IMPROVEMENT OF DEFICIENT LATERITE SOIL USING CEMENT AND CALCIUM CARBIDE RESIDUE

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ABSTRACT

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

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ABBREVIATIONS, GLOSSARIES AND SYMBOLS

AASHTO	American Association for State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
A_f	final area of sample
A_O	initial area of sample
BS	British Standard
BSI	British Standards Institution
CBR	California Bearing Ratio
CCR	Calcium Carbide Residue
CH	Clay of High Plasticity
CL	clayey soil
ε	strain
Gs	specific gravity
ISO	International Organization for Standardization
LL	liquid Limit
ΔL	change in length deformation of the specimen
Lo	initial length of the specimen
M	mass
m	metre
MDD	Maximum Dry Density
M_s	Mass of compacted soil
OMC	Optimum Moisture Content
OPC	Ordinary Portland Cement
r	initial radius
TRRL	Transport and Road Research Laboratory

PI	plasticity Index
PL	plastic Limit
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System
V	Volume of mould
ρ_b	Bulk density
ρ_d	Dry density
w	Natural moisture content

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

The ever increasing world population, especially in developing nations has led to increasing demand and magnitude of civil engineering 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.

Building of infrastructures (road, buildings, dams, etc.) in the developing nations has been a major challenge to Government at all levels and to different specialists in the construction industry. The challenge facing Government is the limited resources available for the construction and the high cost of normally put forward by the construction companies. On construction site e.g. road), the contractor is most a time faced with the problem of non-availability of suitable construction materials, within the vicinity. A situation that normally results in the usage of materials imported from other locations, leading to additional cost that does not guarantee economy in construction. One of the ways of ensuring economy in such situations is making the in-situ material suitable for the construction through stabilization.

In Nigeria and other tropical countries of the world, one of such material that is readily available for road construction is laterite. Although some of the deposits are good, other are deficient, in their natural state. Laterite as defined by Osula (2013) is a highly weathered tropical soil, rich in secondary oxide of any or a combination of iron, aluminium and manganese. Lateritic soils according to Bello and Adegoke (2010) can be categorized into laterite, lateritic, and non-lateritic soils, but stressed that such definition may not be convenient from an engineering point of view, especially where there is lack of adequate laboratory facilities, because the mode of differentiation is based on silica (SiO_2) to sesquioxide (Fe_2O_3, Al_2O_3) ratios. Ration less than 1.33 are of laterites, those between 1.33 and 2.00 are regarded as

laterite, while those greater than 2.00 are non-lateritic (Bell, 2015). The definition of laterite by Ola (2004),as the products of tropical weathering with red, reddish brown, and dark brown colour, with or without nodules or concretions and generally (but not exclusively) found below hardened ferruginous crust or hard pan, is adopted in this study. Laterite soils according to Bello and Adegoke (2010) are formed in hot and wet tropical regions with an annual rainfall between 750 to 3000 mm (usually in area with a significant dry season) on a variety of different types of rocks with high iron content. Laterite according to Ford (2014) is found mainly, but not exclusively, as a residual weathering product on partially or wholly decomposed basalts and other basic to intermediate igneous rocks. Occurrences are locally extensive, but in general have not been mapped, although some studies made on material from specific localities have proved that they are good material for road work.

Nigeria according to Umar and Elinwa (2005) is among the countries blessed with vast deposits of laterite, which is residual in nature, and one of the cheapest materials for road construction. However, not all deposits of these soils are, in their natural state, suitable for use as sub-base and base materials. Treatment with additives is normally required before they can attain the desired properties. Cement and lime have been widely used for soil improvement/stabilization (Reids and Brooks, 2016; Basha*et al.,* 2005; Eze-Uzomaka and Agbo, 2010; Joel and Agbede, 2011; Joel and Agbede, 2010). Improvement in properties of soil treated with cement is attributed to its hydration reaction, while that of lime can be attributed to the cation exchange, pozzolanic and carbonation reactions.

The use of cement for soil stabilization is very effective when the plasticity index is less than 10%. According to Joel and Edeh (2014)where plasticity index of soil is greater than 10% more cement will be required for effective stabilization. An alternative to the use of high percentage of cement is the use of lime as a modifier to reduce the plasticity index before cement can use for stabilization.

The relatively high cost of these two additives (for example, in Nigeria, a 25 kg bag of hydrated lime or quick lime now cost ₦12,000, while the cost of 50kg bag of cement is ₦4,000, an indication that the cost of hydrated lime is 6.00 times the equivalent cost of ordinary Portland cement), have hindered adequate soil stabilization to meet the standard, recommended for road construction.

In order to reduce the cost of stabilization of materials for road construction, one alternative is the use of wastes, both industrial and agricultural. Researchers have shown that utilization of wastes has resulted to improvement in soil properties with considerable savings in construction costs (Umar and Elinwa, 2005; Umar and Osinubi, 2003; Okafor and Okonkwo, 2009). Calcium carbide waste is of little or no cost, as it is usually disposed.

Calcium carbide waste is a by-product from production of acetylene gas (C_2H_2), used in oxyacetylene welding. It consists mainly of lime ($Ca(OH)_2$), a caustic solid substance. It is white in appearance when pure. The waste is normally dumped at different locations, especially mechanic villages and industries where oxy-acetylene gas welding is carried out. Such sites and locations are common features in most urban centers and some rural areas, in Nigeria. In some cases, the waste is normally disposed via land fill or open dumping, which has effect on surface and ground water, arising from leaching of harmful compounds and alkali, to ground and surface water. Therefore, alternative means of its disposal is desirable. Utilization of the waste material to upgrade engineering properties of soil would serve as one of the disposals means. Utilization of calcium carbide waste in soil stabilization was reported by (Tsakiridis *et al.,*2014).

1.2 Statement of the Research Problems

The increasing rate of depletion of deposits of good lateritic soil has become a concern. Good lateritic soil deposits that were initially thought to be inexhaustible have proved otherwise,

especially in capital cities of Nigeria (example Minna, the capital city of Niger state and its environs) (Saiduand Mu,azu, 2020). These, coupled with the ever rising cost of cement and lime, which are the most popular soil stabilizing agents, has further necessitated the search for less costly additives that can be used for stabilization/improvement of the available deficient lateritic soils.

1.3 Aim and Objectives of the Study

The aim of this study is to study the improvement of deficient soil using cement and calcium carbide residue.

To achieve the aim, the following objectives were pursued:

i. Determination of index properties of the natural soil.
ii. Determination compaction characteristics of the natural soil and the soil-cement-CCR mixtures.
iii. Determination of unconfined compressive strength of the natural soil and the soil-cement-CCR mixtures.

1.4 Scope and Limitation

The study was limited to determining index properties of the natural soil, determining compaction characteristics of the natural soil and the soil-cement-CCR mixtures, and determining unconfined compressive strength of the natural soil and the soil-cement-CCR mixtures.

1.5 Justification of the Study

There have been reports of structural failures as a result of bad foundation soil, as well as large quantities of industrials waste dumped in open spaces, causing damages to environment. Soil stabilization with these will improve engineering properties of the soils and also serve as a way of reducing environmental hazards caused by these waste dumps.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Laterite Soil

Residual soils, otherwise called laterite or lateritic soils are the dominant soil type in the tropics and subtropics of the world. The tropical residual red soil forms the major surface deposit of engineering material in this part of the world. The presence of these residual soils, mainly in the tropical and subtropical regions of the world, suggests that there are certain characteristics required for the formation and its abundance. There are several mechanisms attributable to its formation which is centered on the climatic conditions of these regions. The climate shapes the stratigraphy of the soil with regards to the depth of deposition of salts, the degree of surface desiccation and/or saturation (Gidigasu and Kuma, 2016). Describes climatic requirements for formation of residual soils in a region as having an average annual rainfall of at least 1200mm and a daily temperature in excess of 25ºC. In addition, it is portrayed to occur mostly in humid tropical climate within 30º N and 30º S of the equator (Madu, 2013). Laterite is described as a product of in-situ weathering of igneous, sedimentary, and metamorphic rocks commonly found under unsaturated conditions (Rahardjo*et al.,* 2014) or by the ferruginization of existing soils (D'Hoore andFripiat, 2012). Laterite needs high rainfall and temperature of the tropics to form. The disintegration of these underlying rocks occurs as water washes out the soil minerals such as sodium, potassium, calcium, magnesium, and other metals, and enriches the soil with aluminum, phyllosilicates, aluminum oxides, iron (III) oxides, and hydroxides (Brainy, 2015). The particular presence of iron gives the soil the typical red color associated with it;thus, it is described as residual red soil.

There is modification to the climate requirement, which is the physical feature of the region. The environment extensively shapes the mode of deposition and development of the soil, and the type of clay minerals present (Gidigasu and Kuma, 2016).

Conditions under which residual soils are formed are described as (LovetoKnow, 2013; LovetoKnow, 2014):

i. First, a high seasonal temperature, which occurs only in tropical districts and in plains or mountains up to about 1,500m (5000 ft) in height;
ii. Secondly, a heavy rainfall with well-marked alternation of wet and dry seasons (in arid countries laterite is seldom seen, and where the rainfall is moderate the laterite is often calcareous);
iii. Thirdly, the presence of rocks containing aluminous minerals such as feldspar, augite, hornblende and mica. On pure limestone such as coral rocks and on quartzite laterite deposits do not originate except where the material has been transported.

Gidigasu and Kuma (2016) and Novais (2013) characterize the conditions which must be prevalent for laterization weathering process to occur as:

i. Chemical and mineralogical composition of parent rock having appreciable amount of ferric and aluminous compounds
ii. Permeable profile permitting good circulation of water
iii. Tropical climate with heavy rainfall and dry season
iv. High atmospheric temperature during the day
v. Flattish topography of sufficient elevation
vi. Fluctuating water table
vii. Vegetation for tropical and savannah.

TuncerandLohnes(2009) described the genesis of laterite as the weathering process which involves leaching of silica, formation of colloidal sesquioxides and precipitation of the oxides with increasing crystallinity and dehydration as the soil is weathered. Primary minerals in the parent rock such as feldspar, quartz, and ferromagnesian minerals are transformed to a porous clayey system, containing kaolinite, sesquioxides, and some residual quartz. The primary

feldspars are further transformed to kaolinite and subsequent gibbsite. Primary ferromagnesian minerals are converted to diffuse goethite, then to well-crystallized goethite, and finally hematite. In highly developed stages, weathering crystallization leads to the formation of iron and/or aluminum oxide concretions (Malomo, 2017), followed by coalescence of concretions and their cementation, which eventually leads to the entire system becoming a continuous cemented crust (LovetoKnow, 2013; LovetoKnow, 2014).

Evidently, factors leading to weathering of the tropical soil involve evolution of the soil system, the type of mobile salts, the process of deposition and leaching, and the type of clay mineral. Field and laboratory studies have shown that residual soils consist of different zones of weathering with differing morphological, physical and geotechnical characteristics, and vary for different locations due to the heterogeneous nature and highly variable degree of weathering (Adekoya, 2015; Rahardjo*et al*., 2014). The differences in characteristics of laterite soil is associated with the climatic and topographic conditions, which involves the weathering front, translocation of materials through groundwater and percolating rainwater, alternating wet and dry climatic conditions and biological factors, which include both faunal and floral activities in the soils (Norton, 2016; Faniran, 2011; Schorin, 2010; Leprun, 2013). In addition, differences in textural and mineralogical characteristics of parent rocks could be responsible for significant differences in engineering properties of the derived soils (Adeyemi andAbolurin, 2015). These properties are in turn influenced by the structure of the soil.

2.1.1 Structure of laterite soils

Soil structure generally refers to both the geometric arrangement of the soil particles and the inter-particle forces which may act between these particles (Day, 2014). Accordingly, the structure of a soil provides for its integrity and response to externally applied and internally induced forces (Yong and Warkentin, 2017). There are varying hypotheses of particle arrangement in natural soils (Lambe, 2011). However, observations have established that there

is no exact singular arrangement of particle grouping characteristic of any soil type. Only sedimentary soil formations may have similarity in its arrangement and some are more prevalent in certain soils than others (Collins and McGowan, 2014). The assumptions that soil properties are dependent on the initial structure and porosity as deposited, and on its subsequent stress history (Nnadi, 1987) cannot be completely true for soils in the tropics. The actions of weathering and erosion in the tropics steadily alter the properties of residual soils, thus making it difficult to relate the soil structure to the stress history (Vaughan and Kwan, 2013). Therefore, origin of the soil determines it's the micro-fabric (Osipov and Sokolov, 2015), and the microstructure is strongly related to its environment of formation and consequent transformation during compaction (Malomo, 2017).

Lateritic weathering products derived from different rock types in the tropics varies in different locations (Gogo-Abite, 2005). The soil structure differs according to the diverse rock types residual soil formation involves some form of a complex weathering process which is likely to cause the variability in the intermediate and final structures (Gogo-Abite, 2005). Studies on some lateritic soils revealed that they possess a porous granular structure consisting of iron impregnated clayey material in minute spherical aggregations (Hamilton, 2014). The aggregations derive its strength from the thin film, found within the micro-joints of the elementary clay particles, which in addition coats the particles (Gidigasu and Kuma, 2016). Study by Malomo (2017) revealed that laterite soils show strongly cemented surfaces covered by iron oxides, which initially exist as a semi gelatinous coating and thus follow these steps:

i. Becoming denser through the loss of moisture but retaining its non-crystalline structure
ii. Crystallizing slowly into forms such as goethite or hematite.

Microstructure of soils tends to influence the engineering properties of tropical residual soils (Terzaghi, 2018). Nnadi (1987) stated that there exist a wide variety of microstructures for residual soils. Malomo (2017) stated that examination under microstructure reveals two major

micro-structural arrangements, namely matrix and skeletal, which are resultants of different stages in the laterization.

Matrix microstructure (dense region) is characterized by strong cementation and coating with iron oxide, while the skeletal microstructure (porous region) has its surfaces and voids coated in similar manner like the matrix microstructure but the extent of filling is minor (Sergeyev*et al.,* 1987). Gogo-Abite (2005) posited that these microstructures development is based on the deposition of iron oxides at different stages of the weathering process. Skeletal microstructure (porous region) develops at the early stages of weathering with fewer deposition of iron oxide when compared to the matrix microstructure (dense region) which occurs at an advanced stage (Malomo, 2017). Influence of microstructure of soils has been identified as a leading factor responsible for the unique properties. The soil microstructure consists of the micro-fabrics, composition and the inter-particle forces, (Collins and McGowan, 2014; Wallace, 2016; Mitchell and Sitar, 2012). Hence, there is an increasing interest in relating the microstructure of soil to its engineering properties (Tuncerand Lohnes,2009; Gidigasuand Kuma*,* 2016; Rahardjo*et al.,* 2014). This is evidently seen in the effect of the granular structure of the soil to its engineering properties (Townsend *et al.,* 2013).

Tropical residual soils consist of an accumulation of particles ranging from larger granular constituents to clay-size materials as well as sesquioxides which are present as cementing materials (Nnadi, 2010). In-situ laterite possesses a granular structure due to the presence of sesquioxides, which coat and knit the indigenous soil particles into tiny spherical aggregations (Alexander and Cady, 2016).

2.1.2 Laterite soil characterization

Laterite soils, depleted of most of its elements except iron and aluminum oxides, are derived from weathering of the parent rocks (Ramanaidou, 2009). The loss of soil's elements is as a

result of its exposure to high rainfall which washes out these elements (sodium, potassium, magnesium, and calcium) and other metals from the soil (Gachene*et al*., 1997). In substitution, the soil is enriched with aluminum phyllosillicate, aluminum oxide, iron oxides and hydroxides, concern for the effect of these elements to the geotechnical properties is indicative of the interest in the study of characterization of this soil type (Gachene*et al*., 1997). Soil characterization is intended to identify the soil properties, its predictability, and responses to varying loading conditions.

In response to the need for characterization of laterite soils, temperate region soil classification techniques and methods are widely used (Gidigasu, 2012). However, researches show that these methods do not adequately predict tropical soil behavior (Tuncer and Lohnes, 2009; Nnadi, 1987; Gidigasu and Kuma, 2013; Rahardjo*et al.,* 2014). Thus, it is suggested that engineering characterization of the laterite soils should be based on the parent material and degree of weathering (Adekoya, 2015; Rahardjo*et al.,* 2014). Accordingly, studies have been carried out in various regions of the tropics to adequately characterize the residual soils and their engineering properties, which are greatly influenced by the formation process, climatic and environmental conditions of the varying localities, and types of parent rocks (Adekoya, 2015)

An understanding of the engineering characteristics of lateritic soils, from bed rock to totally weathered soil, is necessary for proper application of these soils to engineering works. It is therefore required that a proper characterization of the residual soils be based on these facts:

i. the material is the most common, naturally occurring;
ii. there is a wide variation in weathering environments and resulting soil profiles;
iii. the soil exhibit wide variation in engineering characteristics; and
iv. it is the most economic engineering material for use in diverse developmental projects.

Laterite soil characteristics is dependent on the factors mention above, and these influence the type of mineralogy, clay type and content, grain size, and degree of dehydration (Nnadi, 1987). A description that involves the soil profile horizons and the constituent particles, such as the color, soil texture, soil structure, mineralogy, and organic content is necessary to adequately state the engineering properties of these soils.

2.2 Soil Stabilization

Soil stabilization is the process of improving the physical and engineering properties of a soil to achieve a predetermined target level of performance (Latifi*et al*., 2016). Various mechanisms of soil stabilization can be employed by a given soil improvement process, including mechanical, chemical, biological, and electrical means(Osinubi and Medubi, 1997).

Soil stabilization is the biological, chemical or mechanical modification of soil engineering properties. In civil engineering, soil stabilization is a technique to refine and improve the engineering properties of soils. The properties include mechanical strength permeability, compressibility, durability and plasticity. Physical or mechanical improvement is common but some schools of thought prefer to use the term stabilization in reference to chemical improvements in the soil properties by adding chemical admixtures (Behnood, 2018).

Cement and lime have been the major traditional additives used in soil stabilization process.

2.3 Cement

Cement, in general, is adhesive substances of all kinds, but, in a narrower sense, is the binding materials used in building and civil engineering construction (Naidu *et al.*, 2017). Cements of this kind are finely ground powders which, when mixed with water, set to a hard mass (Naidu *et al.*, 2017). Setting and hardening result from hydration, which is a chemical combination of the cement compounds with water that yields submicroscopic crystals or a gel-like material with a high surface area (Naidu *et al.*, 2017). Because of their hydrating properties,

constructional cements, which will even set and harden under water, are often called hydraulic cements. The most important of these is Portland cement.

2.3.1 Applications of cement

Cements may be used alone ("neat" as grouting materials), but the normal use is in mortar and concrete in which the cement is mixed with inert material known as aggregate(Naidu *et al.*, 2017). Mortar is cement mixed with sand or crushed stone that must be less than approximately 5mm in size. Concrete is a mixture of cement, sand or other fine aggregate, and a coarse aggregate that for most purposes is up to 19 to 25mm in size, but the coarse aggregate may also be as large as 150mm when concrete is placed in large masses such as dams. Mortars are used for binding bricks, blocks, and stone in walls or as surface renderings (Quercia Bianchi*et al*., 2012).Mixtures of soil and Portland cement are used as a base for roads. Portland cement also is used in the manufacture of bricks, tiles, shingles, pipes, beams, railroad ties, and various extruded products. Because concrete is the most widely used of all construction materials in the world today, the manufacture of cement is widespread.

2.3.2 Composition of cement

Portland cement consists essentially of compounds of lime calcium oxide (CaO) mixed with silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3) (Altwair and Kabir, 2009). The lime is obtained from a calcareous (lime-containing) raw material, and the other oxides are derived from an argillaceous (clayey) material. Additional of raw materials such as silica sand, iron oxide (Fe_2O_3), and bauxite containing hydrated aluminum, $Al(OH)_3$ may be used in smaller quantities to get the desired composition (Tsakiridis*et al*., 2014).

The commonest calcareous raw materials are limestone and chalk, but others, such as coral or shell deposits, also are used (Naidu *et al.*, 2017). Clays, shales, slates, and estuarine muds are the common argillaceous raw materials. Marl, a compact calcareous clay, and cement rock

contain both the calcareous and argillaceous components in proportions that sometimes approximate cement compositions. Another raw material for cement production is blast-furnace slag, which consists mainly of lime, silica, and alumina and is mixed with a calcareous material of high lime content (Naidu *et al.*, 2017). Kaolin, a white, clay that contains little iron oxide, is used as the argillaceous component for white Portland cement. Industrial wastes, such as fly ash and calcium carbonate from chemical manufacture, are other possible raw materials, but their use is small compared with that of the natural materials.

The magnesium oxide (MgO) content of raw materials must be low because the permissible limit in Portland cement is 4 to 5 percent (https://www.constrofacilitator.com). Other impurities in raw materials that must be strictly limited are fluorine compounds, phosphates, metal oxides and sulfides, and excessive alkalies (https://www.constrofacilitator.com). Another essential raw material is gypsum, some 5 percent of which is added to the burned cement clinker during grinding to control the setting time of the cement (www.constrofacilitator.com).

2.3.3 The major cements composition and properties

2.3.3.1 *Portland cement*

2.3.3.2 *Chemical composition*

Portland cement is made up of four main compounds: tricalcium silicate ($3CaO \cdot SiO_2$), dicalcium silicate ($2CaO \cdot SiO_2$), tricalcium aluminate ($3CaO \cdot Al_2O_3$), and a tetra-calcium aluminoferrite ($4CaO \cdot Al_2O_3Fe_2O_3$). In an abbreviated notation differing from the normal atomic symbols, these compounds are designated as C_3S, C_2S, C_3A, and C_4AF, where C stands for calcium oxide (lime), S for silica, A for alumina, and F for iron oxide. Small amounts of uncombined lime and magnesia also are present, along with alkalies and minor amounts of other elements (Quercia Bianchi*et al*., 2012).

2.3.3.3 *Hydration*

The most important hydraulic constituents are the calcium silicates, C_2S and C_3S(Garcia-Lodeiro*et al*.,2013).Upon mixing with water, the calcium silicates react with water molecules to form calcium silicate hydrate ($3CaO.2SiO_2 \cdot 3H_2O$) and calcium hydroxide ($Ca[OH]_2$). These compounds are given the shorthand notations C–S–H (represented by the average formula $C_3S_2H_3$) and CH, and the hydration reaction can be crudely represented by the following reactions: $2C_3S + 6H = C_3S_2H_3 + 3CH$ $2C_2S + 4H = C_3S_2H_3 + CH$ During the initial stage of hydration, the parent compounds dissolve, and the dissolution of their chemical bonds generates a significant amount of heat.

Following the dormant period which can last several hours, the cement begins to harden, as CH and C–S–H are produced. This is the cementitious material that binds cement and concrete together. As hydration proceeds, water and cement are continuously consumed. Fortunately, the C–S–H and CH products occupy almost the same volume as the original cement and water; volume is approximately conserved, and shrinkage is manageable.

Although the formulas above treat C–S–H as a specific stoichiometry, with the formula $C_3S_2H_3$, it does not at all form an ordered structure of uniform composition. C–S–H is actually an amorphous gel with a highly variable stoichiometry. The ratio of C to S, for example, can range from 1:1 to 2:1, depending on mix design and curing conditions.

2.3.4 Structural properties

The strength developed by Portland cement depends on its composition and the fineness to which it is ground. The C_3S is mainly responsible for the strength developed in the first weekof hardening and the C_2S for the subsequent increase in strength(Yadav andShukla, 2014). The alumina and iron compounds that are present only in lesser amounts make little direct contribution to strength.

Set cement and concrete can suffer deterioration from attack by some natural or artificial chemical agents (Yadav and Shukla, 2014). The alumina compound is the most vulnerable to chemical attack in soils containing sulfate salts or in seawater, while the iron compound and the two calcium silicates are more resistant. Because cement liberates heat when it hydrates, concrete placed in large masses, as in dams, can cause the temperature inside the mass to rise as much as 40°C above the outside temperature. The highest heat of hydration is shown by C_3A, followed in descending order by C_3S, C_4AF, and C_2S.

2.3.5 Types of Portland cement

Five types of Portland cement are standardized in United States by the American Society for Testing and Materials (ASTM): ordinary (Type I), modified (Type II), high-early-strength (Type III), low-heat (Type IV), and sulfate-resistant (Type V). In other countries Type II is omitted, and Type III is called rapid-hardening.

There are also various other special types of Portland cement. (Naidu *et al.*, 2017)coloured cements are made by grinding 5 to 10 percent of suitable pigments with white or ordinary gray Portland cement. This increases resistance of the concrete to freeze-thaw damage in cold climates. The air-entraining agent can alternatively be added as a separate ingredient to the mix when making the concrete.

Masonry cements are used primarily for mortar. They consist of a mixture of Portland cement and ground limestone or other filler together with an air-entraining agent or a water-repellent additive. Waterproof cement is the name given to a Portland cement to which a water-repellent agent has been added. Hydrophobic cement is obtained by grinding Portland cement clinkerwith a film-forming substance such as oleic acid in order to reduce the rate of deterioration when the cement is stored under unfavorable conditions.

Oil-well cements are used for cementing work in the drilling of oil wells where they are subject to high temperatures and pressures. They usually consist of Portland or pozzolanic cement (see below) with special organic retarders to prevent the cement from setting too quickly.

2.3.5.1 *Slag cements*

The granulated slag made by the rapid chilling of suitable molten slags from blast furnaces forms the basis of another group of constructional cements. A mixture of Portland cement and granulated slag, containing up to 65 percent slag, is known in the English-speaking countries as Portland blast-furnace (slag) cement.

The German Eisenportlandzement and Hochofenzement contain up to 40 and 85 percent slag, respectively. Mixtures in other proportions are found in French-speaking countries under such names as ciment Portland de fer, cimentmétallurgiquemixte, ciment de hautfourneau, and ciment de liatier au clinker. Properties of these slag cements are broadly similar to those of Portland cement, but they have lower lime content and a higher silica and alumina content. Those with the higher slag content have an increased resistance to chemical attack.

Another type of slag-containing cement is super sulfated cement consisting of granulated slag mixed with 10 to 15 percent hard-burned gypsum or anhydrite (natural anhydrous calcium sulfate) and a few percent of Portland cement. The strength properties of super sulfated cement are similar to those of Portland cement, but it has an increased resistance to many forms of chemical attack. Pozzolanic cements are mixtures of Portland cement and a pozzolanic material that may be either natural or artificial. The natural pozzolanas are mainly materials of volcanic origin but include some diatomaceous earths. Artificial materials include fly ash, burned clays, and shales. Pozzolanas are materials that, though not cementitious themselves, contain silica (and alumina) in a reactive form able to combine with lime in the presence of water to

form compounds with cementitious properties. Mixtures of lime and pozzolana still find some application but largely have been superseded by the modern pozzolanic cement. Hydration of the Portland cement fraction releases the lime required to combine with the pozzolana (Altwairand Kabir, 2009).

2.3.5.2 *High-alumina cement*

High-alumina cement is rapid-hardening cement made by fusing at 1,500 to 1,600°C a mixture of bauxite and limestone in a laboratory or electric furnace or in a rotary kiln. It also can be made by sintering at about 1,250°C. Suitable bauxites contain 50 to 60% alumina, up to 25 percent iron oxide, not more than 5 percent silica, and 10 to 30 percent water of hydration. The limestone must contain only small amounts of silica and magnesia. The cement contains 35 to 40 percent lime, 40 to 50 percent alumina, 15 percent iron oxides, and preferably not more than about 6 percent silica. The principal cementing compound is calcium aluminate ($CaO \cdot Al_2O_3$).

High-alumina cement gains a high proportion of its ultimate strength within 24 hours and has a high resistance to chemical attack. It also can be used in refractory linings for furnaces. A white form of the cement, containing minimal proportions of iron oxide and silica, has outstanding refractory properties (Joel and Agbede, 2010)

2.3.5.3 *Expanding and non-shrinking cements*

These types of cements expand slightly on hydration, thus offsetting the small contraction that occurs when fresh concrete dries for the first time. Expanding cements were first produced in France about 1945. The American type is a mixture of Portland cement and an expansive agent made by clinkering a mix of chalk, bauxite, and gypsum (Ola,2004).

2.3.6 Cement testing

Various tests to which cements must conform are laid down in national cement specifications to control the fineness, soundness, setting time, and strength of the cement.

2.3.6.1 *Fineness*

Fineness was long controlled by sieve tests, but more sophisticated methods are now largely used. The most common methods used both for control of the grinding process and for testing the finished cement, measures the surface area per unit weight of the cement by a determination of the rate of passage of air through a bed of the cement. Other methods depend on measuring the particle size distribution by the rate of sedimentation of the cement in kerosene or by elutriation (separation) in an airstream.

2.3.6.2 *Soundness*

After it has set, cement must not undergo any appreciable expansion, which could disrupt a mortar or concrete. This property of soundness is tested by subjecting the set cement to boiling in water or to high-pressure steam. Unsoundness can arise from the presence in the cement of too much free magnesia or hard-burned free lime.

2.3.6.3 *Setting time*

Setting and hardening of cement is a continuous process, but two points are distinguished for test purposes: initial and final setting times. Initial setting time is the interval between the mixing of the cement with water and the time when the mix has lost plasticity, stiffening to a certain degree. It marks roughly the end of the period when the wet mix can be molded into shape. The final setting time is the point at which the set cement has acquired a sufficient firmness to resist a certain defined pressure. Most specifications require an initial minimum setting time at ordinary temperatures of about 45 minutes and a final setting time no more than 10 to 12 hours.

2.3.6.4 *Strength*

Tests that measure the rate at which cement develops strength are usually made on a mortar commonly composed of one part cement to three parts sand, by weight, mixed with a

defined quantity of water. Tensile tests on briquettes, shaped like a figure eight thickened at the centre, were formerly used but have been replaced or supplemented by compressive tests on cubical specimens or transverse tests on prisms. The American Society for Testing and Materials (ASTM) specification requires tensile tests on a 1:3 cement-sand mortar and compressive tests on a 1:2.75 mortar. The British Standards Institution (BSI) gives as alternatives a compressive test on a 1:3 mortar or on a concrete specimen. An international method issued by the International Organization for Standardization (ISO) requires a transverse test on a 1:3 cement-sand mortar prism, followed by a compressive test on the two halves of the prism that remain after it has been broken in bending. Many European countries have adopted this method. In all these tests the size grading of the sand, and usually its source, is specified.

In testing of most cement, minimum strength at 3 and 7 days and sometimes 28 days is specified, but for rapid-hardening Portland cement a test at 1 day also is sometimes required. For high-alumina cement, tests are required at 1 and 3 days.

Strength requirements laid down in different countries are not directly comparable because of the differences in test methods. In actual construction, to check the strength of concrete, compressive tests are made on cylinders or cubes made from the concrete being placed.

For soil treated with cement, 1710kN/m^2 was recommended by TRRL (1977) and 1750kN/m^2 as criteria for design cement content, considered adequate for soil-cement composite as base course material for highway pavements, with light to medium traffic. Cement has also been used with other additives.

2.4 Calcium Carbide

Calcium carbide, also known as calcium acetylide, is a chemical compound with the chemical formula of CaC_2. Its main use industrially is in the production of acetylene and calcium cyanamide. The pure material is colorless, however pieces of technical-grade calcium carbide are grey or brown and consist of about 80–85% of CaC_2 the rest is calcium oxide (CaO), calcium phosphide (Ca_3P_2), calcium sulfide (CaS), calcium nitride (Ca_3N_2) and silicon carbide (SiC). In the presence of trace moisture, technical-grade calcium carbide emits an unpleasant odor reminiscent of garlic (Morehead andde Chalmot, 2013)

Applications of calcium carbide include manufacture of acetylene gas, and for generation of acetylene in carbide lamps; manufacture of chemicals for fertilizer; and in steelmaking.

Calcium carbide is produced industrially in an electric arc furnace from a mixture of lime and coke at approximately 2,200°C. This method has not changed since its invention in 1892:

$$CaO + 3\ C \rightarrow CaC_2 + CO \qquad (2.1)$$

The high temperature required for this reaction is not practically achievable by traditional combustion, so the reaction is performed in an electric arc furnace with graphite electrodes. The carbide product produced generally contains around 80% calcium carbide by weight. The carbide is crushed to produce small lumps that can range from a few mm up to 50 mm. The impurities are concentrated in the finer fractions. The CaC_2 content of the product is assayed by measuring the amount of acetylene produced on hydrolysis. As an example, the British and German standards for the content of the coarser fractions are 295L/kg and 300L/kg respectively (at 101kPa pressure and 20°C temperature). Impurities present in the carbide include phosphide, which produces phosphine when hydrolysed (Morehead andde Chalmot, 2013)

2.4.1 Crystal structure

Pure calcium carbide is a colourless solid. The common crystalline form at room temperature is a distorted rock-salt structure with the C_2^{2-} units lying parallel.

2.4.2 Application

Reaction of calcium carbide with water, producing acetylene and calcium hydroxide, was discovered by Friedrich Wöhler in 1862.

$$CaC_{2(s)} + 2H_2O_{(aq)} \rightarrow C_2H_{2(g)} + Ca(OH)_{2(aq)} \quad (2.2)$$

This reaction was the basis of the industrial manufacture of acetylene, and is the major industrial use of calcium carbide (Schobert, 2014)

2.4.3 Production of calcium carbide

Calcium carbide reacts with nitrogen at high temperature to form calcium cyanamide:

$$CaC_2 + N_2 \rightarrow CaCN_2 + C \quad (2.3)$$

Commonly known as nitrolime, calcium cyanamide is used as fertilizer. It is hydrolysed to cyanamide, H_2NCN.

2.4.4 Uses of calcium carbide

2.4.4.1 *Steelmaking*

Calcium carbide is used

i. in the desulfurization of iron (pig iron, cast iron and steel)

ii. as a fuel in steelmaking to extend the scrap ratio to liquid iron, depending on economics.

iii. as a powerful deoxidizer at ladle treatment facilities.

Today acetylene is mainly manufactured by the partial combustion of methane or appears as a side product in the ethylene stream from cracking of hydrocarbons

2.4.4.2 *Carbide lamps*

Calcium carbide is used in carbide lamps. Water dripping on carbide produces acetylene gas, which burns and produces light. While these lamps gave steadier and brighter light than candles, they were dangerous in coal mines, where flammable methane gas made them a serious hazard. The presence of flammable gases in coal mines led to miner safety lamps such as the Davy lamp, in which wire gauze reduces the risk of methane ignition. Carbide lamps were still used extensively in slate, copper, and tin mines where methane is not a serious hazard. Carbide lamps are still used for mining in some less wealthy countries, for example in the silver mines near Potosí, Bolivia. Carbide lamps are also still used by some cavers exploring caves and other underground areas, although they are increasingly being replaced in this use by LED lights. Carbide lamps were also used extensively as headlights in early automobiles, motorcycles and bicycles, but have been replaced entirely by electric lamps (Morehead andde Chalmot, 2013).

2.4.4.3 *Other uses*

Calcium carbide is sometimes used as source of acetylene gas, which is a ripening agent similar to ethylene. However, this is illegal in some countries as, in the production of acetylene from calcium carbide; contamination often leads to trace production of phosphine and arsine. These impurities can be removed by passing the acetylene gas through acidified copper sulfate solution, but, in developing countries, this precaution is often neglected.

Calcium carbide is used in toy cannons such as the Big-Bang Cannon, as well as in bamboo cannons. In the Netherlands calcium carbide is used around new-year to shoot with milk churns.

2.5 Calcium Carbide Residue

Calcium Carbide Residue (CCR) is a waste by product from acetylene gas production. The main component of CCR is $Ca(OH)_2$, which can react with siliceous materials through

pazzolanic reaction, resulting in a product similar to those obtained from the cement hydration process. Thus, it is possible to use CCR as a substitute for portend cement in concrete (Tsakiridis*et al.,* 2014).

2.5.1 Properties of calcium carbide

Table 2.1: Chemical composition of calcium carbide residue.

Oxide (%)	CCR
Sio_2	2.1
Al_2O_3	0.50
Fe_2O_3	0.54
CaO	95.69
K_2O	0.47
Na_2O	-
SO_3	0.31
BaO	0.09

Joeland Edeh (2014) investigated the stabilization of Laterite with 2-10 % cement and 2-10 % Calcium Carbide waste, for use as pavement material. Atterberg's limits test, California bearing ratio (CBR) and Unconfined Compressive Strength (UCS)tests were conducted on the natural and stabilized soil. The result showed 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 and 10% CCW, at 7 day curing period theUCSand CBR values was greatly improved from 534to 3157kN/m^2 and from28% to 180% respectively, when treated with a combination of 10% cement and 10% CCW. They concluded that, the use of a mixture of 8% cement and 10%CCW, 10% cement and 10% CCWare recommended for the treatment of Ikpayongo laterite for use as base material.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Laterite

Lateritic soil used for the study was taken from a borrow pit at LapanGwari Village, a suburb of Minna, the capital city of Niger state, along Talba farm road.

3.1.2 Portlandcement

The Portland cement used in the study was purchased at open Market in Minna, the capital city of Niger state, Nigeria.

3.1.3 Calcium carbide residue

The calcium carbide residue used for the study was obtained from various welders' location in Wushishi and Zungeru towns, in Niger state.

3.2 Methodology

The method used in the study involved collection of disturbed laterite soil sample from an existing borrow pit. This soil samples (both natural and treated) were subjected to laboratory tests in order to investigate improvement in its strength properties (compaction characteristics and Unconfined Compressive Strength) and ascertain its suitability for use as pavement material.

The following tests were carried out:

i. Natural moisture content
ii. Sieve analysis
iii. Specific Gravity
iv. Atterberg limit
v. Compaction test
vi. Unconfined Compressive Strength (UCS)test.

Particle size distribution was used to classify soil for engineering proposes, the test is performed to determine the percentage of different grain size contain in the soil.

3.2.1 Natural moisture content

The natural moisture content of the soil sample was carried out in accordance with BS1377 (1990) part 2, which involved weighing two empty cans to the nearest 0.01g ($M_{1)}$.About 30g of fresh soil sample was placed in each of the cans and weighed again to the nearest 0.01g (M_2).

The cans containing the dried soil were weighed (M_3). The natural moisture content was then determined from:

$$w = \frac{m_2 - m_3}{m_3 - m_1} \quad (3.1)$$

Where

m_1 = Mass of empty container

m_2 = Mass of container with wet soil

m_3 = Mass of container with dry soil

3.2.2 Sieve analysis

The procedure adopted was also in accordance with BS 1377 (1990) part 2, which involved soaking 300g of soil for 24 hours and then washing, oven drying and making it ready for the grain size test. The retained samples during washing on sieve size 2.0mm and 0.075mm were carefully removed and placed in a pan, which were in turn placed in oven at 105^{o}C to 110^{o}C for 24 hours. Set of sieves were measured empty and arranged sequentially with the largest on top and 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 base pan. The oven dried samples were poured into the uppermost sieve and the sieves was placed on mechanical sieve shaker and allowed to shake for 10 minutes. The weight of each sieve was taken and recorded. The weights of empty sieves were subtracted to give the weight of the retained soil on each sieve. The percentage of total sample, passing each of the sieves was calculated.

3.2.3 Specific gravity test

The procedure adopted is outlined in BS 1377(1990) part 2. The density bottles with stoppers were washed dried and weighed empty with the stopper as M_1. About 50g of soil sample which pass through sieve size 2mm was poured into the density bottles. The density bottles and

content together with the stoppers were weighed as M_2. Distilled water was added and covered and allowed to fully soak. After this, the stoppers were inserted, the bottles together with the content were shaken, and the stoppers were then removed and water was added to reach 250ml capacities. The bottles with the content and stoppers were weighed as M_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 M_4. The specific gravity of the sample was calculated from:

$$GS = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \quad (3.2)$$

Where;

M_1 = Weight of bottle

M_2 = Weight of bottle +dry soil

M_3 = Weight of bottle + soil + water

M_4 = Weight of bottle + water.

3.2.4 Atterberg limit tests

The test conducted includes Liquid Limit (LL) and Plastic Limit (PL). They were carried out in accordance with BS 1377 (1990) part 2.

3.2.4.1 *Liquid limit test*

Cone penetrometer method of liquid limit determination was used. Reasonable quantity of air-dried sample was pulverized and sieved through 425 μm sieve. About 200g of the sieved sample was placed on a flat glass and mixed thoroughly with clean water using spatula until the soil mass become a thick paste. The paste was pushed into the cup with spatula, making sure air was not trapped, until filled. The top of the soil was trimmed with the top of the cut and placed beneath the cone. The cone was then lowered so that it just touched the surface of

the soil. When the cone was in correct position, a slight movement of the cup gives a small mark on the surface of the soil and the reading of the dial gauge was recorded.

The cone was then released for a period of 1-5 seconds. After penetration, the dial gauge was lowered to the new position of the cone shaft and readings recorded. The difference between the readings at the beginning and at the end of the test was recorded as the cone penetration. Average of two penetrations was recorded. The cone lifted out and cleaned. A moisture content sample of about 10g was taken from the area penetrated by the cone for moisture content determination. The soil was then removed from the cup, remixed and the procedure outlined above was repeated using the same sample with more water added until penetration of about 20mm was recorded. The relationship between the moisture contents and cone penetration was plotted. From the plotted graph, moisture content at 20m penetration was taken as liquid limit of the soil.

3.2.4.2 *Plastic limit test*

About 20g of the pulverized soil sample sieved through 425μm sieve was used for the test. The soil was thoroughly mixed with clean water. A small sample of soil ball was then rolled between the hand and glass plate. The rolling was continued until a thread that grumbles at about 3mm diameter was obtained. The crumbled soil was then gathered and placed in moisture can for moisture content determination. Plasticity Index (PI) was then determined from the result of liquid and plastic limits.

3.2.5 Determination of compaction characteristics

The procedure adopted is as outlined in BS1377 (1990) part 4. The mass of an empty mould was weighed, noted and recorded as M_1. Then, a 3kg of air dried soil sample was thoroughly mixed with small amount of water. The mixed samples (soil-cement-CCR) was compacted into a 940cm^3 cylindrical mould in three layers of approximately equal mass, with each layer

receiving 25 blows of a 2.5kg rammer falling freely through a height of 300mm. after compacting the last (fifth layer), the collar was removed and the surface of the soil was trimmed level with the mould and then weighed as M_2. Specimen from top and bottom of the mould were taken for moisture content determination. The soil sample was removed from the mould and mixed together with the remaining sample on the tray. The above procedure was repeated at varying moisture content, until the mass decreased. The dry density, in each case was calculated and plotted against its corresponding moisture content. The bulk density and the dry density were calculated from

$$\rho_b = \frac{M_2 - M_1}{V} \quad (3.3)$$

M_1 = mass of empty mould

M_2 = mass of mould + soil

V = volume of mould

Also, dry density,

$$\rho_d = \frac{\rho_b}{1+w} \quad (3.4)$$

Where w = moisture content of the soil.

3.2.6 Strength characteristics

3.2.6.1 *Unconfined compressive strength*

The Unconfined Compressive Strength (UCS) tests were performed on the soil samples in accordance with BS 1377 (1990) Part 7 at the Standard Proctor energy level. In moulding the samples, the stabilized soils samples were filled into a properly oiled split mould and collar of height 80mm and diameter 38mm. The samples were given 2 blows using a 3.15kg rammer falling through a height of 30cm for the first layer. More samples were added into the mould

and given another 2 blows for the second layer and another 2 blows for the final layer after addition more sample into the mould. The mould was then untied and excess sample trimmed with a knife. The moulded sample was then wrapped in polyethene, labeled properly and immersed in wet river sharp sand to be cured for 1, 7, 14, 28 and, 60 days.

Before testing the moulded sample are trimmed to a height of 76 mm and moisture content test conducted on the excess soil sample. The mass of the wet sample was also determined to calculate the bulk, the specimen was then placed centrally on the lower platen of the UCS testing machine and a compressive force applied to the specimen. The UCS machine was then switched on and the load reading taken from the proving ring dial gauge at deformation intervals of 0.05, 0.1, 0.2, 0.3, 0.4, etc. continuously until the sample stears. The machine was then unloaded and the sample removed. The procedure was repeated for each sample after 1, 7, 14, 28, and 60 days. Record was also taken simultaneously of the axial deformation and axial force at regular interval until failure of the sample occurs. UCS of the samples were calculated at the point on the stress–strain curve at which failure occurred using the following equation:

$$\text{compressive strength} = \frac{\text{failure load}}{\text{Cross} - \text{sectional area of specimen}} \tag{3.5}$$

The results obtained from different percentage proportions of the stabilizers as well period of curing is shown in Appendix

Cross-sectional area of specimen were determined from

$$A_f = \frac{A_o}{1-\varepsilon} \tag{3.6}$$

Where:

where

$A_i = \text{initial area of sample}$

$\varepsilon =$ strain

$$Ao = \pi r^2 \quad (3.7)$$

Where:

r is initial radius of the specimen

strain was computed from

$$\varepsilon = \Delta L/lo \quad (3.8)$$

ΔL= change in length deformation of the specimen

lo= is initial length of the specimen

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Properties of the Natural Soil

The results of preliminary tests conducted on the natural soil, for identification and classification purposes, is presented on Table 4.1. From the results, the soil is classified as CL and A-6 according to Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO) respectively. The soil is reddish brown in colour, with specific gravity of 2.69, Maximum Dry Density (MDD) of 1.86Mg/m^3, Optimum Moisture Content (OMC) of 12.0%, Unconfined Compressive Strength (UCS) of 57.92kN/m^2 and California Bearing Ratio (CBR) of 28%. The above result indicates that the geotechnical properties of the soil fall below the standards recommended for most civil

engineering construction works, especially pavement structures and therefore need stabilization (Osinubi and Medubi, 1997).

Table 4.1: Geotechnical properties of natural soil

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

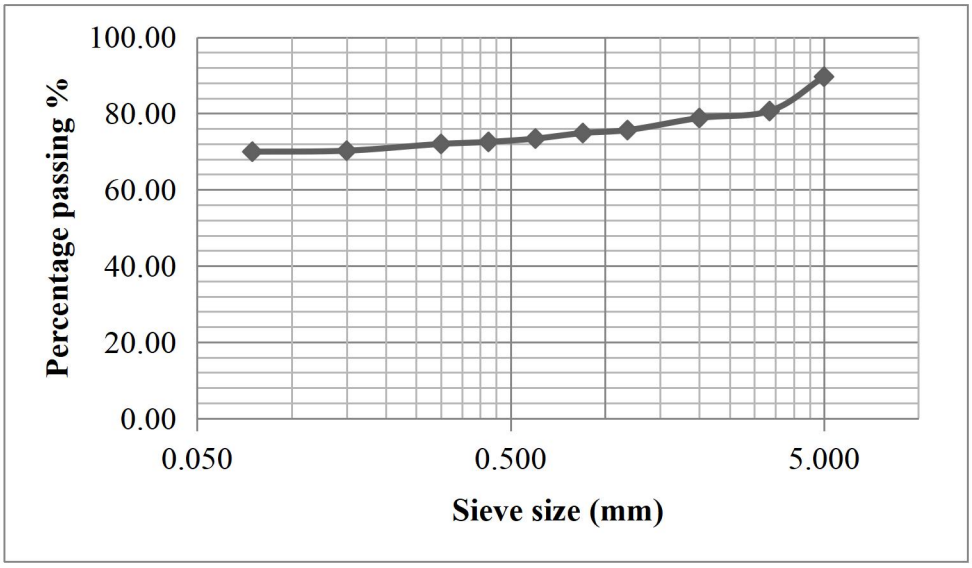

Figure 4.1: Particle size distribution curve for the natural soil

4.2 Variation of Compaction Characteristics with Various Dosages of the Additives

Variations of compaction characteristics with increase in dosage of CCR at various percentages of cement are presented in Figures 4.2 and 4.3 (see Table B1 and B2 in Appendix B) for MDD

and OMC respectively. From Figure 4.2, it can be observed that MDD of the stabilized soil increase with increase in cement content from 1.860Mg/m^3 at 0% cement and 0% CCR to a maximum value of 1.8708Mg/m^3 at 0% cement and 6% CCR.This represents 3.6% increase in MDD of the soil. This is as a result of the relatively higher density (specific gravity of 3.14) of cement as compared to that of the soil (2.69). At constant percentage dosage of cement, MDD of the stabilized soil decreased with increase in percentage of the CCR from 1.8065Mg/m^3 at 0% cement and 6% CCR to a minimum value of 1.7402Mg/m^3 at 2% cement and 6% CCR. This again, can be attributed to the relatively lower specific gravity of the additive (CCR) as compared to those of the soil and cement. With the soil and cement, having specific gravities of 2.69 and 3.14, as compared to that of the CCR (2.25), increase in percentage composition of CCR in the soil-cement mixture will result to reduction in the net density of the composite material.

From Figure 4.3, it is observed that OMC increase with increase in percentage composition of cement from 12% at 0% cement and 0% CCR to a maximum value of 17.58% at 0% cement and 6% CCR.This represents 46.5% increase in OMC of the soil, which is as a result of the morewater needed for hydration of cement. At constant dosage of cement, OMC is also observed to increase with increase in percentage of CCR from 17.58% at 6% cement and 0% CCR to a maximum value of 21.31% at 6% cement and 4% CCR. This is attributed to the reaction between the soil-cement and CCR. While CCR helps in flocculating clay particles in the soil, a phenomenon typical, when lime is used to improve soil, cement hydration produces cementitious materials, binding the soil-additives mass. These reactions require water to proceed, hence increase in the OMC. This trend of MDD and OMC variation is similar to that reported by JoelandEdeh (2014).

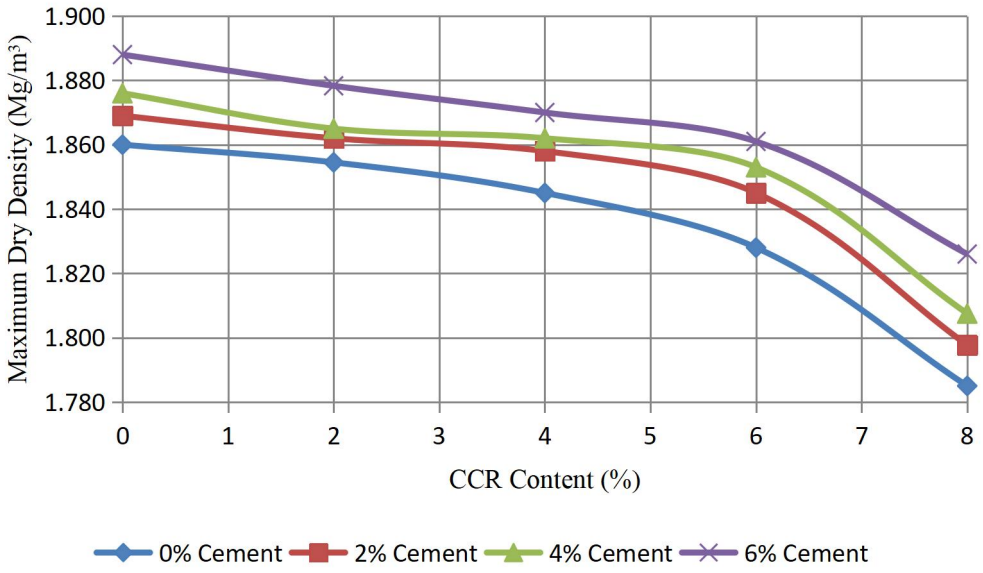

Figure 4.2: Variation of MDD with increase dosage of cement and CCR

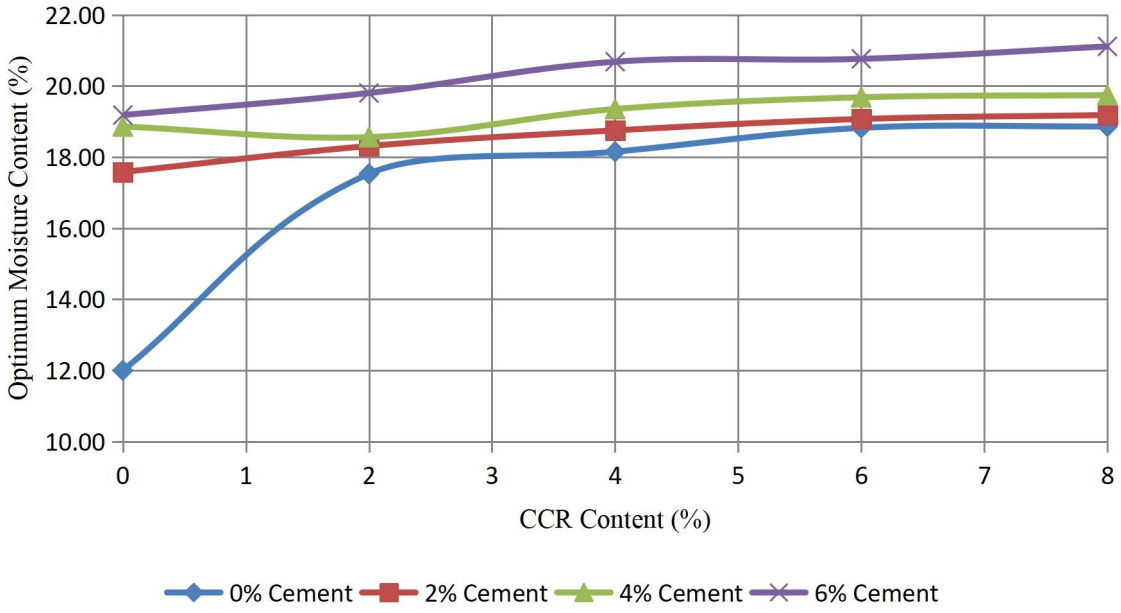

Figure 4.3: Variation of OMC with increase dosage of cement and CCR

4.3 Variation of Unconfined Compressive Strength with Various Dosages of the Additives

Variations of Unconfined Compressive Strength (UCS) with percentage dosage of both cement and CCR are presented in Figures 4.4, 4.5, 4.6, 4.7 and 4.8 (see Table C1, C2, C3, C4, and C5 in Appendix C) for 1, 7, 14, 28 and 60 days curing periods respectively. From the figures, it is

observed that as cement content increase, UCS of the treated soil increased. At constant percent content of cement, UCS increased to their maximum values at 4% CCR content. Also, observation and comparison of the figures revealed that as the curing period increases, unconfined compressive strength of the treated soil increased. This noticeable increase in unconfined compressive strength of the treated soil, with increase in curing time is attributed to the progress in hydration reaction of cement. Addition of CCR initially increased the UCS, because of the modification effect of Ca(OH), which is a typical process when lime is used to treat clayey soil. This modification process manifests itself by flocculating the clay particles in the soil to make them behave as granular once. Since cement hydration proceed, better in granular soil than clay soil, this flocculation, coupled with cementation by products of hydration, results to increase in strength (UCS). The drop in strength after 4% CCR content can be attributed to excessiveness in mixtures of Ca(OH), from the CCR and that liberated by cement hydration reaction. This excessCa(OH) within the mass of the mixtures create barrier that hinders bonding of the soil particles by the formed cementitious materials, resulting to decrease in strength.

Since cement hydration reaction is relatively a time-based reaction, the strength of the mixtures increased with curing period. It was observed that after 1-day curing period (Figure 4.4), only mixtures with 4 and 6% cement at 4% CCR recorded UCS values above the 1710 kN/m^2 recommended by Transportation and Road Research Laboratory (1977) and 1750 kN/m^2 reported by Khannaand Justo(1997), as criteria for design cement content, considered adequate for soil-cement composite as base course material for highway pavements with light to medium traffic. After 7 days curing period (Figure 4.4), mixture with 2% cement met this requirement at 4% CCR. Although, mixtures with higher cement contents also satisfied this criteria, even at relatively earlier curing period, mixture with 2 and 4% cement and CCR respectively, will be more cost effective. SaiduandMu,azu(2020) also reported this combination (2%cement and 4%

CCR contents respectively), as optimal for treatment of full depth reclaimed surface-dressed pavement for road base.

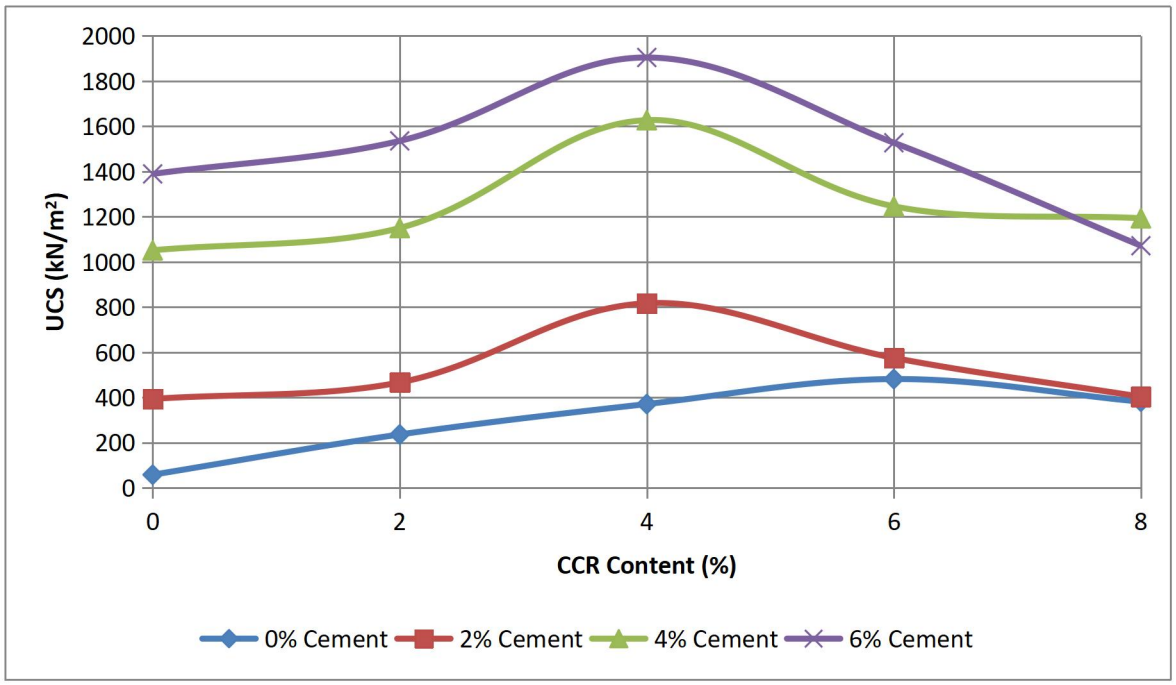

Figure 4.4: Variation of unconfined compressive strength with cement and CCR dosages after 1 day curing period

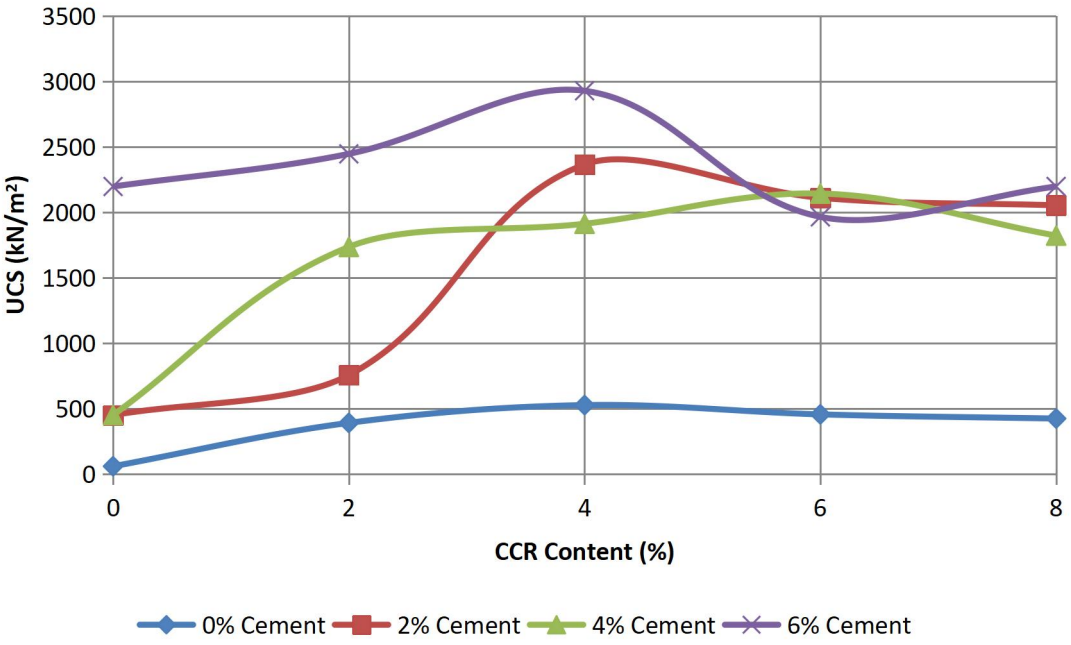

Figure 4.5: Variation of unconfined compressive strength with cement andCCRdosages after 7 days curing period

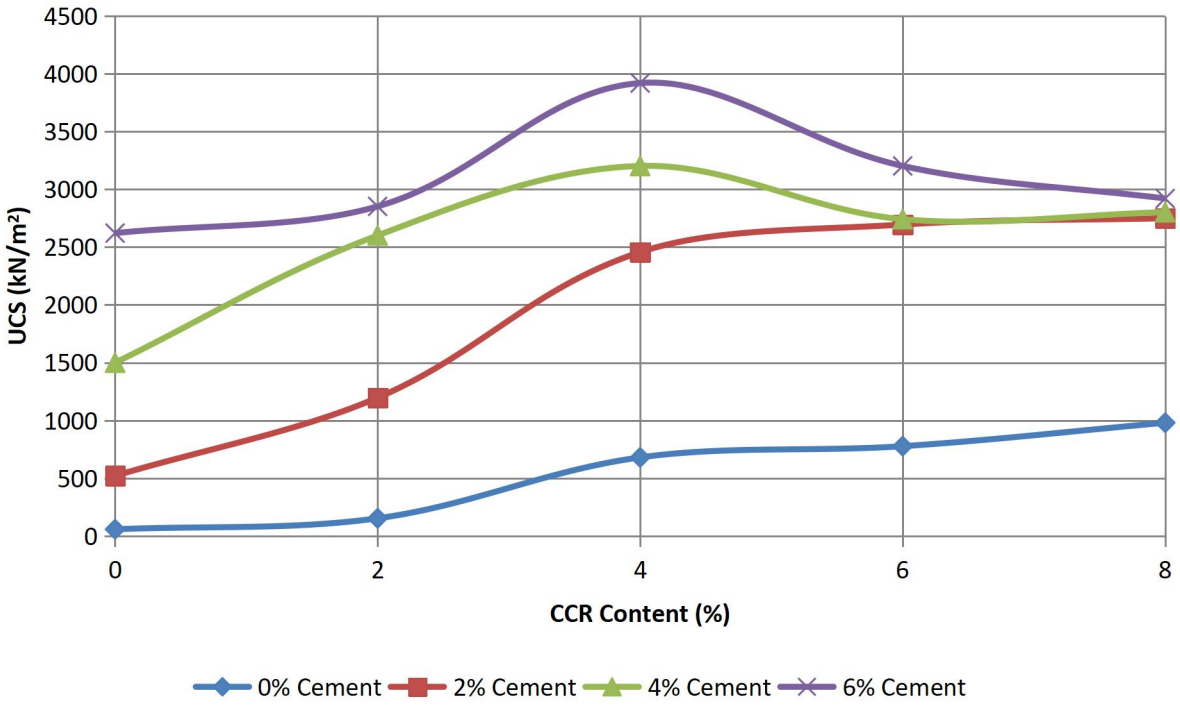

Figure 4.6: Variation of unconfined compressive strength with cement and CCR dosages after 14 days curing period

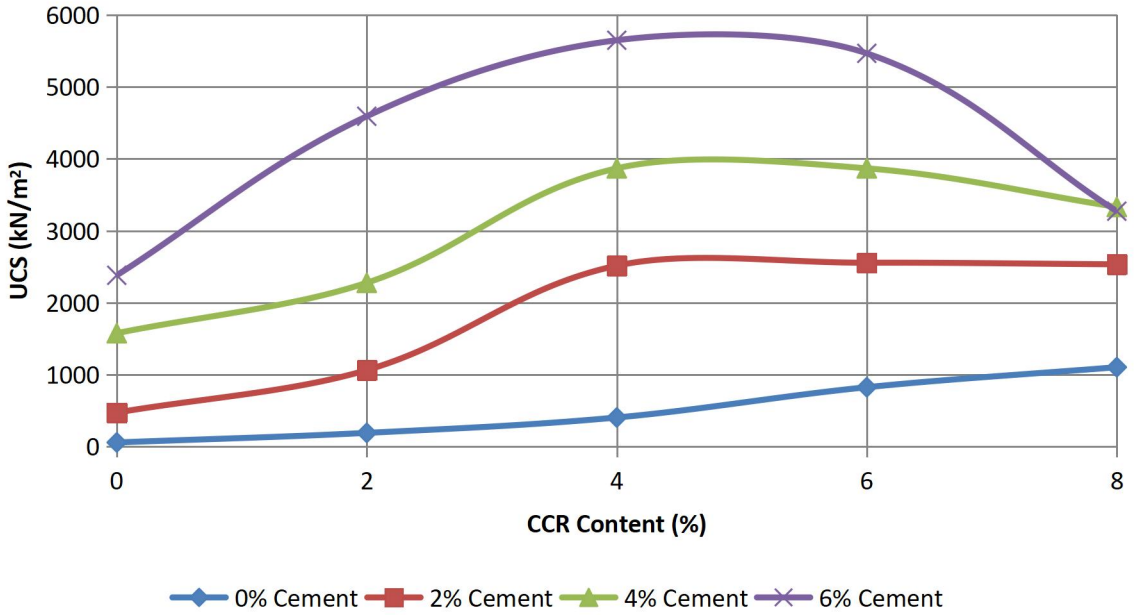

Figure 4.7: Variation of unconfined compressive strength with cement andCCR dosages after 28 days curing period

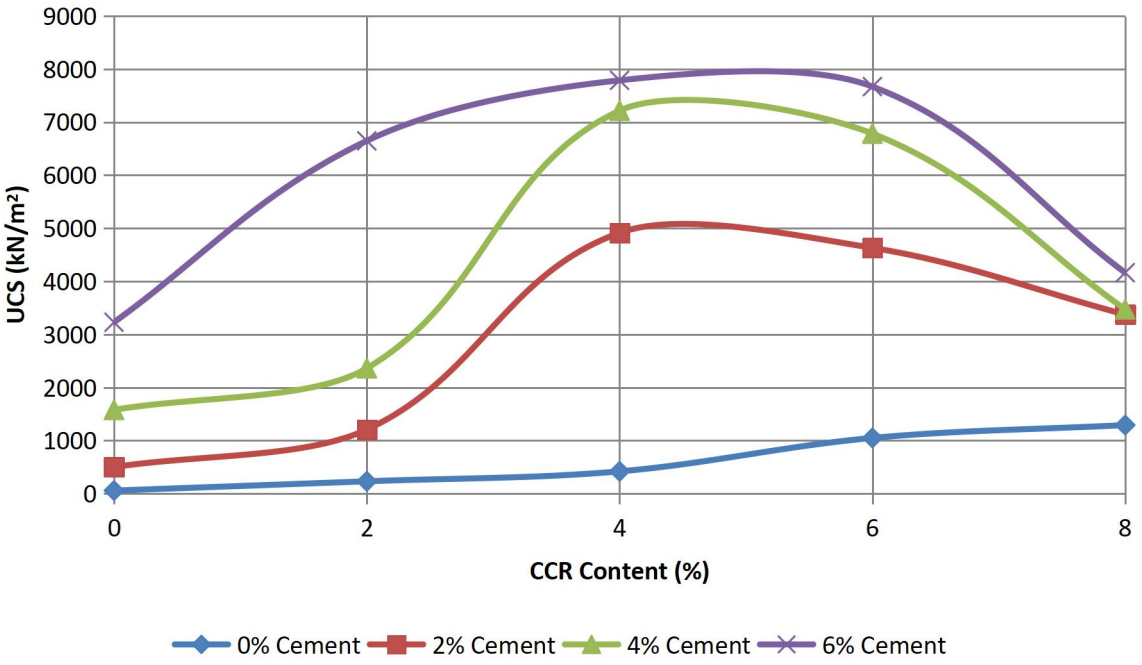

Figure 4.8: Variation of unconfined compressive strength with cement and CCRdosagesafter 60 days curing period

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the study, the following conclusion is drawn:

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

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

After 7 days curing period, mixture with 2 and 4% cement and CCR respectively, satisfied the 1710 kN/m^2 recommended by Transportation and Road Research Laboratory (1977) and 1750kN/m^2 reported by Khanna and Justo, (1997), as criteria for design cement content, considered adequate for soil-cement composite as base course material for highway pavements, with light to medium traffic.

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

5.2 Recommendation

Lateritic soil of class CL and A-6 can be treated with 2 and 4% cement and CCR respectively, for road pavement structure.

5.3 Contribution to Knowledge

The study considered the possibility of treating deficient lateritic soil with up to 6 and 8% (at 2% variation) of cement and calcium carbide residue (CCR) respectively, and showed that the Mixture containing 2 and 4% cement and CCR respectively satisfied the 1710 kN/m^2 strength required for stabilized road base course material.

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APPENDICES

APPENDIX A

Table A1: Sieve Analysis Result for Natural Soil

Sieve size (mm)	Mass of sieve (g)	Mass of sieve+Soil (g)	Mass retained (g)	Percentage Retained	Percentage Passing
5.000	474.70	505.80	31.10	10.37	89.63
3.350	468.00	495.00	27.00	9.00	80.63
2.000	416.80	422.30	5.50	1.83	78.80
1.180	384.90	394.40	9.50	3.17	75.63
0.850	351.70	354.00	2.30	0.77	74.87
0.600	467.80	472.20	4.40	1.47	73.40
0.425	435.10	437.70	2.60	0.87	72.53
0.300	313.00	314.60	1.60	0.53	72.00
0.150	420.40	425.70	5.30	1.77	70.23
0.075	398.50	399.30	0.80	0.27	69.97

Table A2: Natural Moisture Content of Soil

Can Number	**1**	**2**
Weight of can (g)	28.8	25
Weight of can+wet soil (g)	81.5	83.6
Weight of can+dry soil (g)	79.5	81.6
weight of dry soil (g)	29.7	28.3
weight of water (g)	2	2
Moisture content (%)	6.73	7.07
Average MC (%)	**6.90**	

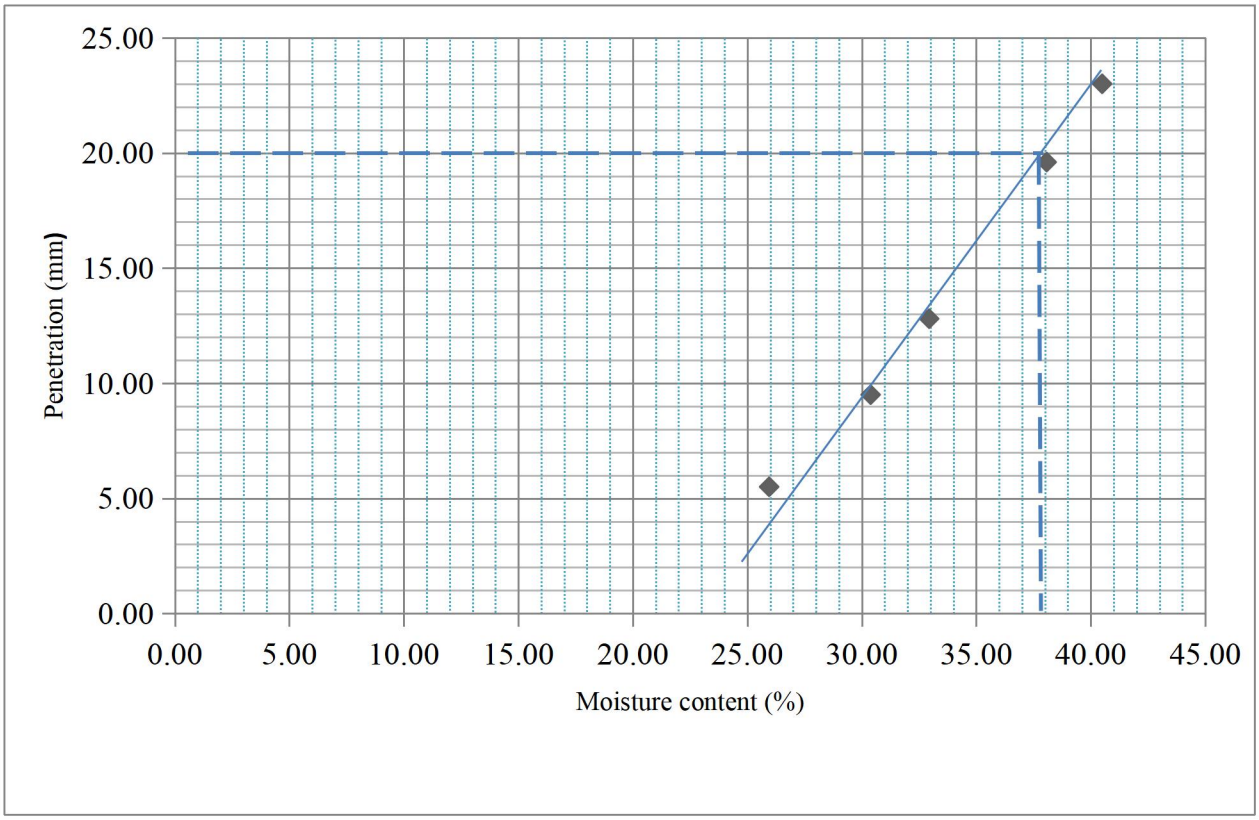
Table A3: Specific Gravity of Natural Soil

Pycnometer Number	1	2	3
Mass of pycnometer, (g)	69.0	69.0	69.0
Mass of pycnometer + dry soil, (g)	94.4	98.1	119.5
Mass of empty pycnometer + dry soil + water, (g)	185.5	189.1	186.0
Mass of empty pycnometer + water, (g)	168.4	168.4	168.4
Specific gravity (Gs)	3.06	3.46	1.53
Average Gs		**2.69**	

Table A4: Atterberg Limits of Natural Soil

	LIQUID LIMIT	**PLASTIC LIMIT**

Can Number	1	2	3	4	5	1	2
Penetration	5.50	9.50	12.80	19.60	23.00		
Can Weight	24.30	24.30	25.30	26.10	38.70	38.2	39.3
Weight of can +wet soil	40.80	47.90	47.90	56.20	72.70	44.5	45.3
Weight of can + Dry soil	37.40	42.40	42.30	47.90	62.90	43.3	44.2
Weight of Moisture	3.40	5.50	5.60	8.30	9.80	1.2	1.1
Weight of Dry Soil	13.10	18.10	17.00	21.80	24.20	5.1	4.9
Moisture Content	25.95	30.39	32.94	38.07	40.50	23.53	22.45
Liquid Limit	**38.41**		**Average Plastic Limit**			**22.99**	



APPENDIX B

Table B1: Results of Maximum Dry Density (g/cm^3) with various dosages of Cement and CCR

Cement (%)	Calcium Carbide Residue (%)				
	0	2	4	6	8
0	1.860	1.8048	1.8242	1.8545	1.745
2	1.8422	1.8392	1.7522	1.7402	1.7377
4	1.8486	1.8255	1.8076	1.7853	1.7575
6	1.8708	1.7826	1.7745	1.7481	1.7451

Table B2: Results of Optimum Moisture Content (%) with various dosages of Cement and CCR

Cement (%)	Calcium Carbide Residue (%)				
	0	2	4	6	8
0	12	19.07	17.65	18.82	20.76
2	19.18	18.36	18.95	18.37	18.86
4	18.86	17.83	20.68	18.74	19.18
6	17.58	18.31	21.31	19.35	19.68

APPENDIX C

Table C1: Results of Unconfined Compressive Strength (KN/m^2) with various dosages of Cement and CCR after 1-day curing period

Cement (%)	Calcium Carbide Residue (%)				
	0	2	4	6	8
0	57.92	236.05	370.78	481.37	381.28
2	393.54	66.51	816.86	575.07	403.26
4	1051.26	1150.13	1627.37	1245.98	1193.27
6	1389.37	1904.68	1535.56	1071.43	1527.38

Table C1: Results of Unconfined Compressive Strength (KN/m^2) with various dosages of Cement and CCR after 7-day curing period

Cement (%)	Calcium Carbide Residue (%)				
	0	2	4	6	8
0	57.92	189.65	425.62	804.64	622.82
2	449.17	554.82	2364.21	2109.82	2052.43
4	449.83	1734.39	1911.38	2142.14	1821.05
6	2196.18	2927.66	2445.51	1964.29	2196.18

Table C1: Results of Unconfined Compressive Strength (KN/m^2) with various dosages of Cement and CCR after 14-day curing period

Cement (%)	Calcium Carbide Residue (%)				
	0	2	4	6	8
0	57.92	152.91	466.66	977.07	1283.49
2	520.65	1196.69	2556.79	2695.19	2749.88
4	1500.00	4397.50	2601.03	5241.73	3202.30
6	2621.32	3919.85	2852.36	2323.07	2392.92

Table C1: Results of Unconfined Compressive Strength (KN/m^2) with various dosages of Cement and CCR after 28-day curing period

Cement (%)	Calcium Carbide Residue (%)				
	0	2	4	6	8
0	57.92	190.97	404.76	825.48	1103.84
2	473.07	1063.39	2514.98	2556.03	2533.80
4	1576.89	1277.08	3867.73	3867.73	3971.93
6	2380.95	5465.96	4591.41	3331.03	5648.16

Table C1: Results of Unconfined Compressive Strength (KN/m^2) with various dosages of Cement and CCR after 60-day curing period

Cement (%)	Calcium Carbide Residue (%)				
	0	2	4	6	8
0	57.92	232.93	420.14	1050.03	1292.40
2	501.30	1207.35	3376.00	4631.00	4914.72
4	1579.63	2363.00	3473.95	6784.00	7217.06
6	3229.07	74670.00	6648.00	4163.62	7788.02