EFFECT OF CERAMIC WASTE ON GEOTECHNICAL PROPERTIES OF CEMENT STABILIZED CLAY SOIL

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ABSTRACT

A clayey soil collected at Barkindo along Lamurde-Adamawa road, Numan Local Government area of Adamawa State, Nigeria, was stabilized with 0, 2, 4 and 6% cement which was admixed with 0, 10, 20, 30 and 40% ceramic waste dust (CWD) each. Index properties test and microstructural tests were conducted on the untreated clay soil while compaction tests and unconfined compressive strength tests were carried out on the untreated clay and clay soil admixed with varied composition of cement and CWD. Results from index properties showed that the soil was classified as clay of high plasticity based on unified soil classification system. The microstructural results revealed that the clay consist majorly of quartz, microcline, kaolinite, brushite and gypsum. The maximum dry densities (MDD) were observed to reduce with increase in cement and CWD while the optimum moisture content (OMC) reduces in the same order. The unconfined compressive strength (UCS) increased with increase in CWD for specific cement addition, to maximum of 30% CWD after which the values were observed to drop. 30% CWD is therefore the optimal CWD required for maximum UCS strength. A maximum of 2700kN/m^2 was recorded at 6% cement and 30% CWD after 90days of curing. This maximum value satisfied the requirement for a stabilized material to be used as base course material for highly trafficked roads. Significant increase in UCS was also observed with increase in curing days which signifies the existence of Pozzolanic reaction in the mixture. 30% CWD can therefore be used for effective stabilization of cement stabilized clay soil.

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ABBREVIATIONS, GLOSSARIES AND SYMBOLS

AASHTO	American Association for State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
AWC	Agricultural Waste Product
BABagasse	Ash
BCS	Black Cotton Soil
BS	British Standard
BSL	British Standard Light
CBR	California Bearing Ratio
CCR	Calcium Carbide Residue
CH	Clay of High Plasticity
CL	clayey soil
CWD	Ceramic Waste Dust
FA	Fly ash
FUTMINNA	Federal University of Technology, Minna
Gs	specific gravity
LL	liquid Limit
M	mass
m	metre
MDD	Maximum Dry Density
M_s	Mass of compacted soil
OMC	Optimum Moisture Content
OPC	Ordinary Portland Cement
TRRL	Transport and Road Research Laboratory
PI	plasticity Index

PL	plastic Limit
SEM	Scanning Electron Microscopy
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System
V_s	Volume of mould
ρ_b	Bulk density
ρ_d	Dry density
w	Natural moisture content
XRD	X-ray Diffraction
XRF	X-ray Fluorescence

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

The increasing population of the world, especially developing nations has led to increasing demand for roadways, railways, housing facilities and other infrastructures. 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 (Balarabe and Mary, 2015).

For the past several years researchers have recognized the use of locally available materials which are cost effective and available from industrial and agricultural wastes to improve the properties of expansive soils. This is aim at reducing stabilization costs, related to conventional stabilizing agents such as cement as well as the emission of CO_2 related to cement manufacturing process stability (Balarabe and Mary, 2015).

Soils used as materials for earthworks in foundation of road pavements play an important role in ensuring the stability and durability of roads. Suitable natural soils are, however, getting fast depleted; making some road pavement designers and constructors favour the stabilization of in situ soils with poor engineering properties over their replacement with suitable materials in order to reduce road construction costs (Isaac *et al.,* 2019; Pratico and Puala, 2012; Pratico*et al.,* 2011). A soil can be said to be unsuitable for use as earthwork material if it is difficult to work with (that is, it has a high plasticity), has low strength, has a tendency to retain moisture and a high natural moisture content (Akinwunmi, 2014).

Soil stabilization means the improvement of the stability or bearing power of a deficient soil by the use of compaction; proportioning and the addition of suitable stabilizers or admixtures. Soil stabilization includes chemical, mechanical, physico-chemical methods to improve the soil properties.This process basically involvesthe excavation of soil. These are the techniques for improvingsoil deficiency at shallow depth as in pavements. Stabilization method may be categorized as two main types: (a) improvement of soil properties of existing soil with-out using any type of admixture; and (b) improving the properties with admixtures(Neeraj and Ahirwar, 2014).

Expansive soils swell or increase in volume in when in contact with water and shrink or reduce in volume because of evaporation of water clearing the dry seasons (Balarabe and Mary, 2015).Expansive soils pose challenges to Civil Engineers Worldwide due to their exhibition of high swelling and shrinking behaviour. They are highly fertile for agricultural purposes, but pose severe problems to pavements, embankments, and light to medium loaded residential buildings due to cyclic volumetric changes caused by moisture fluctuation (Venkatesh*et al*., 2018).

Black Cotton Soils are derived from the weathering action of Basalts and traps of Deccan plateau (Gurugubelli*et al*., 2017).They are highly fertile for agricultural purposes but pose severe problems to the pavements, embankments and light to medium loaded residential buildings resting on them due to cyclic volumetric changes caused by moisture fluctuation. This volume change behaviour is the reason for cracking to the overlying structures. The reason for this behaviour is due to presence of clay mineral such as montomorillonite(Gurugubelli *et al.*, 2017).

Stabilization using ceramic waste is one such waste material which can be used for improving the properties of poor clayey soils. Ceramic waste materials are easily available at various manufacturing units and at construction sites. Ceramic waste can be conveniently used for soil stabilization and problem of their disposal can be overcome in environmentally safer way. Thus use of ceramic waste not only improves the soil properties but problem of their disposal can also be solved. In the present study ceramic waste materials will be used to improve the properties of clayey soils and effect of ceramic dust on various soil properties will be evaluated.

1.2 Problem Statement

Road construction in the developing nations has been a major challenge to Government and different specialists in the construction industry. The challenge facing Government is the limited resources available for the construction of roads and the high cost of road building normally put forward by the construction companies. On road construction site, the contractor is faced with the problem of non-availability of suitable road construction materials, within the vicinity of most road projects. A situation that normally results in the usage of materials imported from other locations, resulting in additional costs that does not guarantee economy in road construction (Chang, 2002).

Also, the environmental challenges posed by most waste materials in our immediate community is at alarming rate and has been a major concern to engineering profession. It is on this backdrop that engineers are finding it necessary to tackling challenges facing our society. These challenges include global warming, environmental pollutions and greenhouse emissions (Hashmi*et al.*,2007)

1.3 Aim and Objective of the Study

The aim of this research work is to determine the effect of Ceramic wastes on the Geotechnical Properties of Cement Stabilized clay Soil. The objectives are:

i- Determined the index properties of the clay soil and micro structural properties of clay soil mixed with varied proportionof Ceramic waste.

ii- Determined the compaction characteristics of cement stabilized clay soil and clay soil mixed with varied proportion of Ceramic waste.

iii- Determined the unconfined compressive strength of cement stabilized clay soil and clay soil mixed with varied proportion of Ceramic waste.

1.4 Justification of Study

One of the ways of ensuring economy is making suitable for road work locally available materials within the vicinity of road projects, through stabilization. One of such materials that are readily available in Nigeria is black Cotton Soil (Manasseh and Joseph, 2013).

Also, In order to reduce the cost of stabilization of materials for road construction, one reasonable alternative is the use of wastes. Researchers have shown that utilization of wastes has resulted in considerable savings in construction costs as well as improvement in soil properties (Umar and Elinwa, 2005).

1.5 Scope of the Study

The scope of the study is to investigate and evaluate the performance of stabilizing clay soil with Ceramic wastes. Geotechnical properties tests such as Particle Size Distribution,Specific Gravity, Moisture Content,Atterberg Limits and Linear Shrinkage will be carried out on the Soil,alsoengineeringproperty tests like Compaction, and Unconfined

Compressive Strength (UCS) will be carried out on the untreated and treated soil at varying percentages.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

Throughout the years researchers have been using a wide array of supplementary cementitious materials and waste products to replace cement. The aim of which is to check the cost of cement, reduce greenhouse emissions through the reduction of cement used, and to find an alternative disposal method for these wastes. Akshaya (2012) in his research work on the stabilization of expansive soil using waste ceramic dust observed that expansive soil collected locally and mixed with ceramic dust from 0 to 30% at an increment of 5% after the analysis of test results found that, liquid limit, plastic limit, plasticity index, optimum moisture content, cohesion and swelling pressure decreased, maximum dry density, unconfined compressive strength, California bearing ratio and angle of internal friction increased with an increase in ceramic dust. Therefore, concluded that ceramic dust up to 30% can be used in strengthening the sub grade of flexible pavements, to save the cost of construction.

Rakhil and Devi (2016) In their experiment, review on the effect of waste ceramic dust on the geotechnical properties of expansive soils revealed that, liquid limit, plastic limit and plasticity index decreased irrespective of the percentage of addition of ceramic dust, addition of 30% ceramic dust changed the soil from CH group to CL group, MDD increased and OMC decreased with increase in percentage of addition of ceramic dust, swelling pressure decreased with addition of ceramic dust for A decrease of 81.5% in swelling pressure of soil was recorded as compared to untreated soil, when 30% ceramic dust was added;from the economic analysis it was found that ceramic dust up to 30% can be utilized for strengthening the sub-grade of flexible pavement with a substantial savings in cost of construction. Kapil and Ameta (2016) in their investigation on Stabilization of fine Sand with Ceramic Tiles Waste as Admixture in Construction of Embankment observed that the engineering properties of the fine sand improved considerably due to stabilized with ceramic tile waste. In the investigation, as they increased the quantity of admixture of ceramic tile waste, the angle of internal friction increased.

Neeraj and Ahirwar (2014) in their studyonPerformance analysis of black cotton Soil treated with calcium carbide Residue (CCR) and stone dust, observed that the combination of equal amount of stone dust and CCR is more effective, which is (10%) than the addition of stone dust and CCR individually, to the black cotton soil in controlling the swelling behaviour. Balarabe and Mary (2015) in their study, Soil Stabilization using Calcium Carbide Residue and Coconut Shell Ash(CSA) observed that, fixation point of CCR was found to be 4% and 6% for CI and CH soil (that is S1 and S2) respectively. Also MMD was found to decrease with respect to that of the virgin soils as both soils were treated with CCR and CSA while OMC increased. Minimum improvement in strength occurred at S1 +4% CCR +19% CSA and S2 +6% CCR +19% CSA with the improvement of 2.5 and 1.46 times that of the Virgin Soil for in soil S1 and S2 respectively. Therefore, suggested that CCR and CSA can be recommended for use in expansive soil stabilization subject to further research.

Joel and Edeh (2013) in their research work, Soil Modification and Stabilization Potential of Calcium Carbide Waste observed that there is no significant difference between the modification potential of both additive as reflected in χ^2 values of 1.293, 0.995 and 0.650 obtained from the comparison of liquid limit, plastic limit and plasticity index test results.

However, difference was observed with CBR and 7 day UCS test results as χ^2 values of 13.75 and 11.64 respectively were higher than the standard value of 9.49 obtained from statistical Table at 4 degree of freedom and 5 % level of significance. Based on result of tests, calcium carbide waste is recommended for use in soil modification and stabilization, as usage will provide an effective way of disposing calcium carbide waste. Manasseh and Joseph (2014) in their study, Stabilization of Ikpayongo Laterite With Cement and Calcium Carbide Waste observed that, The plasticity index of the natural laterite reduced from 14 % to a minimum value of 5 % when treated with a mixture of 10% cement plus 10% calcium carbide waste, strength indices of the laterite was greatly improved as the 7 day UCS and CBR values of Ikpayongo laterite increased from 534kN/m^2 and 28% respectively to 3157 kN/m^2 and 180% respectively, when treated with a combination of 10 % cement plus 10 % calcium carbide waste. Based on results obtained from the study, the use of a mixture of 8 % cement plus 10 % calcium carbide waste, 10 % cement plus 10 % calcium carbide waste are recommended for the treatment of Ikpayongo laterite for use as base material. The use of calcium carbide waste in the stabilization of soil will ensure economy in road construction, while providing an effective way of disposing calcium carbide waste.

Venkatesh *et al.* (2018) in their research study, Multi-scale laboratory investigation on black cotton soils stabilized with calcium carbide residue and fly ash observed that utilization of calcium carbide residue for stabilization of black cotton soil resulted in significant improvement in the strength properties, which was observed from the unconfined compressive strength and California bearing ratio test results.

2.2 Soil

According to Coduto (2003), soil is particulate matter consisting mainly of individual particles assembled together. Soils are aggregates of mineral particles, and together with air and/or water in the void spaces, they form three-phase systems. A large portion of the earth's surface is covered by soils, and they are widely used as construction and foundation materials (Braja, 2008). Soil engineering properties depends largely on the interaction between these particles, and only secondarily on their internal properties. Most civil engineering materials consist of a continuous mass held together with molecular bond, and their mechanical properties depends on their chemical composition and on the nature of the bond. The main engineering properties of soil are permeability, compressibility and shear strength.

Soils are formed by the numerous processes of weathering which include both physical and chemical. Its occurrence in nature is categorically classified into residual soils and transported soils. Residual soils are found at the location where they are formed, whereas transported soils are deposited in a new location from where they have been transported by the transportation agents such as water, wind, ice, and gravity.

2.2.1 Soil types

The major categories of soil are gravel, sand, silt and clay. Gravel and sand are universally considered as coarse-grained soil because its individual particles are considered large enough to be distinguished without magnification while silt and clay are considered fine-grained soils because of their small particle size.

Various laboratory tests are also available to classify soils. The tests relate to the nature of the particles (particle size distribution), and the soil's relationship with water (moisture content, shrinkage, liquid and plastic limits tests).

2.2.2 Problematic soils

Soils with properties that cannot be safely and economically used for the construction of civil engineering structures without any form of stabilization are commonly known as problematic soils. They include expansive/swelling and collapsible soils which exhibit low strength and high compressibility. To geotechnical and highway engineer, a problematic soil is one that possess a lot of problems to construction work as a result of instability of the soil which makes it unsuitable as a construction material in foundations, building, highway, water retaining structures, and so on (Ola, 1987).

Clay is predominant in most of the sub-grade soils of Nigeria, with the clay minerals having the ability to attract and absorb water. In Nigeria, some of the problematic soils have been identified. They include mainly; the black cotton soil which occur widely in the north-eastern part of Nigeria and the Sokoto soft shale (attalpulgite) in the north-western Nigeria (Ola, 1987).

2.3 Black Cotton Soil

Black Cotton soils are the soils which swell significantly when they come in contact with water and shrink when the water squeezes out (Akshaya, 2012). They are also referred to as swelling soils; they are those soils which have tendency to increase in the volume whenever the moisture content (water content) in it is increased (Rakhi and Devi, 2016). Specifically, Nigeria black cotton soils are formed from the weathering of basaltic rocks and clayey shale which are dark grey to black in colour (Ntekim*et al*., 2009).

Black cotton soils are confined to the semi-arid regions of tropical and temperate climates characterized by low rainfall, poor drainage and exceedingly great heat such that the annual evaporation exceeds the precipitation (Chen, 1988). In Nigeria, black cotton soils are found predominantly in the north eastern part of the country which includes Borno, Gombe, Adamawa, Taraba, Bauchi, and Yobe States and also lies within the Lake Chad Basin. They are also found in Cameroun, Sudan, Ethiopia, Kenya, South Zimbabwe, South Africa, India and Australia (Murthy, 2009).

They are characterized by excessive swelling and shrinkage upon the absorption and rejection of water which makes structures constructed on black cotton soils experience foundation cracks and collapse, severe structural damage, heaving and cracking of sidewalks, roads and basement floors due to the volume changes from moisture content which have caused considerable loss of life and properties. Road pavement construction over black cotton soils has continuously tasked the designer. This is also due to the inherent characteristics of excessive volume changes, expansive tendencies and low bearing values under wet conditions. Typical oxide composition of black cotton soil collected from Numan, Adamawa State Nigeria is presented in Table 2.1. These severely impair the performance of pavements built over such formations.

Table 2.1: Oxide Composition of Black Cotton Soil (Osu, 2012)

Oxide	Percentage Composition
Al_2O_3	14.0
SiO_2	54.1
SO_3	0.21
K_2O	1.67
CaO	3.83
TiO_2	2.27
V_2O_5	0.097
MnO	0.24
Fe_2O_3	20.0
ZnO	0.12
Ag_2O	2.29
BaO	0.25
Eu_2O_3	0.29
Re_2O_7	0.2
Cr_2O_3	0.033

2.3.1 Geotechnical properties of black cotton soils

Black cotton soils are expansive clays which absorbs water heavily, swell, become soft, plastic and sticky and losses strength. They are easily compressible when wet and possesses a tendency to heave during wet season. On drying, they shrink heavily, become hard and develop cracks on the surface. The maximum width of these cracks may be up to 20mm or more and travel deep into the ground (Murthy, 2009). Their colours varies from dark-grey to black due to the presence of iron and titanium compounds present and are classified as an A-7-6 soil according to the AASHTO classification system and in the Unified classification system, the soil falls into CL and CH groups (Ola, 1987).

From an extensive research by Morin (1971), the properties of African tropical black cotton soils can be summarized as follows:

Table 2.2: Geotechnical Properties of Black Cotton soil (Morin, 1971)

Sand content	4-41%
Silt content	8-58%
Clay content	40-70%
Liquid limit	22-60%
Plasticity index	8-81%
Activity	0.4-1.70
AASHTO classification	A-7-5 to A-7-6
Group index	13-89
Free swell	50-100%
PH	6.3-9.2
Organic content	1-1.5%
MDD modified AASHTO	1.37-1.92Mg/m^3
OMC modified AASHTO	13.0-32.2%

From another studies carried out by Osinubi (1995) on samples of black cotton soils taken from Numan and Marte areas of the north eastern Nigeria, the following geotechnical properties of the soil which are in agreement with Morin (1971) are summarized below:

Table 2.3: Geotechnical Properties of Black Cotton soil (Osinubi, 1995)

Liquid limit	62.3%
Plastic limit	24.2%
Plasticity index	38.1%
Linear shrinkage	38.6%
Group index	24
AASHTO classification	A-7-6
MDD	1.71 Mg/m^3
OMC	18.0%
Free swell	76.25%
Specific gravity	2.4

2.3.3 Chemical and mineralogical composition of black cotton soil

The behaviour of fine-grained soils depends to a large extent on the nature and characteristics of the minerals present. Black cotton soils, described as heavy cracking soils contain high expanding clay minerals (or smectite). These clay minerals are crystalline in nature because of their definite geometrical pattern. Mineralogical composition of this soil is principally 70% montmorillonite and 30% kaolinite which are the two major clay minerals found in black cotton soil. The predominance of montmorillonite is due to the weathering of the basic igneous rocks under alkaline condition (Osinubi*et al*., 1998; Ola, 1983). Montmorillonitic clays have high proportion of very fine particle sizes and highly hydrated colloidal fraction and hence exhibits asswelling tendency in the presence of water (Nketim*et al*., 2009; Chen 1975). The swell and shrink characteristics of black cotton soil are due to montmorillonite while the kaolinite is likely responsible for the high strength value because of its inability to swell with absorbed water (Thomas, 2005).

2.3.4 Structural component of clay minerals

Chemical weathering process forms two types of sheet like chemical structure. They are: Tetrahedral and Octahedral sheets.

Tetrahedral Unit: This consists of silicon atom surrounded by four oxygen atoms. It is also referred to silica tetrahedron (SiO_4).

Octahedral Unit: Octahedral unit may be aluminium octahedron and/or magnesium octahedron. It consist of aluminium ion (Al^{3+}) or magnesium ion (Mg^{2+}) surrounded by hydroxyls. The sheet structure of this octahedral unit is formed by sharing of hydroxyls.

These sheets then combine in various ways to form dozens of different clay minerals, each with its own chemistry and structure. Amongst which are kaolinite and montmorillonite.

2.3.5 Kaolinite

Kaolinite is formed in a weathering of orthoclase feldspar under good drainage condition with low pH. It is known for very low swelling potential because it has 1:1 lattice structure, low liquid limit, low activity and yields hydraulic conductivity k, that is rarely less than 10^{-8}m/s. k is the coefficient of permeability and this permeability is the ease with which water flows through a porous material. Kaolinite crystals consist of tetrahedron and octahedron sheets that are held together by strong hydrogen bond.

When kaolinite sheets are stacked on each other, the hydroxyls of octahedron sheet (gibbsite) are attracted to the oxygen of the silica tetrahedron sheet by means of oxygen bond. Such bonds which are ionic and covalent are strong but not as strong as the primary bond and therefore cleavages occur. These sheets can extend greatly in two directions and typically such crystals are 70-100 layers thick. Since kaolinite contains tetrahedron and octahedron sheets, it is called a 2-layer sheet or 1:1 mineral. The kaolinite platelets are about 0.05microns thick. They have a diameter to thickness ratio of about 20 and usually hexagonal in shape. The structural formula is $(OH)_8Si_4Al_4O_{10}$. The structure of kaolinite is shown:

Figure 2.1: Basic building block of kaolinite

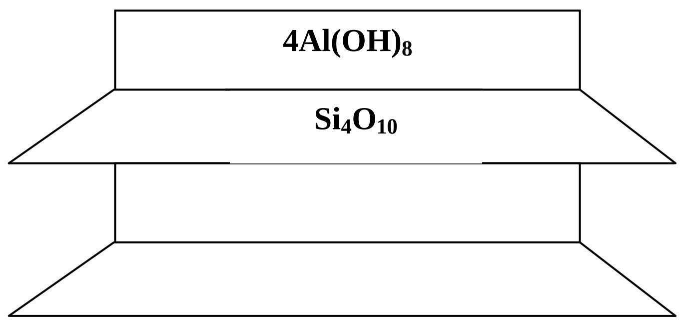

Figure 2.2: Kaolinite structure

2.3.6 Montmorillonite

Montmorillonite also known as smectite which is a group name for the 2:1 layer swelling clays formed from the weathering of volcanic ash under poor drainage conditions. The basic building sheets for smectite consist of two silica sheets and one alumina sheet. The bond holding the sheets is due to Vander Waals forces and exchangeable ions. It is a very weak bond and easily broken by water or other polar or cationic organic fluids entering between the sheets. There is extensive substitution of silica and alumina resulting in considerable charge deficiency. The structural formula is $(OH)_4Si_8(Al_{3.34}Mg_{0.66})O_{20}$. The structure of montmorillonite is shown in Figure 2.3 – 2.4.

Figure 2.2: Layer of montmorillonite

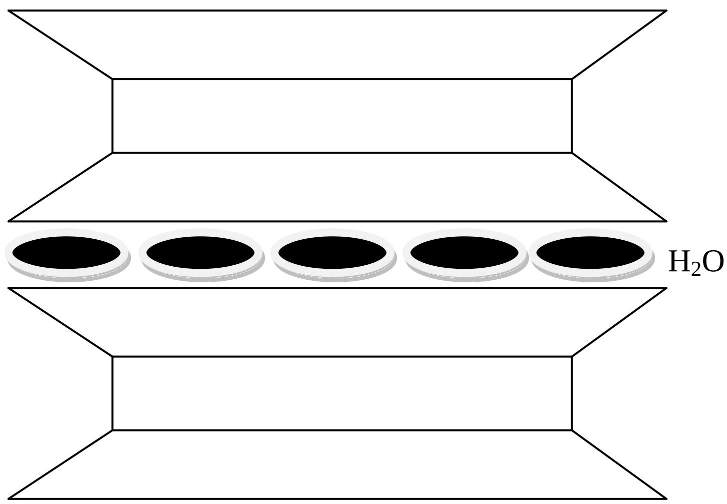

Figure 2.4: Basic building block of Montmorillonite

2.3.7 Classification of Black Cotton Soil

It is quite arent from the laboratory test data, that black cotton soils are not the same. The variations in their particles size distribution, clay and silt content, liquid and plastic limits and swell potential are so wide that black cotton soil cannot be considered as just one type of soil. These soils need to be sub-divided further (NIBRRI, 1983)

i. Category I: (Low Swell Potential)

Plasticity index, < 20%

Free swell, < 50%

Percent smaller than 1 micron, < 20

ii. Category II: (Medium Swell Potential)

Plasticity index, 15-30%

Free swell, 50-80%

Percent smaller than 1 micron, 15-13%

iii. Category III: (High Swell Potential)

Plasticity index, > 30%

Free swell, > 80%

Percent smaller than 1 micron, 30%

2.3.8 Soil Stabilization

Soil stabilization means the improvement of the stability or bearing power of a poor soil by the use of compaction; proportioning and the addition of suitable stabilizers or admixtures (Neeraj and Ahirwar, 2014). Soil stabilization is a procedure where we improve engineering properties of soil with the use of natural or synthesized admixtures. In the past many researchers have carried out their research work for improving the strength of black cotton soil using different types of admixture at different percentages (Dhananjay*et al.*, 2016).

Primarily, the objectives of soil stabilization are to improve the soil strength, to decrease permeability and water absorption, to improve soil bearing capacity and durability under varying weather condition (Moses, 2008). Stabilization using ceramic waste is one such waste material which can be used for improving the properties of poor clayey soils. Ceramic waste materials are easily available at various manufacturing units and at construction sites. In developing countries like Nigeria, waste management is a matter of serious concern because waste materials are generated at rapid rate. Ceramic waste can be conveniently used for soil stabilization and problem of their disposal can be overcome in environmentally safer way. Thus use of ceramic waste not only improves the soil properties but problem of their disposal can also be solved. In the present study ceramic waste materials have been used to improve the properties of clayey soils and effect of ceramic dust on various soil properties have been evaluated.

Treated black cottons soils have a lower permeability, higher strength, and lower shrinkage than the untreated soil (Keller, 2011). Stabilization is not the only solution for expansive soil to improve its strength. Mechanical stabilization can be used for improving the strength properties of expansive soil. Structural measures can also be used to reduce expansive soil problems. Some of the principal preventive methods for safe design of building foundations are, deep piers and footings, and rigid slabs. As shown in the table1,the estimated cost of damages caused by expansive soil varies from country to country. The main properties of soil are strength, compressibility, stability, permeability and durability (Sherwood, 1993, Al-Tabbaa and Evans, 2005). Comparison of various soil stabilizing techniques.

For black cotton soil to be used for any civil engineering construction work there is need to improve its geotechnical properties. There are several methods of improving the properties of deficient soils through stabilization, commonest amongst such methods are:

i. Chemical stabilization: Chemical stabilization of soil comprises of changing the physico-chemical properties around and within clay particles where by the earth obliges less water to fulfill the static imbalance. Calcium chloride being hygroscopic and deliquescent is used as a water retentive additive in mechanically stabilized soil bases and surfacing. The vapor pressure gets lowered, surface tension increases and rate of evaporation decreases. The freezing point of pure water gets lowered and it results in prevention or reduction of frost heave. The depressing of the electric double layer clay soil, the salt reduces the water pick up and thus the loss of strength of fine-grained soils.

Calcium chloride acts as a soil flocculent and facilitates compaction. Frequent alication of calcium chloride may be necessary to make up for the loss of chemical by leaching action. For the salt to be effective, the relative humidity of the atmosphere should be above 30%. Sodium chloride is the other chemical that can be used for this purpose with a stabilizing action similar to that of calcium chloride.

ii. Lime stabilization: This is an economical way of soil stabilization. Lime modification describes an increase in strength brought by cation exchange capacity rather than cementing effect brought by pozzolanic reaction (Sherwood, 1993). In soil modification, as clay particles flocculates, transforms natural plate like clays particles into needle like interlocking metalline structures. Lime stabilization may refer to pozzolanic reaction in which pozzolana materials reacts with lime in presence of water to produce cementitious compounds (Sherwood, 1993, Euro Soil Stab, 2002). The effect can be brought by either quicklime, CaO or hydrated lime, $Ca\ (OH)_2$. Lime stabilizations technology is mostly widely used in geotechnical and environmental alications. Some of alications include encapsulation of contaminants, rendering of backfill (example. wet cohesive soil), highway caing, slope stabilization and foundation improvement such as in use of lime pile or lime-stabilized soil columns.

iii. Cement stabilization: Cement is the oldest binding agent since the invention of soil stabilization technology in 1960's. Cement reaction is not dependent on soil minerals, and the key role is its reaction with water that may be available in any soil (EuroSoilStab, 2002). This can be the reason why cement is used to stabilize a wide range of soils. Numerous types of cement are available in the market; these are ordinary Portland cement, blast furnace cement, sulfate resistant cement and high alumina cement. Usually, the choice of cement depends on type of soil to be treated and desired final strength. Hydration process is a process under which cement reaction takes place. The process starts when cement is mixed with water and other components for a desired alication resulting into hardening phenomena. The hardening (setting) of cement will enclose soil as glue, but it will not change the structure of soil (EuroSoilStab, 2002).

iv. Stabilization with bituminous material: Bituminous soil stabilization refers to a process by which a controlled amount of bituminous material is thoroughly mixed with an existing soil or aggregate material to form a stable base or wearing surface. Bitumen increases the cohesion and load-bearing capacity of the soil and renders it resistant to the action of water. Bitumen stabilization accomplished by using asphalt cement, asphalt cutback or asphalt emulsions. The type of bitumen to be used depends on the type of soil to be stabilized, method of construction and weather conditions. In frost areas, the use of tar as binder must be avoided because of its high temperature maximum susceptibility. Asphalts and tars are bituminous materials which are used for stabilization of soil, generally for pavement construction. Bituminous materials when added to a soil, it imparts both cohesion and reduced water absorption.

v. Electrical Stabilization: Electrical stabilization of clayey soils is done by a process known as electro-osmosis. As a direct current (DC) is passed through a clayey soil, pore water migrates to the negative electrode (cathode). It occurs because of attraction of positive ions (cations) that are present in water towards cathode. The strength of the soil is considerably increased due to removal of water. Electro-osmosis is an expensive method, and is mainly used for drainage of cohesive soils. Incidentally, the properties of the soil are also improved.

vi. Stabilizationwith Geotextile and Fabrics: Geotextiles are porous fabrics made of synthetic materials such as polyethylene, polyester, nylons and polyvinyl chloride. Woven, non-woven and grid form varieties of geotextiles are available. Geotextiles have a high strength. When properly embedded in soil, it contributes to its stability. It is used in the construction of unpaved roads over soft soils. Reinforcing the soil for stabilization by metallic strips into it and providing an anchor or tie back to restrain a facing skin element Chen and Lin (2009). Past research has shown that the strength and load-bearing capacity of subgrades and base course materials can be improved through the inclusion of nonbiodegradable reinforcing materials, such as fibers, geotextiles, geogrids, and geocomposites. Use of these materials can improve the performance and durability of future highways and may reduce the cost of construction.

2.4 Cement

Portland cement is essentially calcium silicate cement, which is produced by firing to partial fusion, at a temperature of aroximately 1500°C, a well-homogenized and finely ground mixture of limestone or chalk (calcium carbonate) and an aropriate quantity of clay or shale. The composition is commonly fine-tuned by the addition of sand and/or iron oxide (John and Ban, 2003).

2.5 Pozzolans and it Types

Pozzolanic materials in finely grinded form and in the presence of water (H_2O) react with calcium hydroxide liberated on hydration of cement at ordinary temperature to form compounds. Pozzolans are categorized into two main types namely (Varghese, 2015):

Natural pozzolans such as volcanic ash, tuffs and pumicites, Calcined diatomaceous earths, Opalinecherts, and Clay and shales. Natural pozzolans requires further processing (grinding) and calcining to activate their pozzolanic properties. Nowadays, the demand for natural pozzolans have reduced due to the availability of more active artificial pozzolans Artificial pozzolans such as, POFA, GGBS, CCA and so on

2.5.1 Propertiesofsome Pozzolans

2.5.1.1 Industrial waste products

i. Palm Oil Fuel Ash (POFA)

Palm Oil Fuel Ash (POFA) is one of the numerous by-products from palm kernel production whose recycling potential is yet to be fully harnessed across the various disciplines. Palm kernel fruit is produced mostly in the southern part of the river Niger in Nigeria (eastern, western and southern parts), a total of about 930 metric tons of palm oil at a growth rate of 2.20 % per annum is produced in Nigeria (Opeyemi and Makinde, 2012). Palm kernel shell (PKS) is a by-product of palm fruit; this by-product is produced in large volume yearly and disposed of in landfills as waste. PKS come in various sizes such as 0-5mm for small sizes, 5-10mm for medium sizes and 10-15mm for large sizes (Odeyemi*et al*., 2019)

POFA contains a large amount of SiO_2 which gives it the pozzolanic property. From various research conducted by Singh and Siddique, 2014; Siddique *et al*., (2012), POFA has high SiO_2 (>60%), low Al_2O_3 (<8%) and high P_2O_3 (3.78%-4.6%). Compared to GGBFS, and MK or kaolin, POFA is composed of higher Fe_2O_3 content, and when compared to class F fly ash and MK, it has higher MgO and CaO content. This chemical composition makes POFA possess both pozzolanic and cementitious properties as there is even distribution of oxides that makes is closer to ordinary Portland cement (Oyejobi*et al*., 2015).

ii. Silica Fume

Silica fume, majorly known as microsilica or condensed silica fume, is a finished material that is used as a pozzolan. This finished material is as a result of the reduction of high-quality quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume rises as an oxidized vapor from the 2000°C (3630°F) furnace Da Costa *et al*., (2016). When it cools it condenses and is collected in huge cloth bags.

iii. Sewage Sludge (SSA)

Sewage Sludge is the general name of all types of fresh or incinerated wastewater. Its chemical composition and availability varies depending on its origin (industrial, water treatment, tannery, and so on.). The majority of the experiences of their use in construction is as a target in fired clay materials (Weng *et al*., 2003; Chiang, and Lin, 2005; Chen and Lin, 2009). Several researchers have shown the possibility of using SSA in the production of pozzolanic materials (Tay and Show, 1997; Cyr *etal*., 2007; Liu *et al*., 2011). Results by Pan *et al.*, (2003) displayed that the pozzolanic activity of SSA was dependent on the surface area. Increase in the particle fineness of SSA is reported to result in improved workability, longer setting time, higher absorption of water due to the larger free surface of particles, higher pozzolanic activity and consequently higher compressive strength (Pan *et al.*, 2003). Monzó *et al*. (2003) also reports that SSA is a reactive material that contributes to the strength of cement mortars due to its pozzolanic characteristics.

iv. Ceramic Waste (CW)

Ceramic wastes include wastes from broken bricks, broken tiles and other fired-clay based materials. These materials when grinded have pozzolanic properties, known since Phoenician times (Baronio and Binda, 1997). This is because they are produced from clay, and the thermal process leaves the Al and Si oxides in an amorphous state

v. Groundnut Granulate Blast-furnace Slag (GGBS)

GGBS is a waste product gotten during the production of pig iron in the blast furnace and is produced by the combination of iron ore with limestone flux. If the molten slag is allowed to cooled and solidify by rapid flowing water reducing it to a glassy state, little or no crystallization of the product occurs. This process leads to the formation of sand sized fragments, usually with some friable clinker-like material known as GGBS. The physical structure and gradation of GGBS depend mostly on the chemical composition of the slag, the temperature of the slag at the time of water quenching and also the method of production. GGBS, when it is produced with small amounts of lime, has a high pozzolanic activity, and it has been widely used in various engineering alications(Wild *et al*., 1998; Binici *et al*., 2007; Oti *et al*., 2009)

vi. Fly ash (FA)

Fly ash is an end product of the combustion of pulverized coal in electric power generating plants. It is the most commonly used supplementary cementitious material in concrete production. It is used in more than half of ready mix concrete. The replacement level of cement with Class F fly ash is often peg at 15-25% by mass of cementitious materials, and between 15-40% by mass of cementitious materials for Class C fly ash (Feng and Clark, 2011). The different properties of fly ash can greatly affect the properties for fresh concrete and hardened concrete. Class F fly ash is pozzolanic and has predominantly (70%)

amorphous silica that controls the pozzolanic activity. From X-ray diffraction analysis the crystalline minerals are identified to be quartz, hematite, mullite, and magnetite. Class C fly ash is produced from burning lignite or sub-bituminous coal. Class C fly ash exhibits both pozzolanic and cementitious properties.

2.5.1.2 Agricultural waste products

These are waste products gotten from agricultural products.

i. Corn Cob Ash (CCA)

Corn cob is the agricultural waste product obtained from maize or corn, which is the most important cereal crop in sub-Saharan Africa (Adesanya and Raheem, 2009). Previous researches on the use of corn cob ash (CCA) as a pozzolan by (Adesanya, 1996) involved the mixing of the CCA with Ordinary Portland Cement at the point of need.

ii. Rice Husk Ash (RHA)

The physical properties of Rice Husk Ash (RHA) as reported by Ayininuola and Olaosebikan, (2013) are specific gravity and bulk density with a specific gravity of RHA varying with the calcination temperature, the specific gravity was reported to decrease from 2.00 at 400^0C to 1.05 at 800^0C. Ayininuola & Olaosebikan, (2013) reported the bulk density of RHA as 368.50 kg/m^3, and fineness modulus of 1.45 without special treatment or milling of the ash.

iii. Coconut shell Ash (CSA)

Coconut shell is one of the most commonly used natural fillers produced in tropical countries. CSA does not have pozzolanic/cementitious property by itself which is responsible for strength generation. It combine with lime obtained from cement and forms hydrated products (C_2S and C_3S) in presence of water, which contributes in attaining the strength and also improving the durabilityDesai, (2017) concluded that Partial replacement of cement with at most 20% PKSA and CSA in concrete will give an average optimum compressive strength at 28 days of curing, it is useful in the production of both lightweight and heavyweight concrete.

iv. Bone Ash (BA)

Bone ash usually obtained by crushing animal bones. Olutaiwo and Yekini, (2018) posited that the 20% usage of CBA in partial replacement of cement in concrete production gives additional environmental benefits, as it provides an alternate and effective solution to the disposal of cow bone wastes

2.6 Chemical Principles of the Pozzolanic Reactions

Pozzolanic reactions take place when significant quantities of highly reactive oxides of CaO, Al_2O_2 and SiO_2 are mixed in the presence of water. CaO is usually added as cement, while Al_2O_2 and SiO_2 are present in the mix to develop cementation gels to be added to the cement. In this process, the hydration of the CaO releases OH- ions, which results in an increase in pH value up to 12.4. Under these favorable conditions pozzolanic reactions occur: the Silicon and Aluminum combine with the available Calcium, producing a cementitious compounds called Calcium Silicate Hydrates (CSH) and Calcium Aluminate Hydrates (CAH) (Dermatas and Meng, 2003; Nalbantoğlu, 2004; Guney *etal,*. 2007; Yong and Ouhadi, 2007; Chen and Lin, 2009). Dermatas and Meng (2003) showed a simplified qualitative representation of these reactions:

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^- \quad (2.1)$$

$$Ca^{2+} + 2OH^- + SiO_2 \rightarrow CSH \quad (2.2)$$

$$Ca^{2+} + 2OH^- + Al_2O_3 \rightarrow CAH \quad (2.3)$$

The chemical equations 1, 2 & 3 are responsible for improving the mechanical properties of the cement mix, due to the increasing development of pozzolanic reactions overtime. Where these oxides (SiO_2,Al_2O_3) are not available in useable quantities in the materials to be cemented, they must be mixed with the binder. In these cases, it is usually advantageous to use stabilizers which are rich in SiO_2 and Al_2O_3 as well as in CaO(Wild *et al.*, 1998; Degirmenci *et al.*, 2007) or for example the use of lime and pozzolan mixes. When these oxides are present in abundance in the material which to be cemented it is not necessary to add them as a binder. The improved mechanical capacities achieved in each case depend on the amount, reactivity and concentration of the oxides, the size and shape of the particles and also on the curing conditions (Misra *et al.*, 2005; Yarbaşı *et al*., 2007; Göktepe *etal*.,2008)

2.7 Ceramic Wastes Powder (CWP)

A ceramic tile is an inorganic, non-metallic, solid material. The earliest ceramics made by humans were pottery objects made from clay either by itself or mixed with other materials like silica. Later ceramics were glazed and fired to create smooth, coloured surfaces, decreasing porosity. The raw materials to form tile consists of clay mineral mined from earth crust, natural mineral such as feldspar(Neeladharan*et al.,* 2017).The chemical and physical characteristics of CWP are shown in Table 2.4. The chemical compositions of CWP were measured by mass. The specific surface area of CWP determined according to ASTM C204. As can be seen from Table 2.5, CWP has aropriate conditions for an ideal pozzolan based on the ASTM C618. Also, in order to find the shape and angular particles of CWP, XRD image were investigated and shown in Figure.2.1. SEM image of the CWP shows angular and irregular particles that are similar to Portland cement particles. Furthermore, XRD analysis of CWP shows the high intensity of quarts peaks.

Table 2.4: Chemical and physical properties of CWP (Mohit and Sharifi, 2019)

Chemicals composition	**CWP (%)**	**Physical properties**	**CWP**
SiO_2	64.04	Moisture Content (%)	0.2
Al_2O_3	21	Specific density (kg/m^3)	2540
Fe_2O_3	6.51	Specific surface area (m^2/kg)	554
CaO	1.29		
MgO	0.88		
K2O	2.35		
Na2O	2.07		
SO3	0.11		
LOI (loss of ignition)	1.1		

Table 2.5: Properties of CWP conforming to the standard ASTM C618

Properties	CWP (%)
SiO_2 + Al2O_3 + Fe2O_3	91.55 > 70%
MgO	0.88 < 5%
SO3	0.11 < 3%
LOI (loss of ignition)	1.1 < 10%
Residue on the sieve 45 mm	26.51 < %35

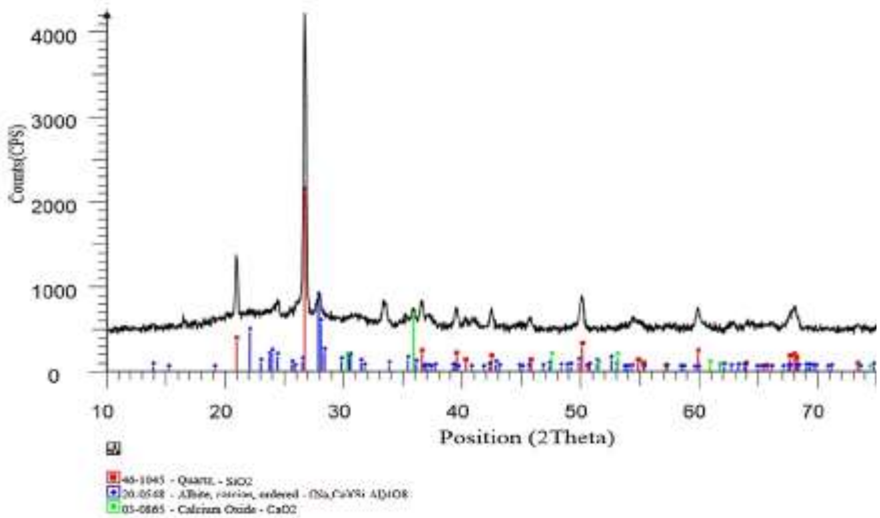

Figure 2.5: XRD pattern of ceramic waste powder (Mohit and Sharifi, 2019)

2.8 Calcium Carbide

Calcium carbide residue (CCR) is a by-product of the acetylene production process that contains mainly calcium hydroxide $Ca(OH)_2$. Compared to hydrated lime, CCR has similar chemical and mineralogical compositions. The $Ca(OH)_2$ contents are aroximately 96.5% and 76.7% for hydrated lime and CCR respectively, CaO contents are 90.13% and 70.78% for the hydrated lime and the CCR, respectively. The high $Ca(OH)_2$ and CaO contents of CCR indicates that it can react with pozzolanic material such as CSA and produce a cementitious material. The production of CCR is best described by equation (2.1) according to Balarabe and Mary (2015):

$CaS_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2$ (2.4)

CHAPTER THREE

3.0 MATERIALS AND METHODS

The materials used for this research includes clay soil, cement, ceramic waste dust and distilled water. The black cotton soil was collected from Barkindo along Lamurde-Adamawa road in Numan Local Government area of Adamawa State, Nigeria. 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. The ceramic waste dust used was a collection of waste tiles and ceramic plates which are crushed in to smaller particles and sieved through BS sieve 0.075mm. The distilled water was purchased from a medical shop opposite General Hospital, Minna, Niger State, Nigeria. These materials are shown in Figure 2.1

Plate I: (a) Clay soil; (b) Ceramic waste dust; (c) Cement

3.1 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 IthembaLaboratory, 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 ZeissAuriga 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, 10, 20, 30 and 40% waste ceramic dust (CWD) each as shown in Table 3.1. The idea behind 40% maximum ceramic waste dust is derived from the works of (Sabat, 2012; Sumayya*et al.*, 2016; Neeladharan*et al*., 2017) whose optimal percentage of CWD used for soil stabilization ranges from 25% to 35%. The clay soil and clay mixed with varied proportions of cement and CWD 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.

Table 3.1: Mixture of cement and CWD

Cement (%)	Waste Ceramic Dust (%)
0	0
	10
	20
	30
	40
2	0
	10
	20
	30
	40
4	0
	10
	20
	30
	40
6	0
	10
	20
	30
	40

Plate II: Unconfined compressive strength test

The UCS specimen of 38mm diameter and 76mm height was molded at standard proctor compaction energy level. The specimen was wax-cured for 1, 7, 14, 28, 60 and 90 daysbefore UCS test as shown in figure 2. The test was carried out in Civil Engineering Department, Federal University of Technology Minna at strain rate of 1.2mm/min.

3.2 Methods Procedure

3.2.1 Sieve analysis test

Apparatus

- Set of sieves
- Large pan
- Scoop
- Sample divider
- Brush (for cleaning sieves)
- Drying oven
- Weighing balances
- Mechanical sieve shaker

Procedure

i. 300g of the air-dry soil sample was weighed and soaked for 24hours.

ii. The soil was washed using B.S sieve 2.0mm and 0.075mm until clay and silty contents were completely washed out.

iii. The retained sample poured into pan and take to oven for drying

iv. The set of sieves were weighed empty and arranged with the largest sieve size at top to the lowest sieve size at button as follows: 5.00, 3.35, 2.00, 1.18, 0.85, 0.600, 0.425, 0.300, 0.150, 0.075mm and base pan.

v. The oven dry soil sample was poured into the top sieve and vibrates for 10 minutes.

vi. The weight of sieve retained particles was weighed and recorded.

vii. The weight of empty sieve was subtracted from the weight of sieve + retained particles to obtained the mass retained on each sieves.

viii. The passage passing was calculated.

3.2.2 Liquid limit (Cone penetrometer method)

Apparatus

- B.S sieve 0.425mm cone penetrometer
- Flat glass (about 00mm^2 and 10mm thick).
- Metal cups
- Was bottle containing distilled water.
- Spatulas
- Moisture content can.
- Weighing balance.

Procedure

i. About 200g of soil puffing B.S 0.425mm was weighed.

ii. The sample was place on the glass plate and distilled water was add to the soil sample and mixed thoroughly to make the soil homogeneous paste by means of spatulas.

iii. The homogenous sample was filled into the cup and finally smooth off level.

iv. The cone tip was lowered to touched the soil surface.

v. The button was pressed to release the cone which allowed penetration to taken placed and readings was recorded.

vi. The code was lifted out and cleaned.

vii. About 10g of sample was taken from where penetration point for moisture content determination.

viii. The sample was removed from the cup and water was added and removed for next trial.

ix. The step 3-8 was repeated with increment of water until the penetration passes 20mm at 5 trials.

3.2.3 Plastic limit test

Apparatus

- Hand of the operator which should be clean
- Glass plate.
- Standard moisture content cans.

Procedure

i. About 20g of soil was mixed with distilled water.

ii. The soil sample was roll in to ball shape between palms and the ball was divided into two part.

iii. The sample was roll into 5mm between the palms.

iv. 5mm diameter sample was placed on the glass plate and further rolling into a thread of 3m by maintaining steady pressure.

When the thread at 3mm diameter started crumble the sample was collected to moisture cans and weighed and taken to over for drying.

3.2.4 Specific gravity test

Apparatus

- Density bottle
- Wash bottle
- Weighing balance

Procedure

i. The empty density bottle was weighed as (M_1).

ii. About 100g of dry soil sample was weighed and shared into 3 portion and filled into each bottle.

iii. Each bottle soil samples were weighed as (M_2).

iv. Distilled water was transferred carefully to each bottle of about half full and shaked to remove the air.

v. The bottle was filled to the brim or particular mark and leave for at least 1 hour.

vi. Bottle + soil sample + water were weighed as (M_3).

vii. The sample in the bottle was poured out and the bottle was clean.

viii. The bottle was filled with water and weighed as (M_4).

ix. Specific gravity was calculate using the equation below

$$G_s = \frac{(M_{2-M_1})}{(M_4-M_1)-(M_3-M_2)} \quad (3.1)$$

3.2.5 Moisture content test

Apparatus

- Moisture can
- Weighing balance
- Oven

Procedure:

i. A dry can was cleaned and weighed as (M_1)

ii. A minimum of 10g of moist soil was placed on the can and weighed as (M_2).

iii. The Can + Soil sample was taken to oven for drying and the oven temperature were regulated within $105^0C + 110^0C$.

iv. The sample + can was removed from oven after 24 hour and weighed as (M_3).

v. The moisture content was calculated using formula

$$M.C = \frac{(M_{2-M_3})}{(M_3 - M_1)} X\ 100 \qquad (3.2)$$

3.2.6 Compaction test

Apparatus

- Cylindrical metal mould with internal volume of $944cm^3$.
- 2.5kg rammer drop.
- B. S. sieve 20mm
- Moisture cans
- Drying oven
- Mixing pan, scoop, straight and knife
- Weighing balance

Procedure

i. 3 kg of air-dried soils sample passing through B.S sieve size 20mm was weighed and pulverized.

ii. Mould with based plates attached was weighed and the internal diameter and height of the mould were measured.

iii. The collar was attached to the mould and the assembled mould was place on solid base that is concrete floor.

iv. 2 -3% of water was added to the soil sample and mixed thoroughly and the moist soil sample was divided into 3 parts.

v. One part of the moist soil sample was place in the mould and 25 below from rammer droing from height of 300mm above the soils layer was distributed alied.

vi. The procedure 5 and 6 were repeated for second and third layer.

vii. The collar was removed and excess soil from the mould was strike off by using straight edge.

viii. The soil + mould with base plate was weighed.

ix. The top and button of compacted sample were taking for moisture content.

x. The remaining sample was extruded and pulverized about 2- 3% of water was added and mixed thoroughly.

xi. Repeating the procedure (5) to 9 continuously until when the soil sample fell that is when mould + wet soil started reducing.

3.2.7 Unconfined compressive strength (according BS 1377-1990)

Apparatus

Unconfined compressive Test Machine

- Spatulas
- Flating
- Ruler

Procedure:

i. The sample at particular curing day was removed from the curing container.

ii. The samples were trimmed to the height of 76mm.

iii. The trimmed samples were weighed and excess of it was use for moisture content determination.

iv. The 76mm height sample was placed on the centrally pedestal of the compressive machine between the user and lower plates.

v. The machine was adjusted so that contact is made between the specimen user plate and the measuring device.

vi. Axial deformation gauge and force were adjusted to zero or

vii. The compressive machine was started and the force dial gauge reading was taken at interval of 0.1mm until the sample fell.

viii. The load was removed from the machine and the sample was removed.

ix. The force readings were converted by multiplied dial gauge reading by the relevant calibrated factor.

x. The compressive strength was calculated using corrected area.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Index Properties Tests

The result of the index properties of the clay soil is shown on Table 4.1 while the compaction characteristic graphs of the clay mixed with varied composition of CWD is presented in Figure 4.1: Liquid limits and plastic limits, measures the unique characteristics of soils concerning water content. Different soils demonstrate different behaviours at different moisture content levels, and these behaviors may be desirable or not, depending on the context of use. Figure4.2 illustrate a detailed result and graphical arrangement limits of the soil sample tested which were 52.11% and the plasticity index as 24.20%.

Table 4.1: Index test result

Description	Quantity
Percentage passing sieve 2.000mm	98.7
Percentage passing sieve 0.425mm	87.1
Percentage passing sieve 0.075mm	77.6
Liquid Limit	52.1
Plasticity Index	27.9
Specific gravity	2.64
MDD (Standard Proctor compaction)	1.651
OMC (Standard Proctor compaction)	22.3
AASHTO soil classification	A-7-6
Unified Soil classification	CH

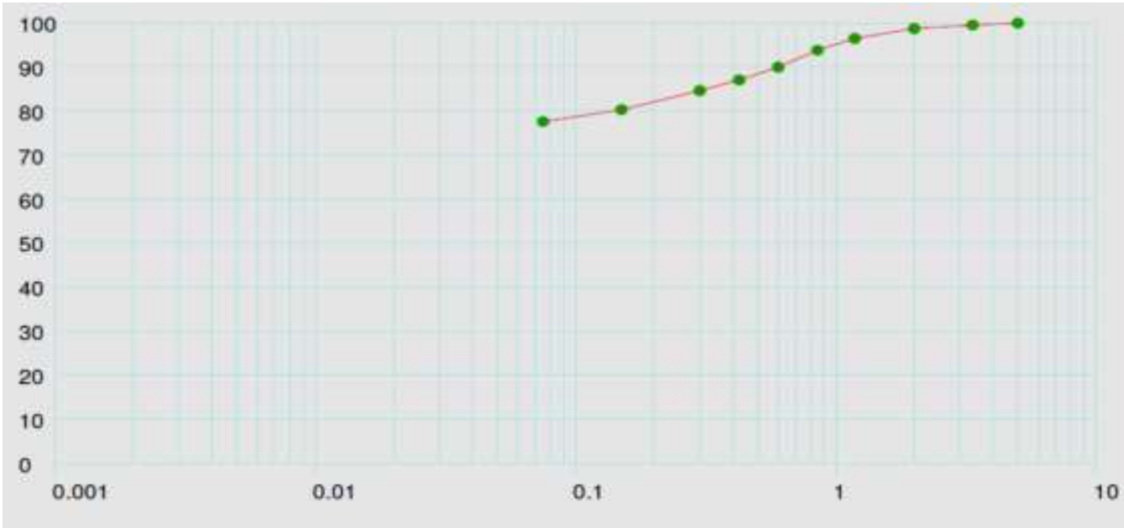

Figure 4.1: Liquid limit test result

From Table 4.1, 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. From the index properties result, this clay cannot be used as material for road pavement structure and cannot also be used to suort pavement structures. It therefore requires stabilization to improve its strength and durability. Figure 4.1 showed that MDD of the soil mixtures decreased with increase in cement and CWD while the OMC increased in the same order.

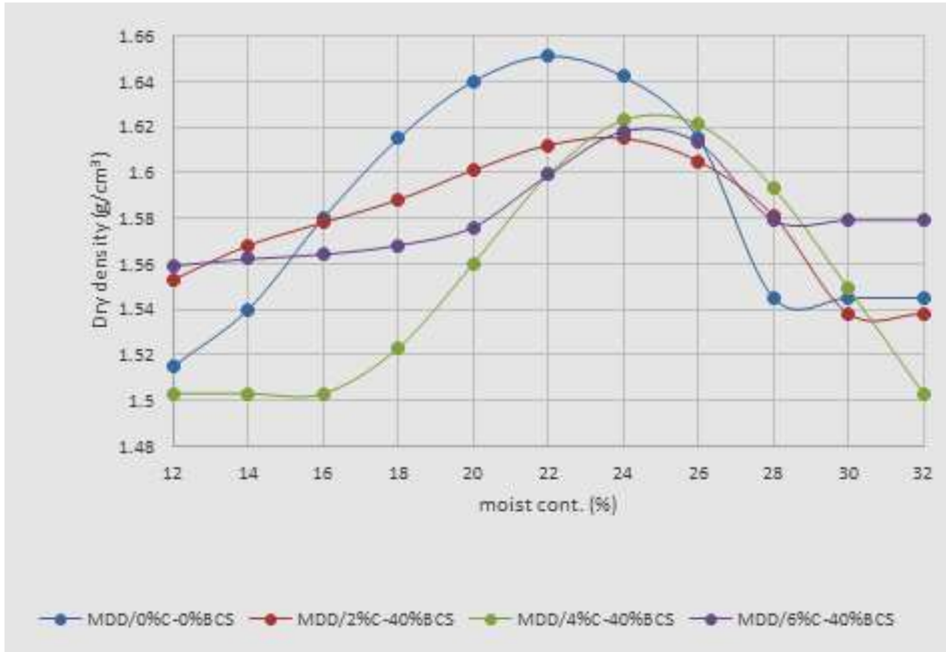

Figure 4.2: Compaction characteristic with varied CWD

4.2 Microstructural Analysis of the Black Cotton Soil

The result of the microstructural analysis of the black cotton soil are shown from XRD, SEM and EDS results as shown in Figures 4.2, 4.3 and 4.4 respectively.

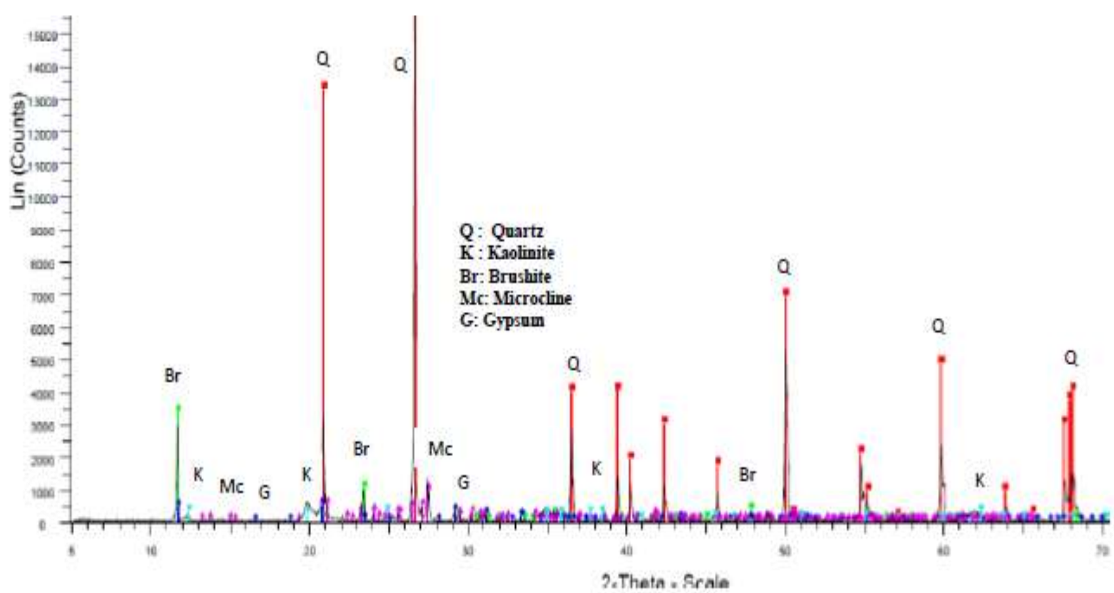

Figure 4.3: Graph of XRD Result

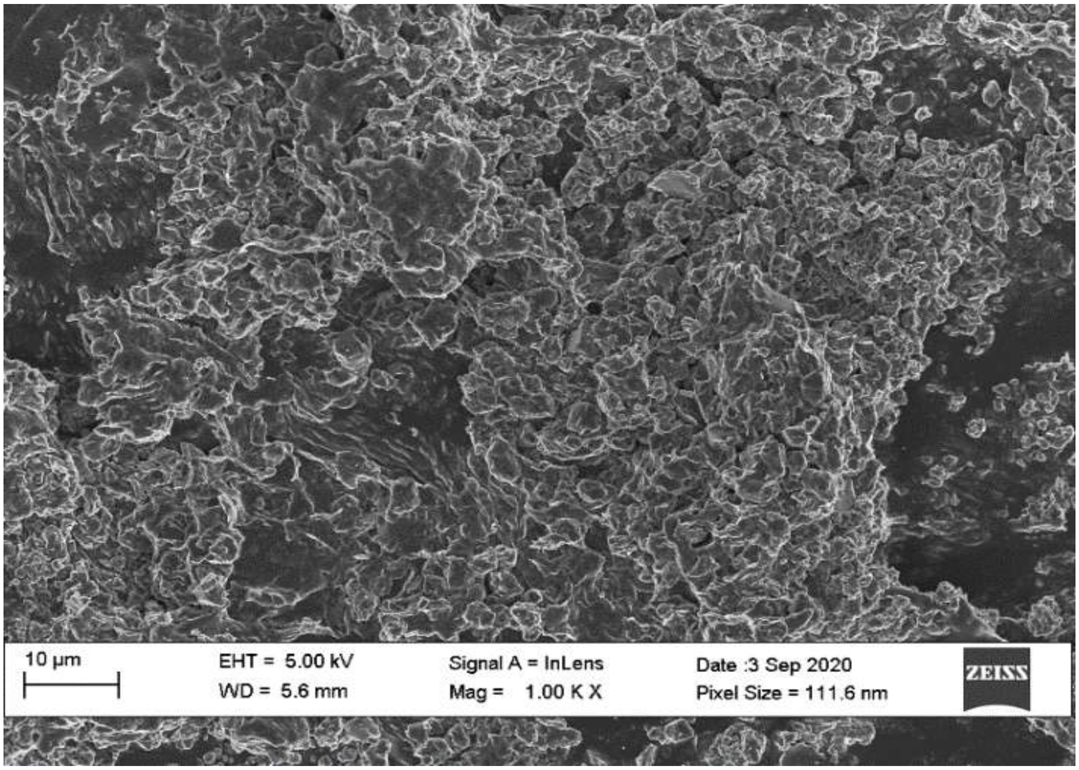

Figure 4.4: Result of SEM Test

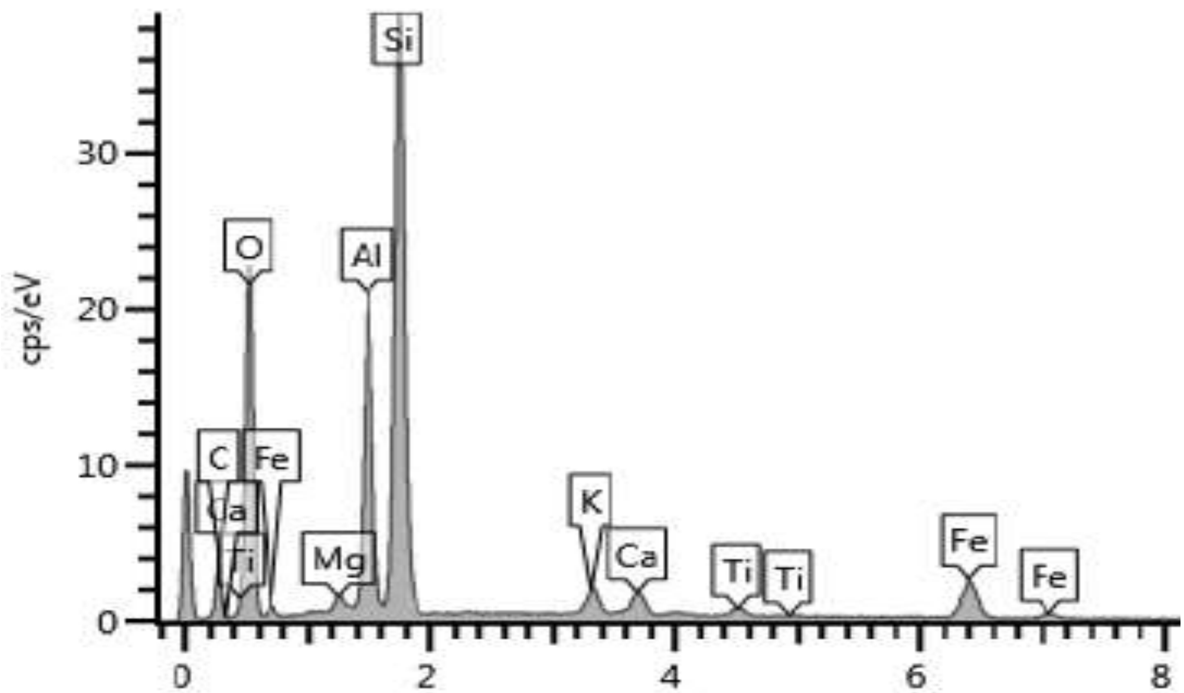

Figure 4.5: Result of EDS test

Result of Scanning Electron Microscopy (SEM) and Electron Dispersion Spectroscopy (EDS) are shown in Figures 4.3 and 4.4. The EDS result showed 22.6% carbon, 39.4% oxygen, 0.51% magnesium, 9.3% Aluminium, 19.4% silicon, 1.25% potassium, 1.31% calcium, 0.59% titanium and 5.7% iron. The silicon-aluminium ratio of 2.09 confirms the absence of montmorillonite mineral. The SEM image of the soil remolded at standard Proctor compaction energy level in Figure 4.2 revealed aggregation of flaky particles with interconnected pore spaces. The aggregation is a dense fabric of flacky clay particles similar to those reported by Zhang *et al*. (2013), and Abdullah *et al*. (2017).

Figure 4.2 present result of XRD test on the clay soil. The result indicates the presence of substantial composition of minerals, including Quartz, kaolinite, brushite, microcline and gypsum minerals. The absence of a peak at 8.96^0 also confirms the absence of montmorillonite mineral. These are both primary and secondary minerals. The MDD and OMC of the clay soil, compacted at Standard Proctor energy level was observed to be 1.651 g/cm^3 and 22.3% respectively.

4.3 Effect of Waste Ceramic Dust on Cement Stabilized Black Clay soil

The effect of UCS with varied composition of CWD for 0, 2, 4 and 6 percentages of cement is shown in Figures 4.10a, 4.10b, 4.10c and 4.10d respectively. Variation of UCS with varied percentage of CWD and 0% cement is shown in Figures 4.9a – 4.9b

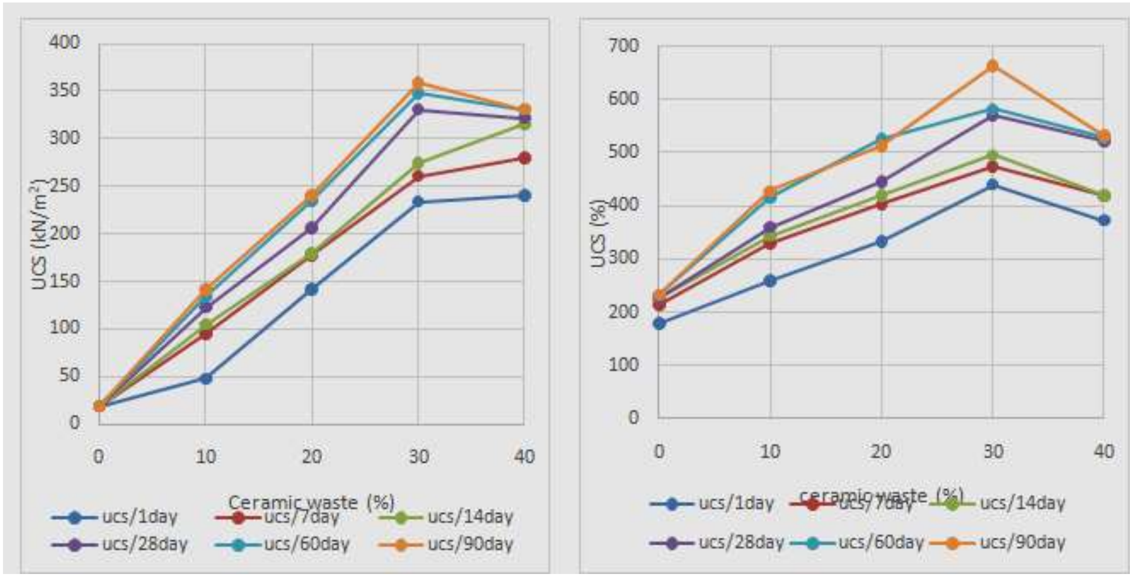

Figure 4.6: UCS with varies composition of Ceramic waste dust

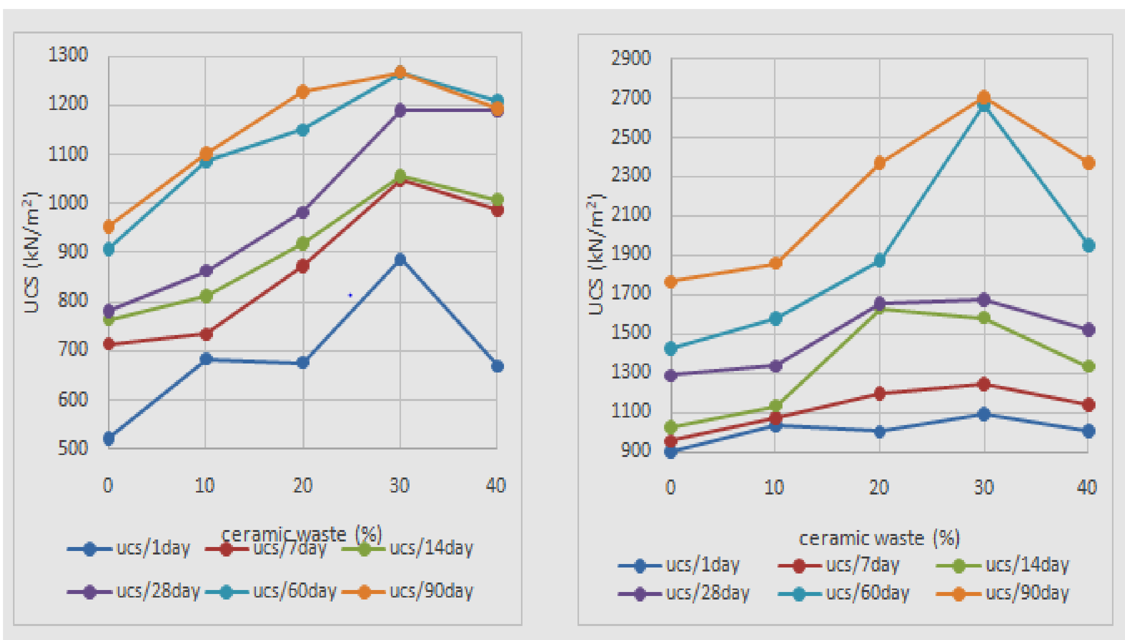

Figure 4.7: UCS with varies composition of Ceramic waste dust

The values increased from 19kN/m^2 at 0% CWD to 48, 142, 234, and 240kN/m^2 at 10, 20, 30, and 40% CWD respectively. The UCS values increased from19 kN/m^2 at 0% cement and 0% CWD to 359kN/m^2 at 0% cement and 30% CWD after 90 days of curing which represents almost 19 times increase in strength of the black cotton soil. This UCS increase in the absence of cement is probably due to calcium based minerals like Brushite and gypsum. For 2% cement after 90 days of curing, the UCS values increased from 178kN/m^2 at 2% cement and 0% CWD within 1 day of curing to 664kN/m^2 at 2% cement and 30% CWD after 90 days of curing. This represents 3.7 times increase in UCS of the stabilized clay soil. Higher values of UCS were observed at 6% cement when mixed with varied composition of CWD. The UCS values increased from 903kN/m^2 at 6% cement and 0% CWD within 1 day of curing to maximum of 2703kN/m^2 at 6% cement and 30% CWD after 90 days of curing. This represents 3.0 times increase in UCS of the stabilized clay soil. This value is within the 2500 to 3000kN/m^2 UCS value specified for stabilized materials to be used as base course for high trafficked road bases.

4.4 Effect of Curing Time on Cement and Ceramic Waste Dust Stabilization of Clay

The variations of UCS values with curing days for varied composition of waste ceramic dust are shown in Figures 4.10a-d. For 0, 2 and 4% cement, it is observed from the graphs that rate of strength gain is higher at between 0 to 28 days after which the rate became gentle. For 6% cement addition however, the rate of strength gain was observed to be averagely constant throughout the 90 days of curing.

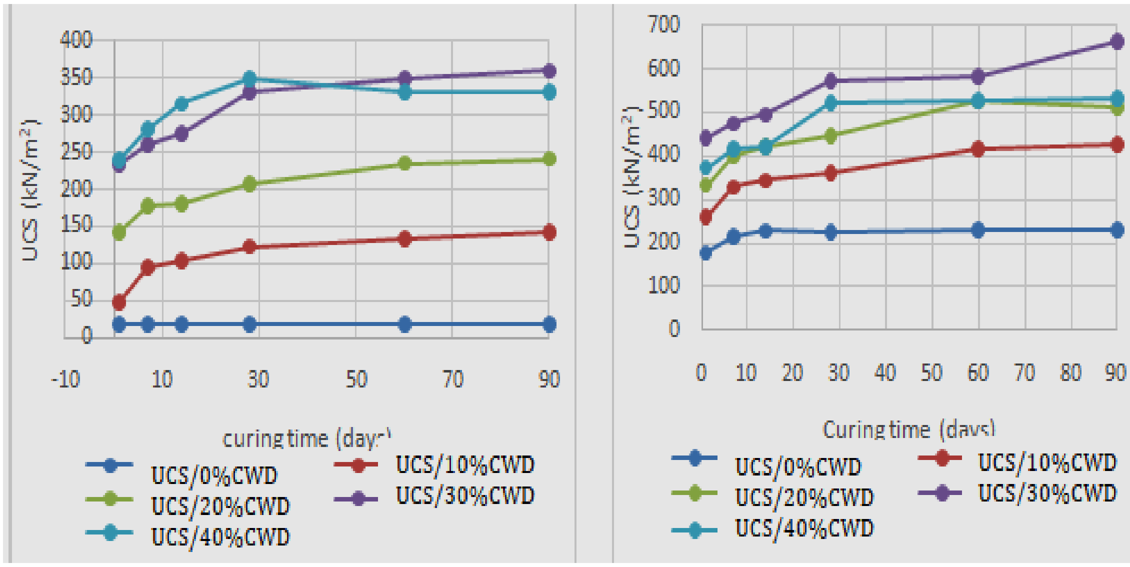

Figure 4.8: Effect of Curing Time on Cement and Ceramic Waste Dust Stabilization of Clay

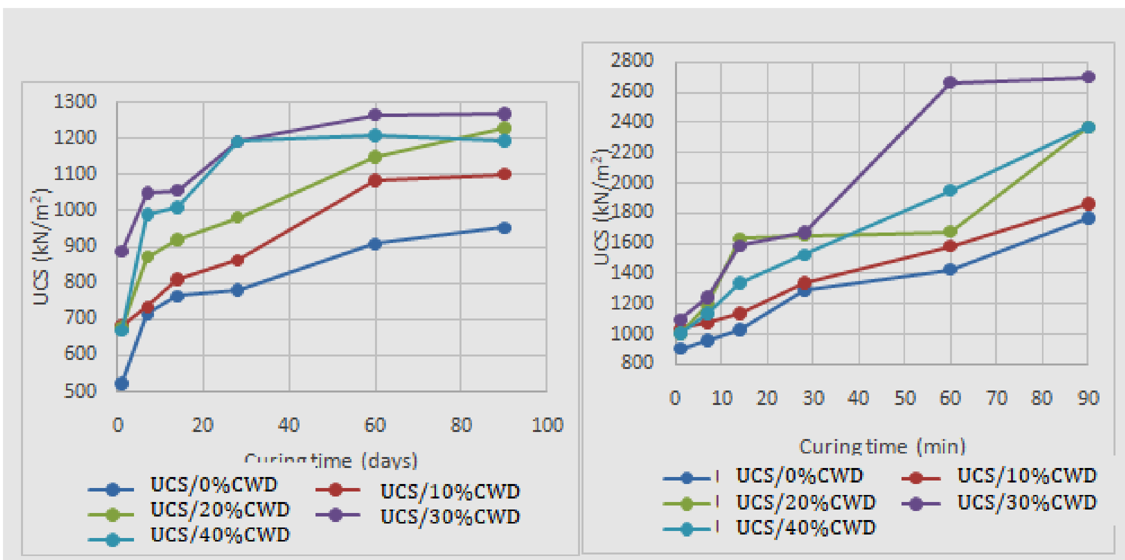

Figure 4.9: Effect of Curing Time on Cement and Ceramic Waste Dust Stabilization of Clay

This is due to the reaction between the Pozzolanic waste ceramic dust and large amount of calcium hydroxide released as byproduct of the reaction of cement in the presence of water. At 0% cement addition, the trend in UCS with curing days for varied composition of CWD showed relatively constant increase in UCS between 0 – 10%, 10 – 20% and 20 - 30% CWD. However, the trend for 30 - 40% CWD with curing days were very close which is an indication that 30% CWD is the optimal CWD required for effective stabilization of clay soil in the absence of cement. For 2, 4 and 6% cement addition, the trend revealed that the trend of the mixture with 30% CWD is always above that with 40% CWD. These results showed that 30% CWD is still the optimal mixture to give the highest strength when used as admixture with cement.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The clay used in this study classified as A-7-6 and Clay of high plasticity (CH) based on AASHTO and Unified Soil Classification Systems respectively.

The major minerals contained in the clay include Quartz, Kaolinite, Brushite, Microcline and Gypsum.

About 19 times increase in UCS strength was recorded on addition of 40% CWD to the clay soil in the absence of cement. The increase in UCS strength with increase in composition of CWD and curing days in the presence of cement, confirm the Pozzolanic reaction between the CWD and calcium hydroxide generated as byproduct from the reaction of cement on addition of water.

Maximum UCS strength of 2700kN/m^2 recorded at 6% cement and 30% CWD is adequate for a soil material to be used as base course material for highly trafficked road bases. From this research.

It was deduced that waste ceramic dust is a good material for enhancing the strength properties of lateritic soil.

5.2.1 Recommendations

Economically and soil strength, it is recommended that ceramic dust, up to 30%, can be utilized for soil improvement (stabilization). This had vast implications on environmental conservation. Laterite material is mostly quarried thus leaving vast areas bare of tree covers and open to erosion and mudslide. However, with as much as 30% replacement of laterite with ceramic waste dust, a large portion of the environment can be conserved over time. Furthermore, ceramic wastes, which constitute a more significant percentage of construction wastes globally, will find use in road construction, thereby reducing the waste load on the environment. Also, observing the substantial improvement in the CBR-value of stabilized soil using CWD presents a cheaper alternative for soil stabilization, which may be deployed for road construction purposes.

5.3 Contribution to Knowledge

This study established the possible use of Pozzolanic waste ceramic dust (CWD) as admixture with cement to stabilize black cotton soil from north-east Nigeria and also to determine the optimal CWD that is required in the mixture. Result showed that CWD can effectively be used as admixture to increase the strength of cement stabilized clay and 30% CWD was observed to be the optimal composition required as admixture with cement to give the higher strength. 6% cement admixed with 30% CWD gave the highest unconfined compressive strength of 2700kN/m^2 which is sufficient strength for a soil to be used as sub-base material for highly trafficked roads based on Nigeria General Specification for Roads and Bridge works.

REFERENCES

Abdullah, H. H., Shahin, M. A., and Sarker, P. (2017). Stabilization of Clay with Fly-Ash Geopolymer Incoporating GGBFS. *Proceedings of the Second World Congress on Civil, Structural and Environmental Engineering* (CSEE 17), Barcelona, Spain, ICGRE141-1 – ICGRE141-8.

Adesanya, D. A. (1996). Evaluation of blended cement mortar, concrete and stabilized earth made from ordinary Portland cement and corn cob ash, *Construction and Building Materials,* 10(6), 451–456. doi: 10.1016/0950-0618(96)00001-3.

Adesanya, D. A. and Raheem, A. A. (2009). A study of the workability and compressive strength characteristics of corn cob ash blended cement concrete, *Construction and Building Materials*. Elsevier Ltd, 23(1), 311–317. doi: 10.1016/j.conbuildmat.2007.12.004

Akinwunmi, I. (2014). Soil modification by the alication of steel slag. Periodical*Polytechnica Civil Engineering*, 58 (4), 371-377.

Akshaya, K. S. (2012). Stabilization of expansive soil using waste ceramic dust.Electronic *Journal of Geotechnical Engineering*, 17, 3915-3926.

Al Tabbaa, A. and Evans W. (2005).Stabilization Solidification Treatment and Remediation. Part I: Binders and Technologies Basic Principal. *Proceedings of the International Conference on Stabilization/Solidification Treatment and Remediation*(367 385). Cambridge, UK:Balkerma.

ASTM C204, Standard Test Methods for Fineness of Hydraulic Cement by Air.Permeability Aaratus, *ASTM International*, West Conshohocken, USA, 2007.

ASTM C6(2008), Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, *ASTM International*, West Conshohocken, USA, 2008.

Ayininuola, G. M., and Olaosebikan, O. I. (2013). Influence of Rice Husk Ash on Soil Permeability, *Transnational Journal of Science and Technology, TJST December*, 3(10), 29–33.

Balarabe, W. I., and Mary, R. S. (2015). Soil Stabilization Using Calcium CarbideResidue and Coconut Shell Ash. *Journal of Basic and Alied EngineeringResearch,* 2 (12), 1039-1044.

Baronio, G. and Binda, L. (1997). Study of the pozzolanicity of some bricks and clays, *Construction and Building Materials*, 11(1): 41–46. doi: 10.1016/S0950-0618(96)00032-3.

Binici, H., Temiz, H. and Köse, M. M. (2007). The effect of fineness on the properties of the blended cements incorporating ground granulated blast furnace slag and ground basaltic pumice, *Construction and Building Materials*, 21(5), 1122–1128. doi: 10.1016/j.conbuildmat.2005.11.005.

Braja, M. D. (2008). *Advanced Soil Mechanics* (3rd ed.). (Taylor.and Francis, Ed.): Taylor and Francis Group, New York

BS 1377. (1992). Methods of Testing Soil for Civil Engineering Purposes.*British Standards Institute*, London,

Chang, A. S. (2002). Reasons for cost and schedule increase for engineering design project. *Journal of Management Engineering*, 18(1), 29-36

Chen, F.H.(1988). Foundations on expansive soils, Elsevier Science publication,Newyork

Chen, L. and Lin, D. F. (2009). Stabilization treatment of soft subgrade soil by sewage sludge ash and cement, *Journal of Hazardous Materials*, 162(1), 321–327. doi: 10.1016/j.jhazmat.2008.05.060.

Coduto, D. P. (2003). Geotechnical engineering principle and practice, *Prentice - Hall*, New Dellin PP.118.

Cyr, M., Coutand, M. and Clastres, P. (2007). Technological and environmental behavior of sewage sludge ash (SSA) in cement-based materials, *Cement and Concrete Research*, 37(8), 1278–1289. doi: 10.1016/j.cemconres.2007.04.003.

Degirmenci, N., Okucu, A. and Turabi, A. (2007). Alication of phosphogypsum in soil stabilization, *Building and Environment*, 42, 3393–3398. doi: 10.1016/j.buildenv.2006.08.010.

Dermatas, D. and Meng, X. (2003). Utilization of fly ash for stabilization/solidification of heavy metal contaminated soils, *Engineering Geology*, 70(3–4), 377–394. doi: 10.1016/S0013-7952(03)00105-4.

Desai, B. (2017). Experimental Study on Concrete by Partial Replacement of Cement with Coconut Shell Ash, Incorporating Steel Fibres: A Review, *International Journal for Research in Alied Science and Engineering Technology*, V(III), 161–164. doi: 10.22214/ijraset.2017.3029.

Dhananjay, K.T., Dixit, R.K., and Subrat, R. (2016). Study on stabilization of black cotton soil by using stone dust and polypropylene fibres,*International Journal of Innovative Research in Science, Engineering and Technology(IJIRSET),* 9, September 2016, ISSN(O) - 2319 - 8753, ISSN(P) - 2347 - 6710.

EuroSoilStab.(2002).Development of Design and Construction Method to Stabilize Soft Organic Soil: Design Guide for soft soil stabilization CT97-0351, EuropeanCommission, Industrial and materials technologies Programme (Rite-Euram III) Bryssel.

Feng, X. and Clark, B. (2011). Evaluation of the Physical and Chemical Properties of Fly Ash Products for Use in Portland Cement Concrete, in *Evaluation of the Physical and Chemical Properties of Fly Ash Products for Use in Portland Cement Concrete*, 1–8.

Göktepe, A. B., Sezer, A., Sezer,G. L., and Ramyar, K.(2008). Classification of time-dependent unconfined strength of fly ash treated clay, *Construction and Building Materials*, 22(4), 675–683. doi: 10.1016/j.conbuildmat.10.008.

Guney, Y., Sari, D.,Cetin,M., Tuncan, M. (2007). Impact of cyclic wetting-drying on swelling behavior of lime-stabilized soil, *Handbook of Environmental Chemistry, and Water Pollution*, 42(2), 681–688. doi: 10.1016/j.buildenv.2005.10.035.

Gurugubelli, S., Prasad, D. S. and Eswararao, B. (2017). A laboratory study on thestrength improve of expansive soil treated with calcium carbide residue and fly ash.*International Journal of innovative research in technology,* 3(12), 120-125.

Hashmi, H. N., Malik N. E., and Usman, A. (2007). Enviromental Impact Of ImproperMunicipal Solid Waste Management, *International Conference, ESDev, COMSATS Abbottabad*, 963 - 972.

Isa, N., Olowosulu, A., and Manasseh, J. (2018). Mechanistic Evaluation of the Effectof Calcium Carbide Waste on Properties of Asphalt Mixes. *Nigerian Journal ofTechnological Development,* 15 (1), 20-25.

Isaac, I. A., Oluseyi, O. A., Michael, C. A., Adebanji, S. O., Oluwapelumi, O. O. andAyodeji,O. D.(2019). Investigation of calcium carbide residue as a stabilizer fortropical sand used as pavement material.*Transactions on The BuiltEnvironment.*182, 285-294.

Jaiswal, M. and Lai, B. 2016. Impact of Rice Husk Ash on Soil Stability (Including Micro LevelInvestigation).*Indian Journal of Science and Technology, 9(30), 1-7.*

Joel, M. and Edeh, J. E. (2013). Soil Modification and Stabilization Potential ofCalcium CarbideWaste. *Advanced Materials Research*, 824, 29-36.

John, N. and Ban, S. C. (2003). Advanced Concrete Technology. Burlington: ElsevierLtd.

Kapil, P., and Ameta, N. K. (2016). Stabilization of Fine Sand with Ceramic TilesWaste asAdmixture for Construction of Embankment. *American Journal ofEngineering Research*5 (8), 20621.

Killer Inc.(2011).ImprovementofWeakSoilsbytheDeepSoilMixingMethod.KellerBronchure,32-01E:http://keller-foundations.co.uk/technique/deep-dry-soilmixing.

Lin, K. L., Chiang, K. Y. and Lin, C. Y. (2005). Hydration characteristics of waste sludge ash that is reused in eco-cement clinkersa, *Cement and Concrete Research*, 35(6), 1074–1081. doi: 10.1016/j.cemconres.2004.11.014.

Liu, Z., Chen, Q., Xie, X., Xue, G. (2011). Utilization of the sludge derived from dyestuff-making wastewater coagulation for unfired bricks, *Construction and Building Materials*. Elsevier Ltd, 25(4), 1699–1706. doi: 10.1016/j.conbuildmat.2010.10.012.

Manasseh, J. and Joseph, E. E. (2013). Stabilization of ikpayongo laterite with cementand calcium carbide waste. Global *Journal of pure and alied sciences*, 20, 49-55.

Misra, A., Biswas, D. and Upadhyaya, S. (2005). Physico-mechanical behavior of self-cementing class C fly ash–clay mixtures, *Fuel*, 84(11), 1410–1422. doi: 10.1016/j.fuel.2004.10.018.

Mohit, M. and Sharifi, Y. (2019). Thermal and microstructure properties of cement mortar containing ceramic waste powder as alternative cementitious materials, *Construction and Building Materials*. Elsevier Ltd, 223, 643–656. doi: 10.1016/j.conbuildmat.2019.07.029.

Monzó, J., Paya, J.,Barrochero, M. V., Girbes, I. (2003). Reuse of sewage sludge ashes (SSA) in cement mixtures: the effect of SSA on the workability of cement mortars, *WasManagement*, 23(4), . 373–381. doi: 10.1016/S0956-053X(03)00034-5.

Morin,W. J. (1971). Properties of African tropical black cotton clay soil. *Proceeding 5th Reginal Conference for Africa on Soil Mechanics and Foundation Engineering* Luanda. 51-59

Moses, G. (2008). Stabilization of black cotton soil with ordinary portland cement Using Bagasse ash as admixture *IRJI Journal of Researchin Engrg.* Vol.5 No.3, pp.107-115

Murthy, V. N. S. (2009). Geotechnical Engineering: Principles and Practices of soil mechnics and foundation engineering. Marcel Dekker Inc., York.

Nalbantoğlu, Z. (2004) Effectiveness of class C fly ash as an expansive soil stabilizer, *Construction and Building Materials*, 18(6), 377–381. doi: 10.1016/j.conbuildmat.2004.03.011.

NBRRI (1983). Engineering properties of black cotton soils of Nigeria and related pavement design.*Nigerian Building and Road Research Institute, Research*, 1-20

Neeladharan, C., Vinitha, V., Priya, B. and Saranya, S. (2017). Stabilisation of Soil byusing Tiles waste with Sodium Hydroxide as Binder. *International Journal ofInnovativeResearch in Science, Engineering and Technology.* 6 (4), 6762-6768.

Neeraj, K. and Ahirwar, S. K. (2014). Performance analysis of black cotton Soil treatedwithcalcium carbide Residue and stone dust. *International Journal of Engineering Research And Science and Technology,* 3 (4), 202-209.

Ntekim, E. E, Ejikeme, S. Preliminary assessment of chemical and mineralogical composition of black cotton soil in Ngurore - Numan Area, Northeastern Nigeria. *Continental Journal of Earth Science*, 4(2009), 34 - 39.

Odeyemi, S. O., Abdulwahab, R., (2019). Bond and Flexural Strength Characteristics of Partially Replaced Self-Compacting Palm Kernel Shell Concrete, *Malaysian Journal of Civil Engineering*, 31(2), 1–7. doi: 10.11113/mjce.v31n2.535.

Ola, S.A. (1987). Laboratory Testing and Geotechnical Characterization of Black Cotton Soil and Expansive Shales in Nigeria, *9th Regional conf. on Soil Mechanics and Foundation Engineering for Africa*, Vol. I A.A Balkeme/ Rotterdam/Boston, 991-995.

Olutaiwo, A.O., Yekini, O.S., E. I. I. (2018). Utilizing Cow Bone Ash (CBA) as Partial Replacement for Cement in Highway Rigid Pavement Construction, *SSRG International Journal of Civil Engineering (SSRG - IJCE)*, 5(2), 13–19.

Opeyemi, D. A. and Makinde, O. O. (2012). The Suitability of Partial Replacement of Cement with Rice Husk Ash and Bone Powder in Concrete Structures, *International Journal of Emerging Technology and Advanced Engineering*, 2(9), 261–265.

Osinubi, K. J. (1995). Lime modification of black cotton soil. *Spectrum Journal*, 2(1 and 2), 112-122 2.

Osinubi, K. J. and Medubi, A. (1998). Evaluation of cement and phosphatic waste admixture on tropical black clay road foundation.*Proc. Of the 4th Int. Conf. on Sructural Engineering Analysis and Modelling* (SEAM 4). Accra, 2, 297-307

Osinubi, K. J. (1999a). Evaluation of admixture stabilization of Nigerian black cotton soil." The Nigerian Society of Engineers Technical Transactions, 34(3), 88 - 96.

Oti, J. E., Kinuthia, J. M. and Bai, J. (2009). Engineering properties of unfired clay masonry bricks, *Engineering Geology*. Elsevier B. V, 107(3–4), 130–139. doi: 10.1016/j.enggeo.2009.05.002.

Oyejobi, D. O., Raji, S. A., Aina, S. T., Siva, A. (2015). Physio-chemical and Microstructural Characteristics of Selected Pozzolanic Materials for Cement and Concrete Production, *Nigerian Journal of Technological Development*, 16, 111–119.

Pan, Shih-cheng, Chin-chi, L. D. T. (2003). Influence of the fineness of sewage sludge ash on the mortar properties, *Cement and Concrete Research*, 33(11), 1749–1754. doi: 10.1016/S0008-8846(03)00165-0.

Pratico, F. G. and Puala, A. J. (2012). Lime and cement treatments of subgrades in Southern Italy: Facing interports issues and challenges. *Procedia Social and Behavioral Sciences*. 53, 389–398

Pratico, F., Saride, S. and Puala, A. (2011). Comprehensive life-cyclecost analysis for selection of stabilization alternatives for better performance of low-volume roads. *Journal of the Transportation Research Board ,* 120-129.

Rakhil, K. R. and Devi, K. (2016). Review on the effect of waste ceramic dust on the geotechnical properties of expansive soil.*International Research Journal of Engineering and Technology*, 3 (12), 1336-1342.

Sabat, A.K.(2012) A study on some geotechnical properties of lime stabilized expansive soil –quarry dust mixes, *International Journal of Emerging Trends in Engineering and Development*, 1(2), 42-49.

Sherwood, P. (1993). Soil stabilization with cement and lime.State of the Art Review. London: Transport Research Laboratory, HMSO.

Siddique, R., Aggarwal, P. and Aggarwal, Y. (2012). Influence of water/powder ratio on strength properties of self-compacting concrete containing coal fly ash and bottom ash, *Construction and Building Materials*. Elsevier Ltd, 29, 73–81. doi: 10.1016/j.conbuildmat.2011.10.035.

Singh, M., and Siddique, R. (2014). Strength properties and micro-structural properties of concrete containing coal bottom ash as partial replacement of fine aggregate, *Construction and Building Materials*. Elsevier Ltd, 50, 246–256. doi: 10.1016/j.conbuildmat.2013.09.026.

Sumayya, K. P., Mohammed, R. K., Sameer, V. T., Firoz, Khais, P. T. and Jithin, K. (2016), Stabilization of Expansive Soil Treated with Tile Waste, *International Journal of Civil Engineering, 3 (3) 60-68*

Tay, J. H. and Show, K.Y. (1997). 958d72412bb8816d5ac04ead9dff05b4.pdf, *school of civil and structural engineering, Nanyang Technological University*, 36(11), 259–266

Umar, S. Y., and Elinwa, A. U. (2005). Effects of Iron ore tallings (IOT) and Lime onEngineering Properties of problem laterite. *Journal of Raw Materials Research*,2, 56-66.

Varghese, P. C. (2015). Publisher: PHI Learning Pvt. Ltd. Delhi p54.

Venkatesh, N., Heera, L. M., and Rakesh, J. P. (2018). Multi-Scale Laboratoryinvestigation on Black Cotton Soils Stabilized with Calcium Carbide Residue andFly Ash. *Journal of Engineering Research*, 6 (4), 1-15.

Weng, C. H., Lin, D. F. and Chiang, P. C. (2003). Utilization of sludge as brick materials, *Advances in Environmental Research*, 7(3), 679–685. doi: 10.1016/S1093-0191(02)00037-0.

Wild, S.Kinuthia,S.J.M., Jones, G. I., Higgins, D. D.(1998). Effects of partial substitution of lime with ground granulated blast furnace slag (GGBS) on the strength properties of lime-stabilised sulphate-bearing clay soils, *Engineering Geology*, 51, 37–53.

Yarbaşı, N., Kalkan, E., and Akbulut, S. (2007).Modification of the geotechnical properties, as influenced by freeze–thaw, of granular soils with waste additives', *Cold Regions Science and Technology*, 48(1), 44–54. doi: 10.1016/j.coldregions.2006.09.009.

Yong, R. N., and Ouhadi, V. R. (2007).Experimental study on instability of bases on natural andlime/cement-stabilized clayey soils, *Alied Clay Science*, 35(3–4), 238–249. doi:10.1016/j.clay.2006.08.009.

Zhang, M., Guo, H., El-Korchi, T., Zhang, G., and Tao, M. 2013. Experimental Feasibiity Study of Geopolymer as the Next-generation Soil Stabilizer. *Construction and Building Materials*, 47, 1468-1478.

APPENDICES

Appendix A: Sieve Analysis of Sample

Sieve size	Mass Retained	%Retained	%Passing
5.000	0	0.00	100.00
3.350	1.4	0.47	99.53
2.000	2.4	0.80	98.73
1.180	6.7	2.23	96.50
0.850	8	2.67	93.83
0.600	11.6	3.87	89.97
0.425	8.7	2.90	87.07
0.300	7.3	2.43	84.63
0.150	12.9	4.30	80.33
0.075	8.2	2.73	77.60

Appendix B: Liquid Limit Determination (Cone Penetrometer Method)

Test Location: BP from Adamawa

Sample No: 1 :

Sample Description: Clay Soil

	LIQUID LIMIT					PLASTIC LIMIT	
Can Number	1	2	3	4	5	1	2
Penetration	6.5	11.0	16.2	20.2	24.7		
Can Weight	35.2	38.5	39.3	21.4	24.8	23.5	21.4
Weight of Can + Wet Soil	53.7	61.2	62.7	47.4	55.0	29.6	27.1
Weight of Can + Dry Soil	48.8	54.4	55.1	38.4	44.1	28.4	26.0
Weight of Moisture	4.90	6.80	7.60	9.00	10.90	1.20	1.10
Weight of Dry Soil	13.60	15.90	15.80	17.00	19.30	4.90	4.60
Moisture Content	36.03	42.77	48.10	52.94	56.48	24.49	23.91
Liquid Limit	52.11%		Average Plastic Limit			24.20%	

Appendix C: Compaction Test

Test Location: BP from Adamawa

Sample No: 4%cmt 40%cmt

Volume of mold: 944 cm^3

Sample Description: Clay soil

Weight of mold (g)	3690		3690		3690		3690		3690	
Weight of mold + wet soil(g)	5362		5435		5555		5620		5564	
Weight of wet soil (g)	1,672.00		1,745.00		1,865.00		1,930.00		1,874.00	
Wet destiny (g/cm^3)	1.77		1.85		1.98		2.04		1.99	
Can number (g)	1	2	3	4	5	6	7	8	9	10
Weight of can (g)	38.4	38.7	34.8	39.0	10.0	38.4	38.8	9.9	24.9	23.5
Weight of can + wet soil (g)	104.4	94.2	95.8	101.4	62.8	108.3	116.8	67.9	95.8	85.5
Weight of can + dry soil (g)	95.9	87.0	85.6	91.6	53.1	95.3	100.5	55.7	78.5	70.5
Weight of water (g)	8.50	7.20	10,20	9.80	9.70	13.00	16.30	12.20	17.30	15.00
Weight of dry soil (g)	57.50	48.30	50.80	52.60	43.10	56.90	61.70	45.80	53.60	47.00
Moisture content (g)	14.78	14.91	20.08	18.63	22.51	22.85	26.42	26.64	32.28	31.91
Av. Moisture content (g)	14.84		19.35		22.68		26.53		32.10	
Dry Destiny (g/cm^3)	1.5422		1.5488		1.6104		1.6158		1.5028	

Appendix D: Compaction Test

Test Location: BP from Adamawa

Sample No: 6%cmt 40%cmt

Volume of mold: 944 cm^3

Sample Description: Clay Soil

Weight of mold (g)	3690	3690		3690		3690		3690		
Weight of mold + wet soil(g)	5396	5469		5580		5592		5580		
Weight of wet soil (g)	1,706.00	1,779.00		1,890.00		1,902.00		1,890.00		
Wet destiny (g/cm^3)	1.81	1.88		2.00		2.01		2.00		
Can number (g)	1	2	3	4	5	6	7	8	9	10
Weight of can (g)	24.9	38.2	24.7	24.6	24.5	24.3	24.5	24.7	35.2	37.9
Weight of can + wet soil (g)	71.2	78.2	67.7	80.8	75.5	77.2	90.0	84.7	91.1	91.4
Weight of can + dry soil (g)	64.9	72.9	60.6	71.6	65.7	67.2	75.9	71.8	77.2	78.2
Weight of water (g)	6.30	5.30	7.10	9.20	9.80	10.00	14.10	12.90	13.90	13.20
Weight of dry soil (g)	40.00	34.70	35.90	47.00	41.20	41.90	51.40	47.10	42.00	40.30
Moisture content (g)	15.75	15.27	19.78	19.57	23.79	23.87	27.43	27.39	33.10	32.75
Av. Moisture content (g)	15.51	19.68		23.83		27.41		32.92		
Dry Destiny (g/cm^3)	1.5645	1.5747		1.6169		1.5814		1.5062		

Appendix E: Compaction Test

Test Location: BP from Adamawa

Sample No: 6%cmt 40%cmt

Volume of mold: 944 cm^3

Sample Description: Clay Soil

Weight of mold (g)	3690		3690		3690		3690		3690	
Weight of mold + wet soil(g)	5396		5469		5580		5592		5580	
Weight of wet soil (g)	1,706.00		1,779.00		1,890.00		1,902.00		1,890.00	
Wet destiny (g/cm^3)	1.81		1.88		2.00		2.01		2.00	
Can number (g)	1	2	3	4	5	6	7	8	9	10
Weight of can (g)	24.9	38.2	24.7	24.6	24.5	24.3	24.5	24.7	35.2	37.9
Weight of can + wet soil (g)	71.2	78.2	67.7	80.8	75.5	77.2	90.0	84.7	91.1	91.4
Weight of can + dry soil (g)	64.9	72.9	60.6	71.6	65.7	67.2	75.9	71.8	77.2	78.2
Weight of water (g)	6.30	5.30	7.10	9.20	9.80	10.00	14.10	12.90	13.90	13.20
Weight of dry soil (g)	40.00	34.70	35.90	47.00	41.20	41.90	51.40	47.10	42.00	40.30
Moisture content (g)	15.75	15.27	19.78	19.57	23.79	23.87	27.43	27.39	33.10	32.75
Av. Moisture content (g)	15.51		19.68		23.83		27.41		32.92	
Dry Destiny (g/cm^3)	1.5645		1.5747		1.6169		1.5814		1.5062	

Appendix F: Values of UCS at 1 Day of Curing

	Dial Reading	Force (KN)	Deformation	Strain E	1- E	New Area	Stress
0% C + 0% CW	0.4	0.022	1.8	0.02368	0.97632	0.0011615	18.9409
0% C + 10% CW	1	0.055	1.2	0.01579	0.98421	0.0011522	47.7351
0% C + 20% CW	3	0.165	1.7	0.02237	0.97763	0.0011599	142.248
0% C + 30% CW	5	0.275	2.6	0.03421	0.96579	0.0011742	234.208
0% C + 40% CW	5.1	0.2805	2.4	0.03158	0.96842	0.001171	239.543
2% C + 0% CW	3.8	0.209	2.4	0.03158	0.96842	0.001171	178.483
2% C + 10% CW	5.8	0.319	2.2	0.02895	0.97105	0.0011678	273.162
2% C + 20% CW	7	0.385	1.5	0.01974	0.98026	0.0011568	332.805
2% C + 30% CW	9.3	0.5115	1.8	0.02368	0.97632	0.0011615	440.375
2% C + 40% CW	7.8	0.429	1.1	0.01447	0.98553	0.0011507	372.831
4% C + 0% CW	11	0.605	1.5	0.01974	0.98026	0.0011568	522.98
4% C + 10% CW	14.4	0.792	1.6	0.02105	0.97895	0.0011584	683.709
4% C + 20% CW	14.2	0.781	1.4	0.01842	0.98158	0.0011553	676.026
4% C + 30% CW	18.7	1.0285	1.7	0.02237	0.97763	0.0011599	886.679
4% C + 40% CW	14	0.77	1.1	0.01447	0.98553	0.0011507	669.185
6% C + 0% CW	19	1.045	1.5	0.01974	0.98026	0.0011568	903.329
6% C + 10% CW	21.8	1.199	1.5	0.01974	0.98026	0.0011568	1036.45
6% C + 20% CW	20	1.1	1.1	0.01447	0.98553	0.0011507	955.978
6% C + 30% CW	23	1.265	1.3	0.01711	0.98289	0.0011537	1096.44
6% C + 40% CW	21	1.155	0.8	0.01053	0.98947	0.0011461	1007.8

Appendix G: Values of UCS at 7 Day of Curing

	Dial Reading	Force (KN)	Deformation	Strain E	1- E	New Area	Stress
0% C + 0% CW	1	0.055	1.6	0.02105	0.97895	0.0011584	47.4798
0% C + 10% CW	2	0.11	1.6	0.02105	0.97895	0.0011584	94.9596
0% C + 20% CW	3.8	0.209	2.6	0.03421	0.96579	0.0011742	177.998
0% C + 30% CW	5.6	0.308	3.6	0.04737	0.95263	0.0011904	258.739
0% C + 40% CW	6	0.33	2.7	0.03553	0.96447	0.0011758	280.667
2% C + 0% CW	4.6	0.253	2.9	0.03816	0.96184	0.001179	214.591
2% C + 10% CW	7	0.385	2.3	0.03026	0.96974	0.0011694	329.232
2% C + 20% CW	8.5	0.4675	1.8	0.02368	0.97632	0.0011615	402.494
2% C + 30% CW	10	0.55	1.6	0.02105	0.97895	0.0011584	474.798
2% C + 40% CW	8.8	0.484	1.5	0.01974	0.98026	0.0011568	418.384
4% C + 0% CW	15	0.825	1.4	0.01842	0.98158	0.0011553	714.112
4% C + 10% CW	15.5	0.8525	1.9	0.025	0.975	0.0011631	732.97
4% C + 20% CW	18.4	1.012	1.7	0.02237	0.97763	0.0011599	872.454
4% C + 30% CW	22	1.21	1.3	0.01711	0.98289	0.0011537	1048.77
4% C + 40% CW	20.8	1.144	1.6	0.02105	0.97895	0.0011584	987.58
6% C + 0% CW	26	1.43	1.1	0.01447	0.98553	0.0011507	1242.77
6% C + 10% CW	19.8	1.089	1.3	0.01711	0.98289	0.0011537	943.891
6% C + 20% CW	25	1.375	0.8	0.01053	0.98947	0.0011461	1199.76
6% C + 30% CW	23	1.265	0.8	0.01053	0.98947	0.0011461	1103.78
6% C + 40% CW	24	1.32	1.6	0.02105	0.97895	0.0011584	1139.52

Appendix H: Values of UCS at 14 Day of Curing

	Dial Reading	Force (KN)	Deformation	Strain E	1- E	New Area	Stress
0% C + 0% CW	1	0.055	1.6	0.02105	0.97895	0.0011584	47.4798
0% C + 10% CW	2.2	0.121	1.3	0.01711	0.98289	0.0011537	104.877
0% C + 20% CW	3.3	0.1815	1.9	0.025	0.975	0.0011631	156.052
0% C + 30% CW	5.8	0.319	1.7	0.02237	0.97763	0.0011599	275.013
0% C + 40% CW	5.1	0.2805	1.5	0.01974	0.98026	0.0011568	242.473
2% C + 0% CW	4	0.22	1.5	0.01974	0.98026	0.0011568	190.175
2% C + 10% CW	6.8	0.374	1.2	0.01579	0.98421	0.0011522	324.599
2% C + 20% CW	8	0.44	1.2	0.01579	0.98421	0.0011522	381.881
2% C + 30% CW	9.6	0.528	0.9	0.01184	0.98816	0.0011476	460.095
2% C + 40% CW	8.8	0.484	1	0.01316	0.98684	0.0011491	421.192
4% C + 0% CW	16	0.88	1	0.01316	0.98684	0.0011491	765.803
4% C + 10% CW	17	0.935	1.1	0.01447	0.98553	0.0011507	812.581
4% C + 20% CW	22	1.21	0.8	0.01053	0.98947	0.0011461	1055.79
4% C + 30% CW	21	1.155	1	0.01316	0.98684	0.0011491	1005.12
4% C + 40% CW	21	1.155	1.1	0.01447	0.98553	0.0011507	1003.78
6% C + 0% CW	30.9	1.6995	1.1	0.01447	0.98553	0.0011507	1476.99
6% C + 10% CW	23.8	1.309	1.2	0.01579	0.98421	0.0011522	1136.09
6% C + 20% CW	34	1.87	1	0.01316	0.98684	0.0011491	1627.33
6% C + 30% CW	33	1.815	1	0.01316	0.98684	0.0011491	1579.47
6% C + 40% CW	28	1.54	1.3	0.01711	0.98289	0.0011537	1334.8

Appendix I: Values of UCS at 28 Day of Curing

	Dial Reading	Force (KN)	Deformation	Strain E	1- E	New Area	Stress
0% C + 0% CW	0.6	0.033	0.9	0.01184	0.98816	0.0011476	28.7559
0% C + 10% CW	2	0.11	1.6	0.02105	0.97895	0.0011584	94.9596
0% C + 20% CW	4.4	0.242	2.3	0.03026	0.96974	0.0011694	206.946
0% C + 30% CW	7	0.385	2.6	0.03421	0.96579	0.0011742	327.891
0% C + 40% CW	6.2	0.341	2.3	0.03026	0.96974	0.0011694	291.605
2% C + 0% CW	4.8	0.264	1.9	0.025	0.975	0.0011631	226.984
2% C + 10% CW	7.2	0.396	1.7	0.02237	0.97763	0.0011599	341.395
2% C + 20% CW	9.4	0.517	1.7	0.02237	0.97763	0.0011599	445.71
2% C + 30% CW	12	0.66	1.5	0.01974	0.98026	0.0011568	570.524
2% C + 40% CW	11	0.605	1.3	0.01711	0.98289	0.0011537	524.384
4% C + 0% CW	14.8	0.814	1.3	0.01711	0.98289	0.0011537	705.535
4% C + 10% CW	18.2	1.001	1.7	0.02237	0.97763	0.0011599	862.971
4% C + 20% CW	20.6	1.133	1.4	0.01842	0.98158	0.0011553	980.713
4% C + 30% CW	25	1.375	1.4	0.01842	0.98158	0.0011553	1190.19
4% C + 40% CW	25	1.375	1.1	0.01447	0.98553	0.0011507	1194.97
6% C + 0% CW	30	1.65	1.3	0.01711	0.98289	0.0011537	1430.14
6% C + 10% CW	28	1.54	1.3	0.01711	0.98289	0.0011537	1334.8
6% C + 20% CW	34	1.87	1.2	0.01579	0.98421	0.0011522	1622.99
6% C + 30% CW	35	1.925	1.1	0.01447	0.98553	0.0011507	1672.96
6% C + 40% CW	32	1.76	1.3	0.01711	0.98289	0.0011537	1525.48

Appendix J:Values of UCS at 60 Day of Curing

	Dial Reading	Force (KN)	Deformation	Strain E	1- E	New Area	Stress
0% C + 0% CW	1	0.055	0.7	0.00921	0.99079	0.0011445	48.0542
0% C + 10% CW	2.1	0.1155	1	0.01316	0.98684	0.0011491	100.512
0% C + 20% CW	5	0.275	2.3	0.03026	0.96974	0.0011694	235.165
0% C + 30% CW	7.4	0.407	2.2	0.02895	0.97105	0.0011678	348.517
0% C + 40% CW	7	0.385	2	0.02632	0.97368	0.0011646	330.572
2% C + 0% CW	4.9	0.2695	1.7	0.02237	0.97763	0.0011599	232.338
2% C + 10% CW	8.7	0.4785	1.2	0.01579	0.98421	0.0011522	415.295
2% C + 20% CW	11	0.605	1.1	0.01447	0.98553	0.0011507	525.788
2% C + 30% CW	11.2	0.616	1.1	0.01447	0.98553	0.0011507	535.348
2% C + 40% CW	10	0.55	0.8	0.01053	0.98947	0.0011461	479.903
4% C + 0% CW	19	1.045	1.1	0.01447	0.98553	0.0011507	908.179
4% C + 10% CW	22.8	1.254	1.4	0.01842	0.98158	0.0011553	1085.45
4% C + 20% CW	24	1.32	0.9	0.01184	0.98816	0.0011476	1150.24
4% C + 30% CW	26.4	1.452	1.1	0.01447	0.98553	0.0011507	1261.89
4% C + 40% CW	22	1.21	0.9	0.01184	0.98816	0.0011476	1054.38
6% C + 0% CW	30	1.65	1	0.01316	0.98684	0.0011491	1435.88
6% C + 10% CW	33	1.815	0.8	0.01053	0.98947	0.0011461	1583.68
6% C + 20% CW	35	1.925	1.1	0.01447	0.98553	0.0011507	1672.96
6% C + 30% CW	56	3.08	1.3	0.01711	0.98289	0.0011537	2669.59
6% C + 40% CW	41	2.255	1.2	0.01579	0.98421	0.0011522	1957.14