used as the main binder in conformity with BS EN 197-1:2000.

2.1.3 Promoter

The promoter (NaOH and $Cacl_2$) was sourced locally in Minna town. The promoter was obtained in a solid form and dissolved in 1000ml of water to produce 1.0 molar concentration of calcium chloride and 1.5 molar concentration of sodium hydroxide.

2.1.4 Water

The water used was clean and portable water in accordance with BS EN 1008:2002, and was obtained at the permanent site of the Federal University of Technology, Gidan Kwano, Minna. Clean and portable water is of great importance in the stabilization process because the presence of impurities in water can affect the cementitious process and reduce the compressive strength and durability of the stabilized soil.

2.2 Methodology

The laboratory test performed on the soil in order to determine its engineering properties were in accordance with BS 1377 (1990) and BS 1924 (1990). The following tests were performed:

i. Natural moisture content
ii. Specific gravity
iii. Particle size distribution
iv. Atterberg limit (Liquid limit and Plastic limit)
v. Compaction (Standard Proctor and West Africa Standard Energy levels)
vi. Unconfined compressive strength
vii. X-ray Fluorescence
viii. X-ray Diffraction
ix. Screening electron microscopy

The unconfined compressive strength (UCS) was determined in accordance with BS 1377 (1990). A dried soil, mixed with different percentages of the stabilizers by using predetermined weight of soil obtained from the density-volume relationship, was compacted in a 1000 cm^3 cylindrical mould using West Africa Standard and Standard Proctor energy levels after the addition of water at optimum moisture content. The compacted samples were then collected from the mould and placed in sealed transparent plastic bags and cured inside moist river sharp sand for 1, 7, 14, 28, and 60 days. The unconfined compressive strength of the cured samples were determined by placing them in platens of a universal testing machine and then crushed to failure.

3.0 RESULTS AND DISCUSSION

3.1 Geotechnical Properties of Black Cotton Soil

The results of the preliminary tests conducted for identification and the determination of the properties of the natural soil are presented in Table I while the particle size distribution curve is shown in Figure 1. The soil is classified by AASHTO as A-7-6 (13) or CH in the unified soil classification system is greyish brown in colour and its geotechnical properties falls below the standard recommended for most civil engineering construction works especially highway construction (Osinubi and Medubi, 1997).

Table I: Geotechnical properties of natural black cotton soil

Property	Quantity
Percentage passing BS No 200 sieve	68.5
Moisture Content (%)	35.06
Liquid limit (%)	63.00
Plastic limit (%)	28.37
Plasticity Index (%)	34.63
Specific Gravity	2.66
AASHTO Classification	A-7-6 (13)
USCS	CH
NBRRI Classification	High swell potential
Maximum Dry Density (g/cm^3) Standard Proctor	1.6258
Maximum Dry Density (g/cm^3) West Africa	1.7928
Optimum Moisture Content (%) Standard Proctor	24.5
Optimum Moisture Content (%) West Africa	20.95
Colour	Greyish black
Dominant clay mineral	Montmorillonite

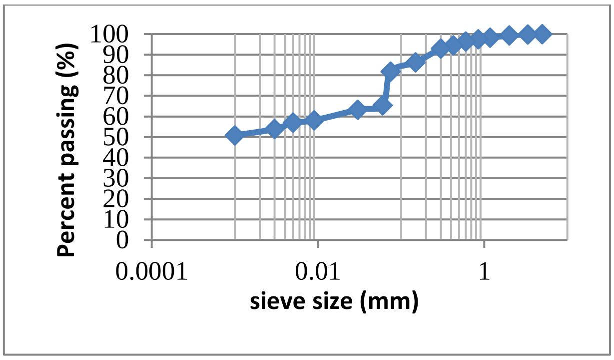

Figure 1: Particle size distribution curve of the natural black cotton soil

3.2 Chemical Composition of RHA

The oxide composition of the RHA used in this study was obtained through a Compact Energy Dispersive X-ray Spectrometer Method (Mini Pal), designed for elementary analysis of a wide range of samples. The test was carried out at the Department of Civil Engineering, Kaduna Polytechnic. The chemical composition is as shown in Table 3.2

Table II: Chemical composition of the Rice Husk Ash

Constituent	Composition%
SiO_2	68.6
Al_2O_3	4.9
Fe_2O_3	0.95
Ca	1.36
MgO	1.81
Loss in Ignition (LOI)	17.78

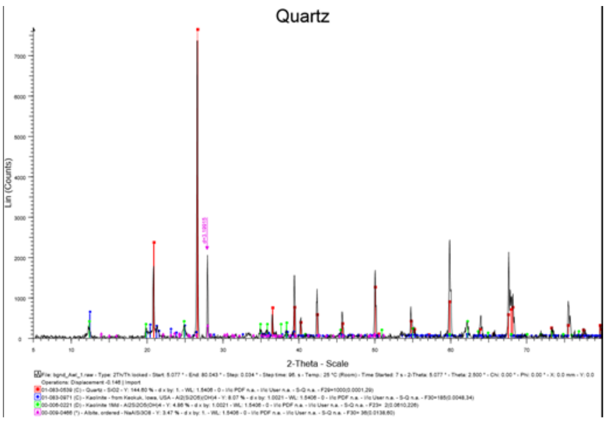

Figure 2: XRF of the black cotton soil

The percentages of SiO_2, Al_2O_3, and Fe_2O_3 combine is more than 70 thus, the Rice Husk Ash falls under class C according to ASTM C618 classification of Pozzolanas, which implies it is a good pozzolan and would help mobilize the CaOH in the soil to form cementitious compounds.

3.3 Unconfined Compressive Strength (UCS)

The main test recommended for use to determine the required amount of additive to be used in the stabilization of soils is the unconfined compressive strength test (Singh, 1991). A total of 128 samples mixed with different proportions of cement, rice husk ash and promoter were tested. The effects of the different mix and curing period of 1, 7, 14, 28 and 60 days on the soil samples compacted at the Standard Proctor and West Africa Standard energy levels were studied and their unconfined compressive strength variations are shown in Figures 2 to 8.

The Variation of UCS with promoter at various percentage of RHA for 1 day curing period is shown in Figure 2 to 11. From the figures, it is observed that there is an increase in UCS as the percentage content of promoter and RHA increases, while UCS gradually decreases in value as the percentage content of cement increases. For specimens compacted at the Standard Proctor and WAS energy levels, UCS values increased from 20 KN/m^2 to peak value of 233 KN/m^2 at 0.3% promoter and 1% RHA and 102 KN/m2 to peak value of 389 KN/m2 at 1% promoter and 3% RHA respectively. The increases in UCS can be attributed to ion exchange at the surface of clay particles as the Ca^{2+} in the RHA and promoter reacts with the lower valence metallic ions in the clay microstructure which results in agglomeration and flocculation of the clay particles which contribute to the increase in strength (Osinubi (2001). The reduction in UCS at 2 % cement content may be due to excess Ca^{2+} that could not be neutralized therefore forming weak bonds between the soil and the cementitious compounds formed. Generally, UCS values were relatively significant for specimens compacted at WAS energy levels.

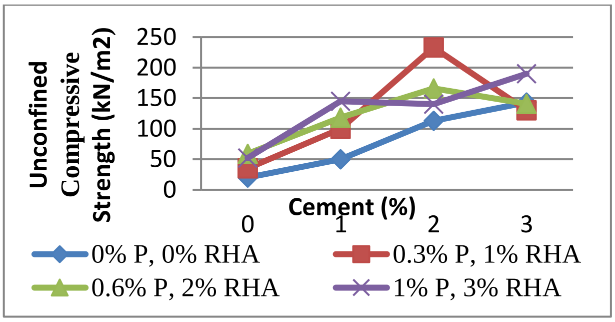

Figure 2: Variation of UCS with cement at various percentages of RHA and promoter for 1 day curing period (Standard Proctor Compaction)

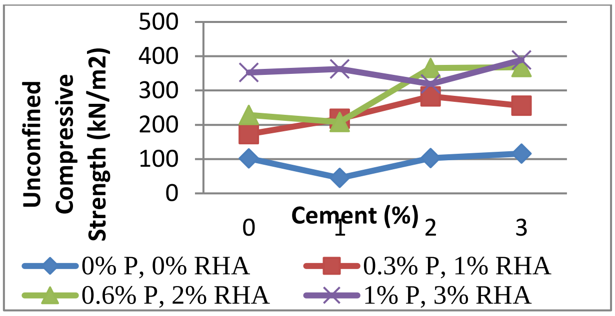

Figure 3: Variation of UCS with cement at various percentages of RHA and promoter for 1 day curing period (WAS Compaction)

Variations of UCS with promoter at various percentage of RHA for 7 days curing period are shown in Figure 4 and 5. From this figures, it was observed that UCS values gradually decreases with increase in promoter, increases with reduction in RHA. UCS decreased from 170 KN/m2 to 127 KN/m2 at 1% cement content for specimens compacted at Standard Proctor energy level and from 450 KN/m2 to 440 KN/m2 at 2% cement,1% promoter and 3% RHA content for specimens compacted at WAS energy levels. This trend in the variation of UCS values can be attributed to the reason advanced in the case of 1 day curing period.

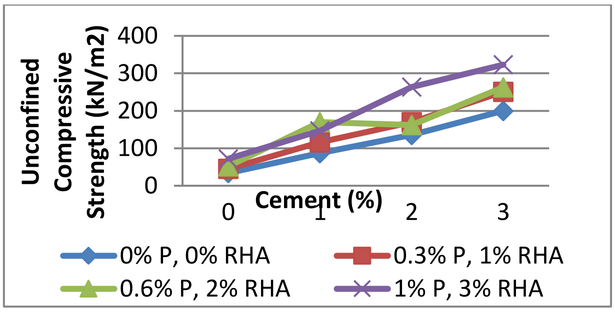

Figure 4: Variation of UCS with cement at various percentages of RHA and promoter for 7 days curing period (Standard Proctor Compaction)

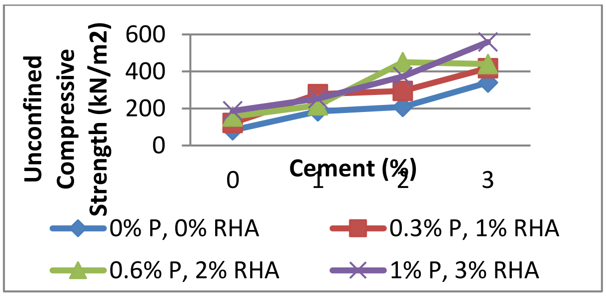

Figure 5: Variation of UCS with cement at various percentages of RHA and promoter for 7 days curing period (WAS Compaction)

Figure 6 and 7 shows the variation of UCS with cement at different percentages of RHA and promoter for 14 days curing period. From the figures, it was observed that UCS gradually decreases as percentage of cement increase, and increases with increase in promoter and RHA content. UCS reduced from 244kN/m2 to 224kN/m2 at 2% cement and increased from 117kN/m2 to a peak value of 552kN/m2 at 3% RHA and 1% promoter. Generally, UCS increases with increase in compactive effort. The increase in UCS can be attributed to cationic exchange reaction which led to flocculation and a subsequent increase in strength while the reduction was due to the deflocculation induced by the disequilibrium in the cationic exchange reaction (Butcher and Sailie, 1984)

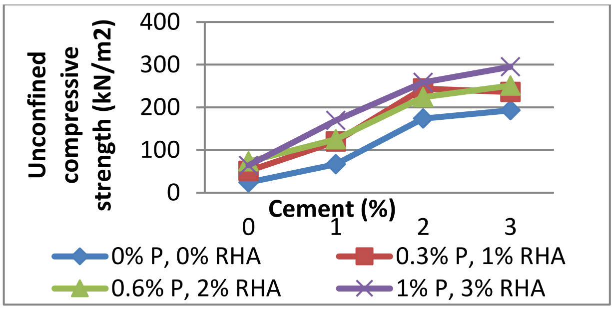

Figure 6: Variation of UCS with cement at various percentages of RHA and promoter for 14 days curing period (Standard Proctor Compaction)

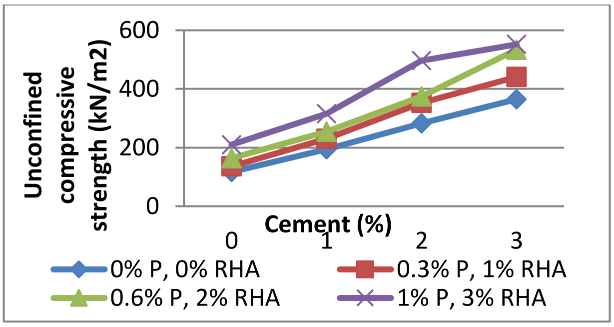

Figure 7: Variation of UCS with cement at various percentages of RHA and promoter for 14 days curing period (WAS Compaction)

The UCS of specimens compacted at the energy levels of Standard Proctor and WAS and cured for 28 days are shown in Figure 8 and 9. Generally, UCS values increased with higher compactive effort and RHA and promoter content. However, it was noted again that the increase in UCS was relatively significant for specimens compacted at WAS which recorded a sharp increase from 330KN/m2 to a peak value of 560KN/m2 at 2% cement, 3% RHA and 1% promoter. Subsequent treatment of the black cotton soil with higher dosages of cement, RHA and promoter will decrease UCS.

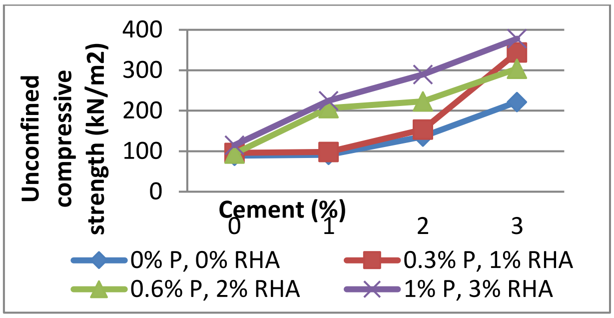

Figure 8: Variation of UCS with cement at various percentages of RHA and promoter for 28 days curing period (Standard Proctor Compaction)

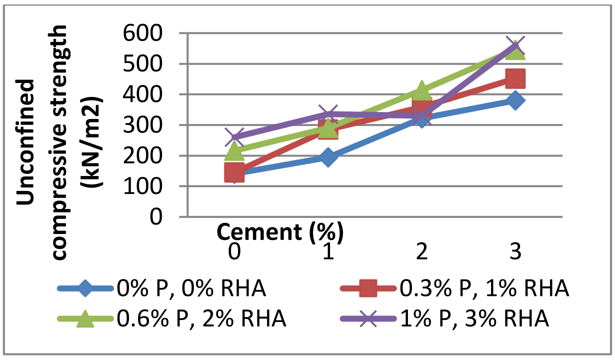

Figure 9: Variation of UCS with cement at various percentages of RHA and promoter for 28 days curing period (WAS Compaction)

The results of the unconfined compressive strength (UCS) test conducted on specimens compacted at the energy levels of Standard Proctor and WAS and cured for 60 days are shown in Figure 10 and 11. Generally, UCS values increased with higher compactive effort and RHA and promoter content. However, it was noted again that the increase in UCS was relatively significant for specimens compacted at WAS which recorded a sharp increase from 340KN/m2 to a peak value of 582kN/m2 at 3% cement, 3% RHA and 1% promoter. For specimens compacted at Standard Proctor energy level, UCS from 200kN/m2 to a peak value of 353kN/m2 at 3% cement, 3% RHA and 1 % promoter content. The increase in unconfined compressive strength is due to the production of CSH from the pozzolanic reaction between the stabilizers which is greatly enhanced by longer curing periods.

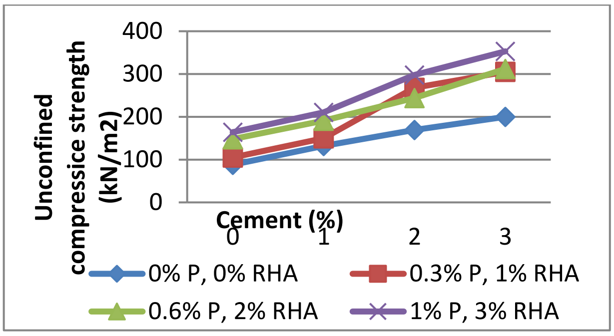

Figure 10: Variation of UCS with cement at various percentages of RHA and promoter for 60 days curing period (Standard Proctor Compaction)

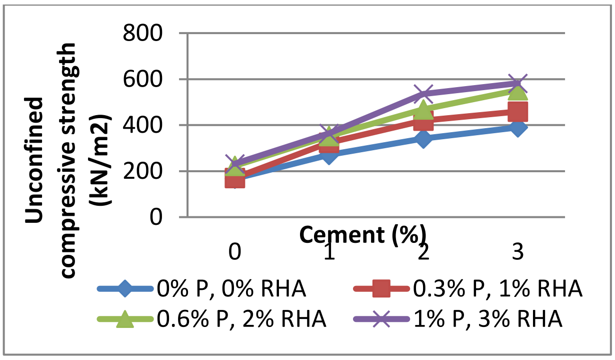

Figure 11: Variation of UCS with cement at various percentages of RHA and promoter for 60 days curing period (WAS Compaction)

4.0 CONCLUSION

The results of the laboratory investigation indicated that the inclusion of RHA and promoter in the soil improved the UCS of the soil.

- Cement was used as a chemical agent and the values of UCS gradually decrease as the proportion of cement increase and increased with increase in RHA and promoter.
- UCS increased from 340KN/m2 to a maximum strength value of 582kN/m2 at 3% cement, 3% RHA and 1% promoter for specimens compacted at WAS energy levels. For specimens compacted at Standard Proctor energy level, UCS increased from 200kN/m2 to a maximum strength value of 353kN/m2 at 3% cement, 3% RHA and 1 % promoter content.
- Maximum compressive strength is achieved for a black cotton soil stabilized with 3% cement, 3% RHA and 1% promoter. Also, UCS increases with higher compactive effort.
- The unconfined compressive strength of black cotton soil also increases with increase in curing period.

- Also, it can be concluded that increase in Rice Husk Ash and promoter increases the unconfined compressive strength and changes the mode of failure of the soil from brittle to ductile.
- Agricultural waste materials such as rice husk ash could be used effectively in civil engineering construction for soil stabilization.

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