# SUSTAINABLE USE OF CALCIUM CARBIDE RESIDUE TO ENHANCE THE STRENGTH OF CEMENT STABILIZED CLAY SOIL IN ROAD CONSTRUCTION

BY

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# THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ENGINEERING IN CIVIL ENGINEERING (GEOTECHNICAL ENGINEERING)

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#### ABSTRACT

Clayey soil collected along Gwagwalada – Garki road was characterized and classified as A-7-6 soil according to American Association of State Highway and Transportation Officials (AASHTO) soil classification system. The clay was treated with 0, 2, 4 and 6% cement which was admixed with 0, 3, 6, 9, 12 and 15% Calcium Carbide Residue (CCR). Unconfined Compressive Strength (UCS) test was used as evaluation criterion to measure the effect of CCR on the cement stabilized clayey soil. Results showed significant increase in UCS with increase in cement and CCR. In the absence of cement, the UCS was observed to increase from 71 kN/m<sup>2</sup> at 0% CCR to 602 kN/m<sup>2</sup> at 15% CCR and 90 day curing. At 6% cement, the UCS increased from 473 kN/m<sup>2</sup> at 0% CCR to 3589 kN/m<sup>2</sup> at 15% CCR and 90 day curing. This UCS strength has satisfied the strength required for a soil material to be used as base course for high trafficked road bases. It was also observed that 12 - 15% CCR is the optimal content required for efficient stabilization of clayey soils.

# TABLE OF CONTENTS

| Conte            | ent                               | Page |  |  |
|------------------|-----------------------------------|------|--|--|
| Title p          | bage                              | i    |  |  |
| Decla            | ration                            | ii   |  |  |
| Certif           | ication                           | iii  |  |  |
| Dedic            | ation                             | iv   |  |  |
| Acknowledgements |                                   |      |  |  |
| Abstract         |                                   |      |  |  |
| Table            | of contents                       | viii |  |  |
| List of          | f Tables                          | xi   |  |  |
| List of          | f Figures                         | xii  |  |  |
| Abbre            | viations, Glossaries and Symbols  | xiii |  |  |
| CHAI             | PTER ONE                          |      |  |  |
| 1.0              | INTRODUCTION                      | 1    |  |  |
| 1.1              | Background to the Study           | 1    |  |  |
| 1.2              | Statement of the Research Problem | 2    |  |  |
| 1.3              | Aim and Objectives of the Study   | 3    |  |  |
| 1.4              | Scope of the Study                | 4    |  |  |
| 1.5              | Justification of the Study        | 4    |  |  |
| CHAI             | PTER TWO                          |      |  |  |
| 2.0              | LITERATURE REVIEW                 | 6    |  |  |
| 2.1              | Stabilization                     | 6    |  |  |
| 2.1.1            | Classification of stabilization   | 7    |  |  |
| 2.1.2            | Component of stabilization        | 7    |  |  |
| 2.2              | Clays                             | 8    |  |  |
| 2.3              | Stabilizing Agent                 | 9    |  |  |
| 2.3.1            | Cement                            | 9    |  |  |

| 2.3.2   | Lime  | 10 |
|---------|---|----|
| 2.3.3   | Calcium carbide residue   | 12 |
| CHAP    | TER THREE   |    |
| 3.0     | MATERIALS AND METHODOLOGY   | 17 |
| 3.1     | Materials   | 17 |
| 3.1.1   | Clay soil   | 17 |
| 3.1.2   | Calcium carbide residue   | 17 |
| 3.1.3   | Cement  | 17 |
| 3.1.4   | Distilled water   | 17 |
| 3.2     | Method/Experiment   | 18 |
| 3.2.1   | Scanning electron microscopy                                      | 19 |
| 3.2.2   | X-ray diffraction analysis  | 19 |
| 3.2.3   | Index properties  | 20 |
| 3.2.3.1 | Specific gravity  | 20 |
| 3.2.3.2 | Sieve analysis  | 20 |
| 3.2.5.3 | Hydrometer analysis   | 21 |
| 3.2.3.3 | Liquid limit  | 21 |
| 3.2.3.4 | Plastic limit   | 22 |
| 3.2.4   | Compaction  | 22 |
| 3.2.5   | Unconfined compressive strength                                   | 23 |
| CHAP    | TER FOUR  |    |
| 4.0     | <b>RESULTS AND DISCUSSIONS</b>                                    | 25 |
| 4.1     | Index Properties  | 25 |
| 4.2     | Microstructural Analysis of Clay                                  | 26 |
| 4.2.1   | Oxide composition of the clay, cement and CCR                     | 26 |
| 4.2.2   | X-ray diffraction analysis  | 27 |
| 4.2.3   | Scanning electron microscopy and electron dispersion spectroscopy | 29 |

| 4.2.4      | Effect of CCR on cement stabilized clay                       | 31 |
|------------|---|----|
| 4.2.4      | Effect of curing time on cement and CCR stabilization of clay | 35 |
| СНАР       | TER FIVE  |    |
| 5.0        | CONCLUSION AND RECOMMENDATION                                 | 39 |
| 5.1        | Conclusion  | 39 |
| 5.2        | Recommendations   | 40 |
| 5.3        | Contribution to Knowledge                                     | 40 |
| REFERENCES |   |    |

# LIST OF TABLES

| Table | Title                                     | Page |
|-------|---|------|
| 2.1   | Physicochemical properties of CCR         | 13   |
| 4.1   | Index properties of the soil sample       | 25   |
| 4.2   | Oxide composition of clay, cement and CCR | 26   |

### LIST OF FIGURES

| Figure | Title  | Page |
|--------|--|------|
| 3.1    | (a) Calcium carbide residue, (b) Clay soil                         | 18   |
| 3.2    | Unconfined Compressive Strength test equipment                     | 24   |
| 4.1    | Particle grain size analysis of clay                               | 26   |
| 4.2    | XRD result for untreated clay                                      | 27   |
| 4.3    | XRD result for clay treated with 6% cement                         | 28   |
| 4.4    | XRD result for clay treated with 15% cement                        | 28   |
| 4.5    | XRD result for clay treated with 6% cement and 15% CCR             | 29   |
| 4.6    | Results of Untreated Clay for: (a) SEM, (b) EDS                    | 30   |
| 4.7    | Results of the Clay and Clay mixed with 6% cement for: (a) EDS and |      |
|        | (b) SEM  | 30   |
| 4.8    | Results of the Clay and Clay mixed with 6% cement for: (a) SEM and |      |
|        | (b) EDS  | 31   |
| 4.9    | Results of the Clay and Clay mixed with blend of 6% cement and 15% |      |
|        | CCR for: (a) SEM and (b) EDS                                       | 31   |
| 4.10   | Variation of UCS with CCR for 0% cement                            | 33   |
| 4.11   | Variation of UCS with CCR for 2% cement                            | 33   |
| 4.12   | Variation of UCS with CCR for 4% cement                            | 34   |
| 4.13   | Variation of UCS with CCR for 6% cement                            | 34   |
| 4.14   | Variation of UCS with curring days for 0% cement                   | 35   |
| 4.15   | Variation of UCS with curring days for 2% cement                   | 36   |
| 4.16   | Variation of UCS with curring days for 4% cement                   | 36   |
| 4.17   | Variation of UCS with curring days for 6% cement                   | 37   |

# ABBREVIATIONS, GLOSSARIES AND SYMBOLS

| BS       | British Standard                        |
|----------|---|
| CCR      | Calcium carbide residue                 |
| CL       | Clayey soil                             |
| FUTMINNA | Federal University of Technology, Minna |
| Gs       | Specific gravity                        |
| LL       | Liquid Limit                            |
| М        | Mass                                    |
| m        | Meter                                   |
| MH       | Silt of high plasticity                 |
| ML       | Silt of low plasticity                  |
| NMC      | Natural moisture content                |
| NP       | Non-Plastic                             |
| OPC      | Ordinary Portland cement                |
| PI       | Plasticity Index                        |
| PL       | Plastic Limit                           |
| SC       | Clayey sand                             |
| UCS      | Unconfined comprehensive strength       |
| USCS     | Unified Soil Classification System      |
| XRD      | X-ray diffraction                       |
| XRF      | X-ray fluorescence                      |
| SEM      | Scanning electron microscopy            |
| EDS      | Electron dispersive spectroscopy        |

#### **CHAPTER ONE**

#### **INTRODUCTION**

#### **1.1** Background to the Study

1.0

Expansive clays are common for swelling, shrinkage and other forms of weaknesses which make it difficult as materials to support civil engineering structures or to be used in construction of some civil engineering structures including pavements. In a region where clay soils are the dominant soil materials available, stabilization of the clay soil to meet the requirements is inevitable. Many researchers (Khajuria and Chopra, 2019; Abdullah *et al.*, 2017; Du *et al.*, 2019; Xiao *et al.*, 2019; Pourakbar *et al.*, 2016) have used different additives to improve the strength and durability of weak clay soils.

Fine-grained soils without stabilization are unsuitable for earth structures and pavement. The chemical stabilization is one of the extensively used techniques to improve the engineering properties of fine-grained soils. Portland cement is commonly used for this stabilization in most areas. The resistance to compression and consequent strength development increase with increasing curing time. However, the high unit cost and energy intensive process of Portland cement is driving a search for alternative cementitious additives. For fine-grained soils, which contain high natural Pozzolanic materials, silica rich materials can be used to produce a moderately high strength geomaterial (Horpibulsuk *et al.*, 2011; Songsuda *et al.*, 2013).

Cement stabilization is one of the extensively used techniques to rectify the deficiencies in engineering properties of expansive soils, especially for pavement applications. An advantage of cement stabilization is that the required strength can be attained in a shorter period. The effect of moisture content, replacement ratio, compaction effort, curing period, and cement content on the engineering characteristics and microstructure of cement aided soils is widely being researched (Deng *et al.*, 2012; Venkatesh *et al.*, 2018).

Clays exhibiting poor engineering properties such as low strength, high compressibility, and high shrinkage/swelling potential pose a major challenge to several construction and geotechnical engineering applications (Chen *et al.*, 2017). Chemical stabilization is commonly used to improving engineering properties of problematic soils. Several recent studies have shown that CCR stabilization can improve strength characteristics, dispersibility, and swelling potential of problematic soils (Arulrajah *et al.*, 2016).

Calcium carbide residue (CCR) is a by-product of the acetylene production process that contains mainly calcium hydroxide Ca(OH)<sub>2</sub>. Compared to hydrated lime, CCR has similar chemical and mineralogical compositions. The Ca(OH)<sub>2</sub> contents are approximately 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)<sub>2</sub> and CaO contents of CCR indicates that it can react with Pozzolanic material such as Coconut Shell Ash and produce a cementitious material. The production of CCR is best described by the following equation (Balarabe and Mary, 2015):

$$CaS_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2 \tag{1.1}$$

This study is therefore aimed at determining the effect of CCR on cement stabilized clay soil.

#### **1.2** Statement of the Research Problem

The increasing world population, especially in 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.

Clayey soils swell or increase in volume in tropical rainy seasons on imbibition of water, and shrink or reduce in volume because of evaporation of water in dry seasons. As a result of the alternate swelling and shrinkage of clay soils, structures such as foundations, pavements, residential buildings, constructed on it experienced severe damage.

Also, in developing countries like Nigeria, there are many acetylene gas production units and PVC chemical plants, which produce CCR in huge amounts. It is usually dumped in the landfills and causes environmental problems to landfills due to its alkalinity. Therefore, the use of CCR to stabilize soil will reduce the problem of waste disposal.

#### 1.3 Aim and Objectives of the Study

#### Aim

The aim of this work is to investigate the sustainable use of calcium carbide residue to enhance the strength of cement stabilized clay soil in road construction.

#### **Objectives**

To achieve the above aim, the following objectives are to;

- i. determination of index properties of Clay soil samples.
- determination of Microstructural analysis of the clay using XRD, XRF and SEM.
- iii. determination of Unconfined Comprehensive Strength of untreated clay and clay treated with varied composition of cement and Calcium Carbide Residue.

iv. determination of effect of calcium carbonate residue on cement stabilized clay.

#### **1.4** Scope of Work

The scope of the study focuses on the laboratory tests on clay soil collected from Bako village along Gwagwalada – Garki road using the methods highlighted in BS 1377, (1990). Index properties tests such as natural moisture content, specific gravity, particle size distribution, liquid limits test and plastic limit tests to be carried out on the untreated expansive clay soil. Other engineering properties tests such as Compaction characteristics and Unconfined Comprehensive Strength (UCS) to be carried out on the untreated expansive clay soil and clay soil treated with cement and calcium carbide at cement replacement of 0, 2, 4 and 6% and Calcium Carbide replacement of 3, 6, 9, 12 and 15% concurrently.

#### **1.5** Justification of Study

In order to address the above problems of changes in volume of Clay soils for construction activities in our society and other environmental problems relating to the disposal of waste industrial by-products like Calcium Carbide while reducing costs of construction, Calcium Carbide Residue will be used to stabilized Clay Soil in this research work because of the material constituent compositions which can replace cement without much utilization of energy, with lower temperature rise and improvement in durability and strength.

The findings of this research work will therefore add more knowledge on the existing literatures and will act as a supportive insight for further research on the use of Calcium Carbide Residue as a clay soil stabilizing material.

13

In addition, the use of Calcium Carbide Residue is not common in the Nigerian construction sector. This study will be able to enhance the understanding on the suitability of Calcium Carbide Residue as cement replacement material for stabilization.

#### **CHAPTER TWO**

2.0

#### LITERATURE REVIEW

#### 2.1 Stabilization

Soil stabilization is a procedure where we altered and enhanced engineering properties of the soil to increase its suitability for construction purposes. It is a technique to refine and improve the engineering properties of soils such as mechanical strength, permeability, compressibility, durability and plasticity (Behnood, 2018). In the past, many researchers have carried out their research work for improving the strength of Clay soil using different types of admixture at different percentages (Dhananjay *et al.*, 2016). Stabilization has been applied in various aspects of engineering services. These include:

a. Excavation works: It provides support in trenches, pit and tunnels by permeability variation of the soil and soil surrounding strengthening. Accelerated drainage and grouting are the methods used.

b. Foundations: It improves volume stability, permeability control and strength increment by reducing settlement or heave under buildings.

c. Slope stability: This prevents cut slopes, natural slopes and embankments not to slip. Drainage and surface seals are mainly applied.

d. Construction of pavement: Pavement of higher strength and durability for highways, railways and airfield are provided. Chemical and mechanical methods are basically used.

e. Environmental Conservation: It prevents combat dusting of road surfaces and erosion. The resistance of soil to natural weathering from water or wind ought to be increased for engineering conversation to be achieved.

f. Thickness reduction: It reduces the thickness of the pavement less than what it ought to have been without stabilization.

#### **2.1.1** Classification of stabilization

The stabilization of clay soil can be classified as following:

a. Mechanical Stabilization: This is the oldest of all the classification of soil stabilization which has been defined as the mixture of appropriately proportional soil aggregates with some binder soil like clay, after which the mixture is properly compacted to a stable layer (Ola, 1981).

b. Heat Stabilization: stabilization by means of calcination and heat.

c. Drainage Stabilization: to reduce the water table involves an immediate reduction of the expansive risk.

d. Electrical Stabilization: electromechanical piles, electro-osmosis.

e. Chemical Stabilization: this is addition of stabilizing agents to enhance chemical reaction. A chemical stabilization method is the fundamental for this project. Soil stabilization depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect. Therefore, throughout the rest of this report, the term soil stabilization will mean chemical stabilization (Carlous *et al.*, 2014).

#### 2.1.2 Components of stabilization

In the State-of-the-Art review of soil stabilization methods and materials in engineering practice carried out by Gregory, (2012) reported that, soil stabilization involves the use of stabilizing agents (binder materials) in weak soils to improve its geotechnical properties such as compressibility, strength, permeability and durability. The

components of stabilization technology include soils and or soil minerals and stabilizing agent or binders (cementitious materials)

#### 2.2 Clays

Clays are generally composed of micro-crystalline particles of a group of minerals. Since clay science has been the interest of people from different backgrounds, a specific definition of this material is not available (Sirivitmaitrie *et al.*, 2008; Ali *et al.*, 2016). Generally, clays are naturally occurring material primarily composed of fine-grained minerals, show plasticity when mixed with appropriate amount of moisture and become hard when dried or fired. It can be used when moulded into various forms as bricks, tiles, pottery of all form, tobacco pipes, and other products (Sirivitmaitrie *et al.*, 2011; Das, 2015; Ali *et al.*, 2016). Das, (2015) indicated the characteristics of clay, which included:

- a) Small particle size (usually smaller than 0.002 mm)
- b) Net negative charge
- c) Show plasticity when mixed with moisture.

Clay mineral structures are usually of covalent bonds which permit the flow of water molecule through its chains and leads to significant volume increase which vanishes at the evaporation of the water. The shrinkage and swelling phenomenon has been termed as a volumetric instability which behaves as expansive soil. The attribute of clay to absorb moisture and its volumetric increase is considered to be highly promoting very relevant damages to the infrastructure and to buildings as a whole (Carlous *et al.*, 2014).

#### 2.3 Stabilizing Agents

These are hydraulic (primary binders) or non-hydraulic (secondary binders) materials that when in contact with water or in the presence of pozzolanic minerals reacts with water to form cementitious composite materials. The commonly used binders are (Gregory, 2012):

- i. cement
- ii. hydrated lime

iii. fly ash

- iv. blast furnace slag
- v. calcium carbide residue

#### **2.3.1 Cement**

Portland cement is essentially calcium silicate content, which is produced by firing to partial fusion, at a temperature of approximately 1500°C, a well-homogenized and finely ground mixture of limestone or chalk (calcium carbonate) and an appropriate quantity of clay or shale. The composition is commonly fine-tuned by the addition of sand and/or iron oxide. The utilization of a cement-based stabilizer on weak and expansive clay soils have been studied extensively by various researchers (Xiao *et al.*, 2019; Anil *et al.*, 2017; Deng *et al.*, 2012; Du *et al.*, 2019).

Anil and Ahsan (2017) in their research work, Soil Stabilization Using Cement, investigated that the increasing in cement content helped in: increase of OMC of soil-cement; providing durability and strength for base/sub-base materials with outstanding values; increasing the rate of stabilization by also increasing the value of UCS; evenly distributed of loads, base rutting elimination, control deflection and reduced problem of moisture.

The study by Chuanxin *et al.* (2019), "Multiscale Study of the Influence of Promoters on Low-plasticity Clay Stabilized with Cement-based Composites" presented the results of the utilization of a cement-based composite stabilizer on modification of soil. The stabilization mechanism of a cement-based composite stabilizer was analyzed using XRD and SEM. Though, the effects of other additives on the engineering properties of clay soil were also evaluated and investigated. The reaction between the calcium hydroxide produced by cement hydration and the active clay minerals, such as SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> produced hydrated calcium silicate, which mainly improved the strength of clay. The study concluded that the addition of the additives such as NaOH and the cement improved the conductivity and pH of the soil.

According to Hayder *et al.* (2017), the traditional use of Ordinary Portland Cement (OPC) to stabilize expansive soils through chemical reaction was researched. As a percentage of soil, low amount of cement is being usually added to granular soils and higher amount to plastic soils. Nevertheless, several environmental issues rose from the use of OPC in the last decades, and carbon footprint associated with OPC construction industry formed a main environmental limitation. 0.8-1 tonne of carbon dioxide (CO<sub>2</sub>) is commonly released to the atmosphere form the manufacturing of 1 tonne of OPC. Consequently, 7% of the total CO<sub>2</sub> emission is generated from the cement industry. Considering the effect of such an emission problem along with other environmental effects related to the limitation in sourcing of raw materials, which prompt the research to reduce the use of cement content.

#### 2.3.2 Lime

Lime such as quick lime or slaked lime is one of the major constituent in formation of cementitious compounds. This has been attributed to the presence of Calcium ion in lime which can actively substitute many other ions around clay particles to form agglomeration of smaller particles to bigger ones. This reaction will reduce the plasticity of the clay soils and increase their workability. The use of lime and other Pozzolanic materials to stabilize weak and expansive clay soils have been studied extensively.

The earlier work of Sharma (2012) depicts the use of lime and pozzolanic fly ash to stabilize expansive clay soil. Though, the author concentrated on the microstructural behaviour of weak clays when treated with lime and fly ash as against the use of strength characteristics, X-ray diffraction (XRD) tests, scanning electron microscopy (SEM) tests coupled with Electron dispersive spectroscopy (EDS) tests and Thermal gravimetric analysis were used as evaluation criteria. The author confirmed the breaking down of montmorillonite structures on addition of lime and fly ash. The author also concluded that during stabilization process, Pozzolanic reaction dominated over cation exchange capacity.

The work of Muntohar *et al.* (2013) is a similar research but admixed with rice husk ash and waste plastic fiber. The researcher used compressive, California bearing ratio (CBR), tensile and shear strength tests as evaluation criteria to measure the effect of lime, rice husk ash (RHA) and waste plastic fiber on the strength and durability of silty clay soil. It was concluded that the addition of lime and RHA increased the compressive and tensile strength by 4 times and 5 times respectively. The CBR was observed to increase by 3.6 times on addition of lime and RHA. However, addition of waste plastic fiber to this mixture increased the CBR by 8.7 times. Effect of bagasse ash on lime stabilized lateritic soil was studied extensively (Sadeeq *et al.*, 2015). The lateritic soil used by the author classified as clay of low plasticity (CL) based on Unified Soil Classification System (USCS). The laterite was treated with 0, 2, 4, 6 and 8% of each bagasse ash and lime. The maximum UCS and CBR values of 698 kN/m2 and 43% respectively for the laterite soil treated with 8% lime and 6% bagasse ash.

Kang *et al.* (2015) worked on stabilization of clay soil using class C fly ash and lime kiln dust (LKD) for subgrade use. The researcher used UCS and resilient modulus as evaluation criteria to measure the effect of fly ash and LKD on the engineering properties of clay soil. It was concluded that addition of fly ash and LKD improve the UCS and resilient modulus of the clay tremendously. The author also developed a relationship between UCS and resilient modulus. The study by James and Pandian (2016) is also a contribution to the use of lime and Pozzolanic (ceramic dust) material for stabilization of clay soils. Addition of ceramic dust was observed to give negative result at early stabilization age but gave increased strength of about 12-14%. The microstructural analysis revealed that there is formation of dense and compact microstructure.

#### 2.3.3 Calcium carbide residue (CCR)

Calcium carbide residue (CCR) contains large amount of lime and is a major waste from acetylene factory which constitutes serious nuisance to environment (Horpibulsuk *et al.*, 2013). It is a by-product obtained from producing acetylene gas ( $C_2H_2$ ) used in industrial welding operations, and in chemical synthesis. It is also used in caving to fuel acetylene lamps. Hydrated lime and calcium carbide are synthesised from limestone. The modern industrial synthesis of  $CaC_2$  involves high temperature combustion of a mixture of calcium oxide and coke, as presented in equation

 $CaO + 3C \longrightarrow CaC_2 + CO$  (2.1)

The reaction of calcium carbide with water creates acetylene and calcium hydroxide, presented as equation (Joel and Edeh, 2016):

| Property         | Value |
|------------------|-------|
| Specific gravity | 2.25  |
| pH               | 12.2  |
| CaO (%)          | 90.1  |
| SiO2 (%)         | 5.07  |
| Al2O3 (%)        | 3.62  |
| Fe2O3 (%)        | 1.21  |

Table 2.1:Physicochemical properties of CCR

(Source: Nima et al., 2018)

In developing countries like Nigeria, a lot of local welding exercises by individuals and few groups of people are very common. This action has led to generation of wastes calcium carbide residue. Various researchers have worked on the utilization of CCR in addition to Pozzolanic materials to stabilize deficient soils. The study by Du *et al.* (2016) was a good presentation of the potential of CCR for use as material for subgrade stabilization of weak clay soil. Field CBR, plate load test, Benkelman beam deflection test and dynamic cone penetration (DCP) tests were used as evaluation criteria to evaluate the potential of CCR for stabilization of weak subgrade clay soil. Results showed that treatment of soft subgrade with CCR increased the value of CBR and resilient modulus and resulted in to a low construction cost. Binary blending of CCR and palm oil fuel ash were used to stabilize fine grained soils (Majeed *et al.*, 2018). Atterberg limits and UCS strength were used to evaluate the effect of CCR and palm oil fuel ash on the fine grained soils. It was concluded that UCS showed very high increase for clay treated with binary mixtures compared to those treated with CCR only. The work of Vichan and Rachan (2013) investigated the amount of CCR and biomass ash

22

(BA) required to cause Pozzolanic reaction. The author used SEM and XRD to elucidate the Pozzolanic reaction going on in the clay after addition of CCR and BA. High increase in UCS strength was recorded due to Pozzolanic reaction between the binders and the clay.

Clay of intermediate plasticity (CI) and clay of high plasticity (CH) were both treated with CCR and Cocoanut shell ash (CSA) to improve their strength and stability (Isah and Sharmila, 2015). 4% CCR and 6% CCR were mixed with the (CI) and CH respectively, which were in turn admixed with 4, 9, 14 and 19% CSA each. The MDD was observed to decrease with increase in CSA while the OMC decreased in the same order. The UCS values of the CI clay recorded 11.38 times the value of the untreated clay soil while the CH clay recorded 6.03 times the value of the untreated clay soil.

The study by Akinwumi *et al.* (2019) focused on the potential use of CCR to stabilize tropical sands for pavement structures. The researcher used Atterberg limits, UCS and CBR as evaluation criteria to determine the effect of CCR on tropical sandy soil. The UCS values increased from 220 kN/m2 for untreated clay soil to 420 kN/m2 on addition of 16% CCR, while the CBR increased from 54% for untreated clay to 66% on addition of 16% CCR. The study on the effect of cement and CCR on the engineering properties of residual lateritic soil was carried out by Joel and Edeh (2014). 2 – 10% cement and 2 – 10% CCR were each used to stabilize Ikpayongo laterite to determine the effect of cement and CCR on the engineering the effect of cement and CCR on the lateritic soil. The author concluded that the UCS and CBR values increased from 534 kN/m2 and 28% for untreated soil respectively to 3157 kN/m2 and 180% respectively for clay stabilized with combination of 10% cement and 10% CCR. The use of two industrial wastes (ground granulated blast furnace slag and CCR), to stabilize soil was investigated

(Bandyopadhyay *et al*, 2016). Addition of these two additives improved the permeability, UCS and CBR of the soil thereby reducing the thickness of pavements.

Application of CCR as stabilizer to treat waste sludge was investigated (Liu *et al.*, 2018). The author used direct shear test and UCS tests as evaluation criteria to determine the effect of CCR on the strength of remolded sludge. 10-15% CCR was observed to be the optimum CCR required to give maximum strength to the remolded sludge. A blend of CCR and hydrated lime was used to stabilize lateritic soil by replacing CCR with hydrated lime in 2% incremental order to 100% (Joel and Edeh, 2016). UCS test, durability test and CBR test were used as evaluation criteria to evaluate the effect of replacement of CCR with hydrated lime on the strength and durability of lateritic soil. Results showed that 70% replacement of CCR with hydrated lime was recommended for use to stabilize lateritic soil. The parametric study of soil stabilized with sugarcane bagasse ash (SBA) and CCR was carried out by Hatmoko and Suryadharma (2018). Due to short time reaction, the maximum stiffness occurs at moisture content 2below optimum while after 28 days curing period, the maximum stiffness occurs at optimum moisture content.

Ning-Jun *et al.* (2016) in their study, Multi-scale Laboratory Evaluation of the Physical, Mechanical and Microstructural Properties of Soft Highway Subgrade Soil Stabilized with Calcium Carbide Residue, observed that, the stabilization by CCR or quicklime results in increase in the liquid limit and plastic limit while decease in the plasticity index. The addition of CCR or quicklime also leads to an increase in sand-sized particle percentage. Under the same curing period and binder content, the CCR stabilized soil attains higher sandy-sized particle percentage relative to the quicklime stabilized soil. The increase in the curing time and binder content facilitates larger q<sub>u</sub>, CBR and M<sub>r</sub>. Under the same curing period, binder content and degree of compaction, the CCR stabilized soil exhibits superior mechanical performances relative to the quicklime stabilized soil. That Both CCR and quicklime stabilized soils display a gradual reduction in soil pH with increased curing time, and pH of the CCR stabilized soil is always higher relative to the quicklime stabilized soil. Pozzolanic products like C-S-H, C-A-H and C-A-S-H are identified in both CCR and quicklime stabilized soils. The summed content of Pozzolanic products in the CCR stabilized soil is higher than that in the quicklime stabilized soil. The CCR stabilized soil has a much smaller total pore volume than the quicklime stabilized soil within the initial 28 days, though the difference is almost eliminated at 120 days. The strength of the stabilized soil is found conversely correlated with the large pore volume in the soil. And that, The fundamental mechanisms for the superior mechanical performances of the CCR stabilized soil over quicklime stabilized soil are the faster and more complete formation of flocculation and agglomeration of soil particles at the early stage as well as Pozzolanic reactions within soils for the entire curing time. Finer particle size, greater specific area and higher pH value of CCR than quicklime are the essential contributors to the controlling mechanisms.

#### **CHAPTER THREE**

3.0

#### MATERIALS AND METHODS

#### 3.1 Materials

The materials used for this project were Clay Soil, Calcium Carbide Residue (CCR), Cement and Distilled Water which are shown in Figure 3.1.

#### 3.1.1 Clay soil

The clay was collected from Bako village, a site proposed for T. Y. Danjuma University along Gwagwalada-Garki road. 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 (1990).

#### 3.1.2 Calcium carbide residue (CCR)

The CCR used was collected from local welders at Keteren-Gwari mechanic site, Minna, Niger State, Nigeria. This area contains a lot of calcium carbide residue waste which is usually disposed indiscriminately. The CCR sludge was air-dried, crushed and passed through sieve 0.075mm before used for the test.

#### 3.1.3 Cement

The Cement used for this research work was Ordinary Portland Cement (Dangote) and was purchased from Building Materials Shop in Minna, Niger State, Nigeria.

#### 3.1.4 Distilled water

The distilled water was obtained from medical shop opposite General Hospital Minna, Niger State, Nigeria.



**Figure 3.1:** (a) Calcium carbide residue; (b) Clay soil;

#### **3.2** Method/Experiment

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 (1990). X-Ray Diffraction (XRD) and X-Ray fluorescence (XRF) tests were also carried out on the clay soil. The tests were conducted in Ithemba Laboratory, 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.

The following tests and experiments were conducted on the untreated clay Soil and clay soil treated with varied composition of cement and Calcium Carbide Residue:

- i. Index properties test on the untreated clay soil to characterize the clay.
- ii. Compaction test on the untreated clay to determine the compaction characteristics of the clay.
- iii. Scanning Electron Microscopy (SEM): To determine the morphology of the untreated clay specimen and clay specimen treated with selected composition of cement and calcium carbide residue.

- iv. X-ray diffraction analysis (XRD) on the untreated clay and clay treated with selected composition of cement and calcium carbide residue
- v. Unconfined Compressive Strength (UCS) test on the untreated clay and clay treated with varied composition of cement and calcium carbide residue.

#### **3.2.1** Scanning electron microscopy (SEM)

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 Zeiss Auriga 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.

#### 3.2.2 X-ray diffraction analysis (XRD)

X-Ray diffraction analysis of the clay soil was carried out by conducting the analysis with the use of Bruker AXS D8 XRD system in Ithemba Laboratory, 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 by collection of ten grams of soil sample, which were finely ground to powder form and sieved with a sieve of less than 10um size. The ground sieved sample was then placed into a sample holder, a flat upper surface was ensured by uniformly smeared the sample on a glass slide. X – Rays were directed toward the sample and diffracted rays were recorded. The X – Rays scanning speed was 5.00/min over a range of 0 -  $80^{\circ}$  2 $\theta$  and the X – Rays used were copper K $\alpha$  radiation at 40Kv and 30MA. Moocher (2004) described the relative peak intensities in the XRD pattern by estimated mineral content of the clay sample.

#### **3.2.3** Index properties test

#### 3.2.3.1 Specific gravity (Gs)

The density bottles with stoppers were cleaned and dried and weighed empty with the stopper as  $W_1$ . Approximately 50g of soil sample that passed through sieve size 2mm was transferred into the density bottles. The density bottles with the stoppers and the sieved samples were weighed as  $W_2$ . Distilled water was added at a room temperature and covered and allowed for about 4 hour to fully soak. Immediately after the addition of water, the stoppers were inserted, the bottles together with the content were shaken for about period of 20 mins, and the stoppers were then removed and water was added to reach 250ml capacities. The bottles with stoppers and the content were weighed as  $W_3$ . The density bottles were emptied and thoroughly cleaned and oven dried at 105°C. The clean oven dried density bottles were filled with distilled water to 250ml capacities and stoppers were inserted and then weighed as  $W_4$ . The specific gravity of the sample was calculated from:

$$Gs = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$
(3.1)

Where;

- $W_1$  = Weight of bottle (g)
- $W_2$  = Weight of bottle +dry soil (g)
- $W_3 =$  Weight of bottle + soil + water (g)
- $W_4$  = Weight of bottle + water (g).

#### 3.2.3.2 Sieve analysis

The method used was dry sieving method with mechanical shaker. The procedure adopted involved weighing of 400g of the oven-dried soil. Set of sieves were arranged sequentially with the sieve having the largest apertures on top and that with the lowest size below as follows; 5.0, 3.35, 2.0, 1.18, 0.85, 0.60, 0.425, 0.300, 0.150, and

0.075mm, and ending with the pan at the base. The oven dried samples were poured into the uppermost sieve and the set of the sieves placed on a mechanical sieve shaker, and allowed to shake for 10 minutes. The weight of each retained soil taken from the sieve was taken and recorded. The percentage of total sample passing each of the sieves was calculated.

#### **3.2.5.3 Hydrometer analysis**

All the soil that was washed through 75µm sieve was collected and poured in to a 1000ml graduated cylinder and the mixture made up to 1000ml mark. The cork of the cylinder was inserted and the solution shaken thoroughly for about 5 minutes after which it was placed on top of a flat table. A hydrometer was immediately inserted and hydrometer readings recorded after 15 seconds, 30 seconds, 1 minute, 2 minutes, 4 minutes, 10 minutes, 20 minutes, 30 minutes, 1 hour, 2 hours, 4 hours, 6 hours, 12 hours and 24 hours. The temperature of the mixture was continuously taken during the process using thermometer. In this way, the particle size distribution of silt and clay size particles was determined.

#### 3.2.3.3 Liquid limit (LL)

The method adopted for the determination of liquid limit was cone penetrometer method. Small amount of pulverized air dried sample was sieved through 0.425mm sieve. Sieved sample of about 200g was transferred on a flat glass, and thick paste was formed by adding clean water which was mixed thoroughly by spatula. The paste was placed inside the cup with spatula without air trapped, until the cup was filled. The top of the soil was trimmed with the top of the cut and placed beneath the cone. The cone was lowered just to touch the surface of the soil without penetration. After cone was in right position, the reading of the dial gauge was recorded when a slight movement of the cup gives a small mark on the surface of the soil.

A period of 1-5 seconds was set for the cone to be released. The dial gauge was lowered to the new position of the cone shaft after penetration and readings were recorded. Cone penetration was the readings recorded as a value between the beginning and the end of the test. Average of two penetrations was recorded. The cone was lifted out and cleaned. About 10g of the sample was taken from the area penetrated by the cone for moisture content determination. The mixed sample was removed from the penetration cup, remixed and the procedure mentioned above was repeated until penetration of about 20mm was recorded using the same sample with more water added.

#### **3.2.3.4 Plastic limit (PL)**

Reasonable quantity of about 20g pulverized soil sample, which was already sieved through 0.425mm sieve was used for the test. The soil and clean water were thoroughly mixed with spatula. Soil ball like of a small sample was collected and rolled between hand and glass plate which later formed thread like shape. The rolling continues until about 3mm of thread in diameter was obtained, and then the thread crumbled at a point. The portion of the crumbled soil was then gathered and placed in moisture can for the determination of moisture content.

The plasticity Index (PI) is the range of water content over the soil is in the plastic condition.

$$Plasticity Index (PI) = LL - PL$$
(3.2)

#### 3.2.4 Compaction

Empty mold with base plate was weighed. 3.0kg of air dried soil passing BS sieve aperture of 2.0mm was also weighed and placed on a flat trey about 1.0m X 1.0m. About 7% of water by weight of the dried soil was added immediately and mixed thoroughly until the whole mix formed a uniform paste. The mixture was then

compacted in the mold with extension collar attached, by ramming it in to three layers, each layer been given 25 blows with 2.5kg rammer dropped from height of 30cm above the soil surface. The blows been uniformly distributed. After compaction of the third layer, the collar was removed and the soil trimmed off even with the top of the mold. The mold and the soil were then weighed. Two representative samples for moisture content determination were obtained from top and bottom of the compacted soil.

The compacted soil was crumbled, remixed with the remaining soil and 3.5% of water by weight of the dried soil was added to the mixture and the process repeated. The compaction soil was repeated each time raising the water content until there was drop in weight of mold plus weight soil. The result was presented in terms of dry densities using the expression:

$$\rho_d = \frac{100\rho}{100\times\omega} \tag{3.3}$$

Where:

 $\rho_d$  = dry density of the mix (Mg/m<sup>3</sup>)

 $\rho$  = Bulk density of the mix (Mg/m<sup>3</sup>)

 $\omega$  = Moisture content of the mix (%)

#### **3.2.5** Unconfined compressive strength

The mould used for this test is a cylindrical mold of 38 mm diameter and 76 mm length. Predetermined Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were used to mold soils and soils mixed with varied proportions of cement and calcium carbide residue, after which the specimen were cured in a airtight polythene leather for 1, 7, 14, 28, 60 and 90 days before testing to avoid moisture escaping from the specimen. After curing, the samples were crushed using unconfined compressive strength machine at the rate of 1723 kN/m2 per minute until the failure load for each specimen was recorded. The compressive stress for each sample was calculated as:

$$Compressive stress = \frac{Failure \ load \ (kN)}{Cross \ sectional \ area \ (m^2)}$$
(3.4)



Figure 3.2: Unconfined Compressive Strength Test Equipment

#### **CHAPTER FOUR**

**4.0** 

#### **RESULTS AND DISCUSSION**

#### 4.1 Index Properties

The result of the index properties of the clay soil is shown on Table 4.1 while the grain size analysis graph of the clay is presented in Figure 4.1. From Table 4.1, the clay classified as A-7-6 according to AASHTO (1986) soil classification system and clay of high plasticity (CH) according to Unified Soil Classification System. This is an indication that the clay cannot be used as material for road pavement structure and cannot also be used to support pavement structures. It therefore requires stabilization to improve its strength and durability.

| Property                          | Quantity                 |
|-----------------------------------|--------------------------|
|                                   |                          |
| Sand                              | 18.4%                    |
| Silt                              | 28.9%                    |
| Clay                              | 53.0%                    |
| Liquid limit                      | 64.3%                    |
| Plastic limit                     | 28.4%                    |
| Plasticity Index                  | 35.9%                    |
| Specific Gravity                  | 2.66                     |
| MDD (Standard Proctor compaction) | 16.024 kN/m <sup>3</sup> |
| OMC (Standard Proctor compaction) | 24.5%                    |
| AASHTO soil classification        | A-7-6                    |
| Unified Soil classification       | СН                       |

| Table 4.1: Index Properties | s of the Soil Sa | mple |
|-----------------------------|------------------|------|
|-----------------------------|------------------|------|

The MDD and OMC of the clay soil, compacted at Standard Proctor energy level was observed to be 16.024 kN/m<sup>3</sup> and 18.5%, respectively.



Figure 4.1: Particle grain size analysis of clay

#### 4.2 Microstructural Analysis of Clay

The result of the microstructural analysis of the clay soil are shown from XRD, SEM, XRF and EDS results as shown in Table 4.2 and Figures 4.2 - 4.8.

#### 4.2.1 Oxide Composition of the clay, cement and calcium carbide residue

The result of the X-ray Florescence (XRF) test is shown on Table 4.2. The table showed that the major oxide composition in the clay are silica and alumina, that of cement are quick lime and silica while that of CCR is quick lime. However, high magnitude of loss on ignition (36.46%) was recorded in the CCR which is probably due to presence of organic matter in the CCR. The high value of silica in the clay and high values of calcium oxide in both the cement and CCR can give high amount of cementitious C-S-H and C-A-H which can result in to higher strength increase.

Table 4.2: Oxide composition of clay, cement, and CCR.

| Oxide (%) | Fe <sub>2</sub> O <sub>3</sub> | TiO <sub>2</sub> | CaO   | K <sub>2</sub> O | SiO <sub>2</sub> | $Al_2O_3$ | MgO  | Na <sub>2</sub> O | LOI   |
|-----------|--------------------------------|------------------|-------|------------------|------------------|-----------|------|-------------------|-------|
| Clay      | 9.61                           | 1.66             | 2.06  | 1.35             | 56.64            | 19.07     | 1.38 | 0.64              | 7.14  |
| Cement    | 4.57                           | 0.44             | 64.44 | 0.56             | 21.60            | 4.13      | 1.06 | 0.11              | 0.76  |
| CCR       | 0.26                           | 0.05             | 55.79 | 0.04             | 4.32             | 1.32      | 0.17 | 0.02              | 36.46 |

#### 4.2.2 X-ray diffraction analysis (XRD)

Figure 4.2 a-d presents result of XRD test on the untreated clay, clay treated with 6% cement, clay treated with 15% CCR and clay treated with blend of 6% cement and 15% CCR respectively. Figure 4.2 show minerals including quartz, anorthoclase, orthoclase, ankerite, montmorillonite, silicide and albite. The existence of montmorillonite peak at 20 of 8.96 indicates the very high plasticity and activity of the natural clay soil (Sharma *et al.*, 2012). These minerals are both primary and secondary minerals. Montmorillonite minerals can increase activity, and hence the consistency of the clay soil.



Figure 4.2: XRD result for untreated clay

Addition of 6% cement to the clay gives the result in Figure 4.3. It is observed from Figure 4.3 that most of the primary clay minerals have weathered in to secondary minerals like



Figure 4.3: XRD result for clay treated with 6% cement

Kaolinite and microcline with introduction of calcite which must have resulted from the hydration reaction between the cement and clay soil. The montmorillonite peak at  $8.96^{\circ}$  was observed to have disappeared which is a sign of substitution reaction between the calcium ions and the electrons around the montmorillonite minerals. Addition of CCR



Figure 4.4: XRD result for clay treated with 15% cement

alone gave the result shown in Figure 4.4. In this Figure, it was also observed that the



Figure 4.5: XRD result for clay treated with 6% cement and 15% CCR primary minerals like orthoclase and anorthoclases weathered in to cowlesite, microcline, kaolinite and halloysite. Calcite was also introduced from the reaction Between the CCR and clay. The 2 $\theta$  position of montmorillonite peak was substituted with halloysite peak.

Addition of blend of cement and CCR gave the result presented in Figure 4.5. Orthoclase and anorthoclases depleted in to microcline and kaolinite. Brushite was introduced as byproduct of the reactions that led to these products. The montmorillonite peak observed in the natural clay has also disappeared on addition of cement and CCR.

# 4.2.3 Scanning electron microscopy (SEM) and Electron dispersion spectroscopy(EDS)

Results of and Scanning Electron Microscopy (SEM) are shown in Figures 4.6, 4.7, 4.8 and 4.9. This revealed occasional presence of air voids and dense fabric of flecky clay particles similar to those reported by Zang *et al.* (2013), Jaiswal and Lal (2016) as well as Abdullah *et al.* (2017). These pores will affect the early strength of the natural clay. The EDS result



Figure 4.6: Results of Untreated Clay for: (a) SEM and (b) EDS

revealed that the ratio of silica to alumina of 1.78 revealed the presence of



**Figure 4.7:** Results of the Clay and Clay mixed with 6% cement for (a) EDS and (b) SEM

montmorillonite mineral. Addition of 6% cement gave the morphology shown on Figure4.7. The morphology showed relatively compact structure. Addition of 15% CCR to the



Figure 4.8: Results of the Clay and Clay mixed with 15% CCR for: (a) SEM and (b) EDS clay showed a whitish formation in the structure.



**Figure 4.9:** Results of the Clay and Clay mixed with blend of 6% cement and 15% CCR for: (a) SEM and (b) EDS

Addition of both cement and calcium carbide residue to the clay revealed a compact structure with formation of calcium silicate hydrate (C-S-H). This must have informed the higher strength observed in this mixture.

#### 4.2.4 Effect of CCR on cement stabilized clay

The effect of UCS with varied composition of CCR for 0, 2, 4 and 6 percentages of cement is shown in Figures 4.10, 4.11, 4.12 and 4.13, respectively. Variation of UCS with varied percentage of CCR and 0% cement after 90 days of curing, is shown in Figure 4.4a. The result revealed continuous increase in UCS with increase in CCR. The values increased from 71 kN/m<sup>2</sup> at 0% CCR to 181, 246, 294, 534 and 602 kN/m<sup>2</sup> at 3, 6, 9, 12 and 15% CCR, respectively. Addition of 15% CCR therefore, represent 7.5 times increase in UCS of the clay.

The optimal percentage CCR to give the maximum strength occurs between 12% and 15% for 2% cement, 4% cement and 6% cement. For 2% cement after 28 days of curing, the UCS increased from 290 kN/m<sup>2</sup> at 0% CCR to maximum of 1552 kN/m<sup>2</sup> at 15% CCR. The increase must have resulted from the reaction between the calcium ions contained in the CCR which exchanges with ions present in the clay to form coagulation of clay particles thus increasing the strength of the clay.



Figure 4.10: Variation of UCS with CCR for 0% cement



Figure 4.11: Variation of UCS with CCR for 2% cement



Figure 4.12: Variation of UCS with CCR for 4% cement



Figure 4.13: Variation of UCS with CCR for 6% cement

The UCS strength showed tendency to decrease in value beyond 12% CCR which is probably due to higher byproduct of calcium hydroxide which form unreactive whitish

solids that reduces the strength of the specimen. For 6% cement after 90 days of curing, the UCS increased from 1370 kN/m<sup>2</sup> at 0% CCR to maximum of 3589 kN/m<sup>2</sup> at 15% CCR. This value is beyond the 3000 kN/m2 recommended for soil materials to be used as base course for highly trafficked roads based on Nigerian General Specification for Roads and Bridges, (1997).

#### 4.2.5 Effect of curing time on cement and CCR stabilization of clay

The effect of curing time on the UCS of CCR stabilized clay soil at varied cement compositions are shown in Figures 4.14, 4.15, 4.16 and 4.17 for 0, 2, 4 and 6% cement respectively. For 0% cement shown in Figure 4.14, the strength for 0% CCR was observed to be constant at 71 kN/m<sup>2</sup> throughout the duration of curing. Addition of 3% CCR gave gradual increase in UCS from 120kN/m<sup>2</sup> after 1day curing to 181 kN/m<sup>2</sup> after 90 days of curing which represents 51% increase in strength.



Figure 4.14: Variation of UCS with curing days for 0% cement



Figure 4.15: Variation of UCS with curing days for 2% cement



Figure 4.16: Variation of UCS with curing days for 4% cement



Figure 4.17: Variation of UCS with curing days for 6% cement

At 0% cement and 15% CCR, the UCS increased from 428kN/m<sup>2</sup> after 1day curing to 602kN/m<sup>2</sup> after 90 days curing which also represents 41% increase in UCS. This increase in strength must have resulted from the reaction between calcium contained in CCR and the ions surrounding the clay minerals. Figure 4.15 showed the variation in UCS with addition of CCR at 2% cement. Addition of 12% CCR was observed to stand out with UCS increasing from 560kN/m<sup>2</sup> after 1day curing to 1530kN/m<sup>2</sup> after 90 days curing which represents 17.3% increase in strength of the clay.

The maximum strength obtained on addition of 6% cement with varied composition of CCR occurred at 15% CCR which gave UCS of 995kN/m<sup>2</sup> after 1day curing to 3589kN/m<sup>2</sup> after 90 days curing which represents 260% increase in strength of the clay.

Figure 8a which deals with addition of CCR without cement, revealed gentle slope or gentle rate of increase in strength with increase in curing days except for 15% CCR

which gave high rate of increase in strength during the first 28 days of curing after which the slope flattened. Figures 4.15, 4.16 and 4.17 which compose of 2%, 4% and 6% cements with varied compositions of CCR, all showed faster rate of strength increase from 1 to 28 days after which the slope flattened out.

#### **CHAPTER FIVE**

#### 5.0 CONCLUSION AND RECOMMENDATION

#### 5.1 Conclusion

From the experiment and analysis carried out in this study, the following conclusions can be drawn:

The clay soil studied falls under clay of high plasticity (CH) based on Unified Soil Classification System (USCS) which cannot be used in its natural state for any component of flexible pavement structure.

Microstructural analysis of the clay using XRD and SEM revealed that the clay consists of both primary and secondary minerals including montmorillonite. The SEM showed the morphology of the compacted clay as flaky in nature with pore spaces.

Maximum UCS of 3589kN/m<sup>2</sup> which satisfy a soil material to be used as base course material for highly trafficked road bases. This was achieved at 6% cement and 15% CCR.

The optimal CCR required for effective stabilization of clay soil lies between 12 to 15% for clays with varied cement content.

The UCS obtained for clay stabilized with CCR only increased by 8.5 times the strength of the natural clay while the UCS at 6% cement increased by 280% at 15% CCR addition.

#### 5.2 Recommendation

The clay collected from Bako village along Gwagwalada – Garki road can be stabilized with a blend of 6% cement and 12 - 15% calcium carbide residue and used as base course material for highly trafficked roads base on Nigerian General Specification for Road and Bridge Works (1997).

#### 5.3 Contribution to Knowledge

The originality of this work lies in the possible use of calcium carbide residue as admixture with cement for stabilization of Nigeria tropical clay soils. The clay was treated with 0, 2, 4 and 6% cement which in turn was admixed with 0, 3, 6, 9, 12 and 15% calcium carbide residue each. The unconfined compressive strength was observed to increase from 71kN/m<sup>2</sup> for untreated clay soil to maximum of 3589 kN/m<sup>2</sup> for clay treated with 6% cement and 15% volcanic as. This increase represents 50.5 times increase in strength.

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