SUITABILITY OF USING COMPACTED BLACK COTTON SOIL TREATED WITH GROUNDNUT SHELL ASH FOR HYDRAULIC BARRIER IN MUNICIPAL LANDFILL

BY

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DECLARATION

I hereby declare that this work is the product of my research efforts, undertaken under the supervision Dr. A.Y Abdulfatah and has not been presented elsewhere for the award of a degree or certificate. All sources have been duly acknowledged.

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CERTIFICATION

This is to certify that the research and preparation of dissertation were carried out under my supervision.

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DEDICATION

To my late father Alhaji Usman Nagado Tokari, may Allah grant him Jannatul Firdaus, Amen.

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ABSTRACT

Laboratory tests were conducted on black cotton soil treated with (0 - 12%) groundnut shell Ash (GSA) by dry weight of soil to assess its suitability for use in waste containment application. Specimens were prepared at molding water contents -2%, 0%, +2% and +4% from the optimum moisture content at the compactive energy levels of British Standard Heavy (BSH) and West African Standard (WAS). Index properties, hydraulic conductivity (k), volumetric shrinkage strains (VSS) and unconfined compressive strength (UCS) tests were carried out. Results obtained showed slight changes in index properties. Hydraulic conductivity values recorded at both BSH and WAS produced satisfactory results that met the regulatory $1x10^{-9}$m/s requirement at treatment levels of 4% and 8% for BSH and 12% at WAS. The UCS values at 12% GSA treatment fort WAS compactive energy level and 4% and 8% BSH compactive energy level met the minimum regulatory value of 200kN/m^2 for shear strength. VSS values recorded met the regulatory requirement of less than 4% volumetric shrinkage strain at 4% and 8% GSA content for BSH and 12% GSA contents for WAS energy level. The overall acceptance zone for GSA treated black cotton soil was achieved at 4 and 8% groundnut shell ash content for specimen prepared at molding water content range of < 24.09% and 23.38 – 25.38% for BSH and23.6 – 25.6 for WAS. This study therefore concluded that compacted black cotton soil treated with groundnut shell ash (GSA) is suitable for use in hydraulic barrier in municipal landfill.

CHAPTER ONE

INTRODUCTION

1.1 GENERAL OVERVIEW

Since the beginning of time, man has created and disposed waste material. Solid wastes are the byproducts of human activities. Due to increase in population, change in life style, urbanization and advent of technology and industrialization, there has been radical change in quantity as well as quality of the solid waste produced. These wastes have become more hazardous to environment and demands careful disposal practices. Unfortunately, with the exception of the past 30 - 50 years, this practice has been carried out with little regard for the environment. The total volume of waste materials, being an integral part of any society can be reduced through the use of modern technology, they cannot be completely eliminated. Waste materials that cannot be recycled or eliminated must therefore; be placed in a landfill (Cawley, 1999).

1.2 STATEMENT OF THE PROBLEM

Compacted liners are an important component of a lining system used for municipal and hazardous waste landfills. The ability of compacted soil liners to restrict the movement of water and contaminants depends on particle size, void ratio, specific surface, degree of saturation, and fluid properties (Vuković and Soro, 1992; Foged and Baumann, 1999). Furthermore, hydraulic barrier layer prevents landfill gasses from escaping into the atmosphere. Such gases are shown to be major sources of air pollution and ozone depletion Environmental protection Agency, EPA, 1985 recommends three types of liners and these are: Flexible Membrane Liners (FMLs); Compacted Clay (Soil) Liners and Composite Liners.

Other materials used as liners or cover in waste containment systems, in addition to natural clayey soils include, processed clay/sand-processed clay mixtures, geosynthetic materials and industrial waste products. (Bowders et al, 1987; Frebrer 1996; Cabochons et al, 2002; Albrecht and Benson, 2001). Furthermore, Studies have been carried out on the use of compacted lateritic soil as liners and cover in waste containment application (Liman, 2009; Osinubi and Nwaiwu, 2005, 2005a,b; Osinubi and Eberemu, 2006; Osinubi and Eberemu, 2009b; Osinubi and Amadi, 2006; Osinubi and Amadi, 2009, 2010; Amadi, 2006 and Eberemu, 2006). Lime had been used to stabilize the hydraulic conductivity of clay against chemical attack by organic solutions (Broderick and Daniel 1990), and as an additive to reduce the hydraulic conductivity of fly ash (Bowders and Daniel, 1987).

Due to non-availability of suitable soil for these layers at a site, it is sometimes necessary to blend imported clay materials with local non-productive soils and industrial process wastes to achieve a suitable blended material. The most common blend is a combination of onsite material /industrial process waste with sodium bentonite which can lower hydraulic conductivity as much as several orders of magnitude. Lack of availability of natural clays with satisfactory engineering properties has prompted researchers to look for alternative approaches for liner design. A lot of researches have been done to determine the suitability of using available local materials or industrials waste materials in the construction of liners. Some of the materials used are rubber and bentonite added fly ash (Cocka, et. al., 2004), Blast Furnace Slag (Osinubi et al., 2006), Fly Ash (Kumar, 2002), (Amadi, 2003), Cement Kiln Dust (Moses, et. al., 2010) etc.

1.3 MATERIALS

The materials that were used in this research work were black cotton soil treated with groundnut shell ash. Black cotton soils are black clays that are produced from the breakdown of basic igneous rocks, where seasonal variation of weather is extreme. Specifically, Nigerian black cotton soils are formed from the weathering of shaly and clayey sediments and basaltic rocks. According to Ola (1983) the

Nigerian black cotton soils contain more of montmorillonite with subsequent manifestation of swell properties and expansive tendencies.

Groundnut shell is an agricultural waste obtained from milling of groundnut. The ash from groundnut shell has been categorized under pozzolana (Alabadan et.al , 2006), with about 8.66% Calcium Oxide (CaO), 1.93% Iron Oxide (Fe_2O_3), 6.12% Magnesium Oxide (MgO), 15.92% Silicon Oxide (SiO_2), and 6.73% Aluminum Oxide (Al_2O_3). The utilization of this pozzolana as a replacement for traditional stabilizers will go a long way in actualizing the dreams of most developing countries of scouting for cheap and readily available construction materials. Groundnut shell ash has been used in concrete as a partial replacement material for cement with a measure of success achieved (Alabadan*et al.*, 2005). It has also been used in stabilization of Black cotton soil (Oriola, et al., 2010)

1.4 AIM AND OBJECTIVES:

1.4.1 Aim

The aim of the research was to determine the suitability of using black cotton soil treated with groundnut shell ash in the construction of hydraulic barrier in Municipal Landfills.

1.4.2 Objectives:

The specific objectives are:

1. To collect and characterize black cotton soil samples for basic engineering properties.
2. To produce groundnut shell Ash under controlled environment.
3. To conduct hydraulic conductivity, shear strength and volumetric shrinkage test on black cotton soil samples mixed with different percentages of groundnut shell Ash.
4. To determine an optimum percentage of groundnut shell ash that satisfies landfill barrier specifications.

1.5 JUSTIFICATION

Production of large quantity of Agricultural wastes all over the world faces serious problems of handling and disposal. Safe disposal of Agricultural wastes without adversely affecting the environment and the large storage area required are major concerns. Hence, the use of groundnut shell ash, as an additive to improve the geotechnical properties of Black cotton soil to be used as hydraulic barrier. Previous researches have shown that groundnut shell ash have been effective in the stabilization of black cotton soil (Oriola, et al., 2010).

1.6 SCOPE AND LIMITATIONS

1.6.1 Scope

The research is focused on suitability studies of black cotton soil – groundnut shell mixture as material for hydraulic barrier for municipal land waste; the effect of environmental factors such as desiccation of the compacted liner will also be studied.

1.6.2 Limitations

This research is limited to the use of black cotton soil in a mixture with GSA for assessing their suitability in the containment of municipal landfill. This feasibility study concentrate only on municipal solid waste (MSW), it will not take into cognizance of industrial solid waste.

1.6 SIGNIFICANCE OF THE RESEARCH

This research will add to the knowledge of the following:

- The basic engineering properties of black cotton soil , will be known.
- The basic requirements for compacted clay liner, will also be known
- The effect of GSA on the engineering properties of black cotton soil and the optimum percentage of groundnut shell ash that satisfies landfill barrier specification.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Black cotton soil or otherwise called tropical black clay soil are derived from weathering of basic igneous rocks in areas of seasonal contrast subject to poor drainage favorable to poor leaching and retention on magnesium and calcium in the soil (TRRL). The soil has the tendency to swell freely on application of water and shrinks heavily immediately the water content of the soil is removed. Agriculturally the soil is good for the growth of sugarcane and cotton, hence the name black cotton (Bowles, 1979)

Black cotton soils are major problematic soils of some tropical countries especially in Africa and India. They are poor materials by temperate zone standard and difficult to use for roads and air field construction because they are often expansive due to the presence of large percentages of expansive clay minerals, i.e montmorillonite. The soil swells when in contact with water and shrinks on drying. The soil deposits are usually extensive making it impossible to avoid or by pass during construction of engineering projects. Many roads and foundations of light buildings have been reported distressed due to the seasonal volume change (i.e. swell and shrinkage) of these soils (Chen, 1988). These soils have reportedly inflicted billions of dollars in damages and repairs annually to earth structures and facilities. Some works have been done on the black cotton soils locally and internationally, however, this rather useful information are scattered in various publications and the need to bring these scattered information together has long been felt. This work therefore seeks to address this problem. The work is augmented with results from a current research on Nigerian black cotton soils.

Definition and Nomenclature Black clays or tropical black earth or black cottons are known to be potentially expansive soils which are “black” or “greyish black” or in their eroded phase “greyish white” heavy loam or clay (usually 50%), with predominant clay mineral of the smectite group, rich in alkali earth elements and the horizons sometimes contain calcium carbonate or magnesium oxide concretions. Many other terms have been applied locally, such as *“regur”* soils in India, *“margalitic”* soils in Indonesia, *“black turf”* in Africa and *“tirs”* in Morocco. Although there are several names, the term “black cotton soil” is adopted in this work because of its extensive use in literature. The term “black cotton” is believed to have originated from India where the locations of these soils favour cotton growth. Pedologically, the black cotton soils classify as Vertisols (Table 2) and both terms are used interchangeably in this work. Black cotton soils have been defined differently by different authors, for instance Mohr and Van Baren (1959) proposed the term “margalitic soils” which they defined as “black or greyish black, grey or in the eroded phase greyish-white” heavy loam or clays; which crack when dry and swell when moistened, they are mostly rich in alkaline earths; horizons of calcium concretions develop sometimes or lime concretions are found scattered throughout the profile; they are characterized by montmorillonite or other minerals of the smectite group as clay compound. USAID/BRRI (1971) also defined the tropical black cotton clay to be dark grey to black soil with a high content of clay usually over 50%, in which montmorillonite is the principal clay mineral and are commonly expansive. Morin (1971) defined black cotton soil as dark grey to black soil which has high clay content usually over 50% and are potentially expansive. Bucher and Sailie (1984) described black cotton soil as rich in montmorillonite and therefore prone to high volume change in the presence of water.

The main characteristics of black cotton soils among others are:

1. Black or darkish grey to brown color

2. High content of expansive clay mineral montmorillonite
3. Poses the tendency to shrink and swell with change in moisture condition
4. Exhibits heave and crack as geo-environmental phenomena

2.2 WEATHERING

Weathering is a pedogenic process by which soils are formed as a result of disintegration or decomposition of rocks. This process causes changes in rocks at and near the earth's surface by interaction between the rocks and the chemically active components of the earth's atmosphere, principally water, carbon dioxide and oxygen. The effects of weathering extend below the earth's surface by ground-water movement through or around grains or along joints and fissures. The depth of weathering is largely controlled by topography and the availability of channels of flow for surface water. In some regions where climatic, topographic, and structural conditions are appropriate, weathering caused by circulation of groundwater of surface origin extends tens to hundreds of meters underground and causes notable changes in originally fresh rocks. Within a given area on the earth's surface and at a given geologic time, the particular effects of weathering are assessed in terms of at least five variables:

(1) Climate,

(2) Biological activity,

(3) Topography, as it affects underground movement of water, or contributes to erosional removal of weathered material

(4) Parent material (rocks) and

(5) Time.

A great variety of physical, chemical, and biological processes act to breakdown rock masses. Physical processes reduce particle size, increase surface area, and increase bulk volume. Chemical and biological processes may cause complete changes in physical, chemical and mineralogical composition of the end products.

Robinson (1949) recognized two main stages in chemical weathering. The first stage has to do with the destruction of mineral phases, and the second stage the formation of secondary products. These two stages involve the operation of various processes resulting in two main types of materials of morphogenic interest i.e.,

(i) weathering residues and secondary materials that occur insitu (residual soils), and (ii) materials which are transported before deposition (transported soils). The first process of physical or mechanical weathering is also designated as disintegration while the second stage–chemical weathering is designated as decomposition. Disintegration results in a decrease in size of rocks and minerals without appreciably affecting their composition. By decomposition, however, definite chemical and physico-chemical changes take place, soluble materials are released, and new minerals are synthesized or are left as resistant end products.

The formation of black cotton soils with respect to soil forming factors climate of formation of black cotton soils it was first thought that black cotton soils occur only in monsoonal type of climates with distinct annual wet and dry seasons in the tropics and subtropics, because of earlier recognition of their associations with these climates. However, they are now known to occur in almost every major climatic zone of the world and their classification has developed (Ahmed 1996). Annual rainfall between 300-900mm per year favours the formation of the soils (Katti et. al., 2002), however, higher rainfall values of 1270mm/year have also been recorded. Parent material black cotton soils have been identified on igneous, sedimentary and metamorphic rocks. They are formed mainly by the chemical weathering of mafic (basic) igneous rocks such as basalt, norite, andesites, diabases, dolerites, gabbros and volcanic rocks and their metamorphic derivatives (e.g. gneisses) which are made up of calcium rich feldspars and dark minerals which are high in the weathering order, in poorly drained areas with well defined wet and dry seasons. All constituents weather to form amorphous hydrous oxides and under suitable conditions clay minerals develop. The absence of quartz leads to the formation of fine grained, mostly clay size, plastic soils which are highly impermeable and easily becomes waterlogged. In addition abundant magnesium and calcium present in the rock adds to the possibility of formation of black cotton soil with its attendant swelling problem (Ola, 1983). The black cotton soils have also formed over sedimentary materials such as shale, limestone, slates etc. Ahmad (1983) found that although the parent materials are diverse, one striking feature which is common to all is the fact that the parent materials are rich in feldspar and ferromagnesian minerals which yield clay residue on weathering. He also noted that where the parent rock is not mafic (basic), alkali earth elements can be added through seepage or by flooding waters.

Topography Katti et al., (2002) reported that the black cotton soil deposits are formed under conditions where the slope of the terrain is less than 3˚. The most frequent physiographic position of black cotton soils is flat, alluvial plains (Dudal and Eswaran, 1988; Eswaran et al., 1988) such as those found in Sudan, Texas in the USA, Darling Downs in Australia, the Accra plains, Ho-Keta plains and the Winneba plains in Ghana (USAID/BRRI, 1971; Building and Road Research Institute, 1985). Other fewer occurrences are the Lufina valley of Zaire, the Kafue Flats of Zambia and the Panamalenga plains and the Springbok flats in Botswana, and South Africa respectively. However, black cotton soils also occur in surfaces with greater slopes (Ahmad, 1983). Age Clemente et al., (1996) reported that time of formation of vertisols is usually inferred from the age of the underlying parent material from which the soil has developed. Furthermore, they realized that most vertisols are derived from cenozoic era materials including Tertiary and Quaternary. Some sediments of Cretaceous age have also formed vertisols. They indicated however, that the age of the parent material gives information only on the maximum chronological point, the age of the geomorphic surface and the soils would be much younger.

2.3 DISTRIBUTION OF BLACK COTTON SOILS

Black cotton soils (vertisols) have been reported all over the world and have been found to occupy about 2% (257 million hectares) of the total ice-free land area of the earth with 72million hectares occurring in India, 71million hectares in Australia (Swindale, 1988) and 43million hectares is in Africa(Virmani, 1988). Countries reported to have black cotton soils are Australia (Aitchison, et. al., 1962; Ingles and Metcalf, 1972), Algeria (Afes and Didier, 2000), Botswana, Ethiopia (Mgangira and Paige-Green, 2008), Bulgaria, Hungry, Italy (Dudal and Eswaran, 1985), Togo (Oscar et al., 1977), Nigeria (Ola, 1976, 1983; Osinubi, 2006), South Africa (Van Der Merwe, 1964), Morocco, Chad, Cameroon, Kenya, Zambia, (USAID/BRRI, 1971), Tanzania (Bucher and Sailie, 1984), Sudan (Charlie et al., 1984), India (Michael, 2006; Rao et al., 2001), Ghana (Building and Road Research Institute, 1985; USAID/BRRI, 1971) etc.

2.4 CHEMICAL AND CLAY MINERALOGICAL STATUS OF BLACK COTTON SOILS

Chemical weathering is the main soil forming process of the black cotton soils. In this process, the minerals in the rocks are decomposed, resulting in chemical alteration. It is therefore important to indicate the chemical composition of the soils which will vary with such factors as parent rock, genetic characteristics of soil (transported or residual), degree of weathering, etc.. The black cotton soils are rich in silica, lime, iron, magnesia and alumina. Titanium oxide also occurs in very small concentrations; however, its presence is believed to give the soil the characteristic black colour (Building and Road Research Institute, 1985). In spite of its black colour, low organic matter contents (less than 5%) have been recorded for these soils. USAID/BRRI (1971) found that silica-sesquioxides ratios of the black cotton soils are greater than 2.50 indicating that they are non-lateritic soils.

2.5 CLAY MINERALOGY

The main clay mineral reported in black cotton soil is the smectite group of clay minerals of which montmorillonite is the predominant. Accessory minerals may be kaolinite, illites, etc. According to Sudharkar (2006), low rainfall has hindered the weathering of the active montmorillonite minerals into low active clay mineral such as illite and kaolinite.

Mermut et al., (1996) recognised that the formation and stability of the smectite are dependent on the Si activity as well as pH. At high pH, in the presence of high potentials of Si as well as Mg, smectite develops (a process which is also favoured by poor drainage). Transformation of some primary or secondary minerals into smectite have been reported (Eswaran et. al., 1988). The micro-environmental condition for this transformation is well established as essentially a pH of 7 or higher. If leaching occurs in the upper part of the soil with the generation of an acid environment, montmorillonite tends to be destroyed and other soil forming processes initiate.

2.6 BASIC GEOTECHNICAL CHARACTERISTICS OF BLACK COTTON SOILS

2.6.1 NATURAL MOISTURE CONTENT

The natural moisture content of a black cotton soil in a profile is variable, for instance, the Building and Road Research Institute (1985) reported natural moisture contents for nigerian black cotton soils to be between 20% and 45%; Mgangira and Paige-Green (2008) reported that the moisture contents of sub grade black cotton soils in the Horn region of Africa range between 24% and 54%.

Variation of natural moisture content with depth of typical Nigeria black cotton soil profile (Building and Road Research Institute, 1985) Grading and textural classification The gradation of the black cotton soils varies considerably. There are little or no gravels size in most black cotton soils and those that have show percentages of less than 8% (USAID/BRRI, 1971). The amount of sand varies between 2% and 50 % and silt 11% to 58%. The clay size contents also range from 40% to 75%. Low clay size contents (22%) have been reported for some Tanzania black cotton soils (Bucher and Sailie, 1984). The soils classify as clay, sandy-clay and silty-clay on the U.S. Engineers textural classification chart.

2.6.2 Plasticity Characteristics and Activity

The Liquid Limit of the black cotton soils are variable and range from 28% to190%, and the Plasticity Index range between 14% and 145%. The black cotton soils normally plot above the A-line and classify as inorganic clay of low to very high plasticity on the Casagrande's chart . The location of the black cotton soils on the Casagrande's chart gives an indication of its mineralogy (Wesley, 1988), however, from studies by Sridharan and Prakash (2000) indicate that both kaolinitic and montmorillonitic soils lie above and below the A-line. Hence, nothing can be inferred regarding their expansive nature just by their position on the plasticity chart. . The shrinkage limits range between 7% and 26%. Most black cotton soils classify as A-7-5 and A-7-6 by the AASHTO Classification System (AASHTO, 1986) with group index values varying from 13-89 (USAID/BRRI, 1971) and CH and CL on the Unified Soil Classification System (ASTM, 1992). The activity of the black cotton soils from the data collected (Table 5) was found to range between 0.37-1.70 thus indicating that the soils have low to high expansion potential based on the criteria proposed by Skempton (1953).

2.7 LANDFILL LEACHATES

Landfill leachate is a liquid that moves through or drains from landfill. This liquid may either exist already in the landfill or may be created after rain water mixes with the chemical waste. Modern landfills are often designed to prevent the liquid from leaching out and entering the environment. However if the leachate is not properly managed is at risk of mixing with ground water near the site which can have dire effects.

The most common source of leachate is the rain water filtering down through the landfill aiding the bacteria

2.8 COMPACTED CLAY LINERS

Compacted soil liners are composed of clayey materials that are placed and compacted in layers called lifts. The materials used to construct soil liners include natural mineral materials (natural soils), bentonite-soil blends, and other material

2.8.1 Natural Mineral Materials

The most common type of compacted soil liner is one that is constructed from naturally occurring soils that contain a significant quantity of clay. Soils are usually classified as CL, CH or SC soils in the Unified Soil Classification System (USCS) and ASTM D-2487**.** Soil liners materials are excavated from locations called borrow pits. These borrow areas are located either on the site or offsite. The soil in the borrow pit may be used directly without processing or may be processed to alter the water content, break down large pieces of material, or remove oversized particles. Sources of natural soil liner materials include lacustrine deposits, glacial tills, Aeolian materials, deltaic deposits, residual soils, and other types of soil deposits. Weakly cemented or highly weathered rocks, e.g., mudstones and shales, can also be used for soil liner materials, provided they are processed properly.

2.8.2 Bentonite-soil blends

If the soils found in the vicinity of a waste disposal facility are not sufficiently clayey to be suitable for direct use as a soil liner material, a common practice is to blend natural soils available on or near a site with bentonite. The term bentonite is used in different ways by different people. For purposes of this discussion, bentonite is any commercially processed material that is composed primarily of the mineral smectite. Bentonite may be supplied in granular or pulverized form. The dominant adsorbed cation of commercial bentonite is usually sodium or calcium, although the sodium form is much more commonly used for soil sealing applications. Bentonite is mixed with native soils either in thin layers or in a pugrnill.

2.8.3 Other materials

Other materials have occasionally been used for compacted soil liners. For example, bentonite may be blended with flyash to form a liner under certain circumstances. Modified soil minerals and commercial additives, e.g., polymers, have sometimes been used. To ensure that compacted clay liners are well constructed and perform as they are designed, it is important to implement effective quality control methods emphasizing soil investigations and construction practices. Three objectives of quality assurance and quality control for compacted soil liners are to ensure that

1) Selected liner materials are suitable,
2) Liner materials are properly placed and compacted, and
3) The completed liner is properly protected before, during, and after construction.

2.9 WHAT ISSUES SHOULD BE CONSIDERED IN THE DESIGN OF A COMPACTED CLAY LINER?

The first step in designing a compacted clay liner is selecting the clay material. The quality and properties of the material will influence the performance of the liner. The most common type of compacted soil is one that is constructed from naturally occurring soils that contain a significant quantity of clay. Such soils are usually classified as CL, CH, or SC in the Unified Soil Classification System (USCS). Some of the factors to consider in choosing a soil include soil properties, interaction with wastes, and test results for potentially available materials.

2.10 SOIL PROPERTIES

Minimizing hydraulic conductivity is the primary goal in constructing a soil liner. Factors to consider are water content, plasticity characteristics, percent fines, and percent gravel, as these properties affect the soil's ability to achieve a specified hydraulic conductivity.

2.11 HYDRAULIC CONDUCTIVITY.

It is important to select compacted clay liner materials so that remolding and compacting of the materials will produce a low hydraulic conductivity. Factors influencing the hydraulic conductivity at a particular site include: the degree of compaction, compaction method, type of clay material used, soil moisture content, and density of the soil during liner construction. The hydraulic conductivity of a soil also depends on the viscosity and density of the fluid flowing through it. A criterion was established first the compacted soils were required to have low hydraulic conductivity, and a maximum of 1×10^{-9} m/s was adopted.

2.12 VOLUMETRIC SHRINKAGE STRAIN.

These results are consistent with those of Haines (1923) who described the drying process of saturated soils as having two significant stages; the first stage occurring as water leaves the soil without entry of air. Since air is not entering the volume change is equal to the volume of water leaving the soil. The main volume change occurs during the first stage, water surrounding the individual soil particles is removed, allowing the soil particles to move closer together as the water retreats. At some point, the soil particles contact each other, and the drying process slows, as the structure of the soil begins to resist additional volume change. In the second stage, air enters the soil and replaces the water being removed because the particles are in contact. Little change in soil structure or total volume occurs during this stage. A second criterion was that shrinkage cracking caused by desiccation should not be excessive and a maximum permissible volumetric shrinkage strain of 4% was adopted.

2.13 UNCONFINED COMPRESSIVE STRENGTH

The UCS reduced with higher molding water content. This was so because the basic factor responsible for the strength of a soil is frictional resistance between soil particles in contact. With increasing molding water content, the soil fabrics were increasingly deflocculated hence the shear strength reduced. Furthermore, increasing water resulted in loss of cementation between the particles leading to loss in strength (i.e. reduced cohesive resistance). compacted soils used for liners and cover system must have adequate shear strength not less than 200kN/m^2. Furthermore, the compaction criterion (i.e., water content and dry unit weight) was related to the unconfined compressive strength (> 200 kN/m^2),

2.14 WATER CONTENT.

Water content refers to the amount of liquid, or free water, contained in a given amount of material. Measuring water content can help determine whether a clay material needs preprocessing, such as moisture adjustment or soil amendments, to yield a specified density or hydraulic conductivity.

Compaction curves can be used to depict moisture and density relationships, using either ASTM D-698 or ASTM D-1557, the standard or modified Proctor test methods, depending on the compaction equipment used and the degree of firmness in the foundation materials.

2.15 PLASTICITY CHARACTERISTICS.

Plasticity characteristics describe a material’s ability to behave as a plastic or moldable material. Soils containing clay are generally categorized as plastic. Soils that do not contain clay are non-plastic and typically considered unsuitable materials for compacted clay liners, unless soil amendments such as bentonite clay are introduced. Plasticity characteristics are quantified by three parameters: liquid limit, plastic limit, and plasticity index. The liquid limit is defined as the minimum moisture content (in percent of oven-dried weight) at which a soilwater mixture can flow. The plastic limit is the minimum moisture content at which a soil can be molded. The plasticity index is defined as the liquid limit minus the plastic limit and defines the range of moisture content over which a soil exhibits plastic behavior.

2.16 MOLDING WATER CONTENT ADJUSTMENT.

For natural soils, the degree of saturation of the soil liner at the time of compaction, known as molding water content, influences the engineering properties of the compacted material. Soils compacted at water contents less than optimum tends to have a relatively high hydraulic conductivity. Soils compacted at water contents greater than optimum tend to have low hydraulic conductivity and low strength. Proper soil water content revolves around achieving a minimum dry density, which is expressed as a percentage of the soil's maximum dry density. The minimum dry density typically falls in the range of 90 to 95 percent of the soil's maximum dry density value. From the minimum dry density range, the required water content range can be calculated. For example the soil has a maximum dry density of 115 Mg/m^3. Based upon a required minimum dry density value of 90 percent of maximum dry density, which is equal to 103.5 Mg/m^3, the required water content ranges from 10 to 28 percent. It is less problematic to compact clay soil at the lower end of the required water content range because it is easier to add water to the clay soil than to remove it. Thus, if precipitation occurs during construction of a site which is being placed at the lower end of the required water content range, the additional water might not result in a soil water content greater than the required range. Conversely, if the site is being placed at the upper end of the range, for example at 25 percent, any additional moisture will be excessive, resulting in water content over 28 percent and making the 90 percent maximum dry density unattainable. Under such conditions construction should halt while the soil is aerated and excess moisture is allowed to evaporate. (Guide for Industrial Waste Management, US EPA, 2012)

2.17 PROTECTION AGAINST DESICCATION AND CRACKING

You should consider how to protect compacted clay liners against desiccation and freezing during and after construction. Protection against desiccation is important, because clay soil shrinks as it dries. Depending on the extent of shrinkage, it can crack. Deep cracks, extending through more than one lift, can cause problems. You should measure water content to determine whether desiccation is occurring. There are several ways to protect compacted clay liners from desiccation. One preventive measure is to smooth roll the surface with a steel drummed roller to produce a thin, dense skin of soil; this layer can help minimize the movement of water into or out of the compacted material. Another option is to wet the clay periodically in a uniform manner; however, it is important to make sure to avoid creating areas of excessive wetness. A third measure involves covering compacted clay liner materials with a sheet of white or clear plastic or tarp to help prevent against desiccation and cracking. The cover should be weighted down with sandbags or other material to minimize exposure of the underlying materials to air. Using a light-colored plastic will help prevent overheating, which can dry out the clay materials. If the clay liner is not being covered with a geosynthetic, another method to prevent desiccation involves covering the clay with a layer of protective cover soil or intentionally overbuilding the clay liner and shaving it down to liner grade. (Guide for Industrial Waste Management, US EPA,2012)

CHAPTER THREE

METHODOLOGY, LABORATORY TESTING AND RESULTS.

3.1 DESCRIPTION OF THE SOIL SAMPLE

The soil sample used in this study was collected along Deba /Yamaltu road, Deba local government area in Gombe State, north east Nigeria. Yamaltu/Deba lies between the coordinates: Lattitude10˚13□N, Longitude11□□23□E and has a total area of 1,981km^2 (765 sq mi) to the southeast part of the state capital Gombe. The soil in that area is predominantly covered with grey- black color soil that has high content of montmonirillonite known as black cotton soil. The sample was collected as a disturbed sample obtained at a depth of 0.8m below the ground surface to avoid organic top soil.

3.2 COLLECTION OF GROUND NUT SHELL

Smith (1992) as well as Mohammedhhai and Banuant, (1990) reported that treatment plays a vital role in the production of viable and useful pazzolanas from agricultural wastes. The ground nut shell was collected locally from Dawanau market in Kano state. The groundnut shell was transported to the local incinerator and burnt at control temperature of 500˚C. the resulting ash was then allowed to cool and sieved through a 75µm sieve (BS No. 200 sieve).

The chemical analysis of the groundnut shell ash (GSA) was done at the centre for energy research and training CERT, Zaria.

An oxide composition of the groundnut shell ash (GSA) used in this study is given above.

3.3 METHODOLOGY

The soil sample collected was taken to the laboratory to carry out index properties of soil sample. The index properties are:

- Natural moisture content
- Specific gravity

- Particle size distribution
- Liquid limit
- Plastic limit
- Linear shrinkage
- Volumetric shrinkage strain
- Compaction test.

3.3.1 Natural moisture content

The moisture content was determined according to the specifications of the test (A) of BS 1377 (1990). Known weights of pulverized soil sample were weighted in a pre weighted container. The measurements of the weight of the container and container plus soils were read to the nearest 0.1g. the sample were oven dried for 24 hrs at 105˚C to 115˚C. See table 3.1 for the natural moisture content.

Calculations:

The natural moisture content was determined from the expression

□□= □*2*−□*3*□*3*−□*1*……………………….. (i)

□□= Moisture Content in %

□*2*= weight of container + wet soil (g)

□*3*= weight of container + dry soil (g)

□*1*= Weight of container (g)

Table 3.1 Showing Natural Moisture Content

Natural Moisture Content		
Can No.	36	33
Wgt of Can (g)	16.00	16.00
Wgt of Can + wet soil (g)	82.00	85.00
Wgt of Can + dry soil (g)	76.00	78.00
Wgt of water (g)	6.00	7.00
Wgt of dry soil (g)	60.00	62.00
Moisture Content (%)	10.00	11.29
Average M C	10.65%	

3.3.2 Specific gravity

In determining the specific gravity of the natural soil and the ground nut shell ash (GSA) test 6B of B.S 1377 (1990) which is applicable to fine grained soil and ash was Adopted. The glass jar and sealer was weighed empty and record the mass M1, 400g of the Air dried soil samples were placed in the glass jar water was added to the soil and shake for about 20minutes and fill up the container with water and weighted and record the mass (M2 In g). the jar was emptied and fill with distilled water and weighted and record the mass (M4). See table 3.2 for the determination of the specific gravities of both the soil sample and ground nut shell ash used in this study.

The specific gravity is calculated as follows:

$G_s=\frac{M_2-M_1}{M_4-M_1-(M_3-M_2)}$ ……………………..(ii)

Where:

G_s= specific gravity

M_1= weight of glass jar + sealer (g)

M_2= weight of glass jar + sealer + dry soil (g)

M_3= weight of glass jar +soil+ water (g)

M_4= weight glass jar + water (g)

Table 3.2 showing specific gravity

	Groung nut shell Ash (%)			
Container no.	0	4	8	12
Weight of density bottle W1(g)	1038.5	1038.5	831	1038.5
Weight of density bottle + soil sample W2 (g)	1438.5	1438.5	1231	1231
Weight of density bottle + soil sample + water W3	2567	2559	2280	2276
Weight of density bottle + distilled water W4 (g)	2321.5	2321.5	2047	2319
Specific gravity	2.59	2.53	2.38	2.52

3.3.3 Particle size distribution

The particle size distribution of the soil sample was determined using sedimentation analysis and dry sieving of the coarse fraction by B.S 1377 (1990) for cohesive soils. A 1000g of the soil sample was measured and put in the bucket and washed through B.S sieve No. 200 and the material retained was oven dried and sieved by agitating the materials through range of sieves from B.S No 7 to 2.2μm sieve the materials retained was measured and recorded. See table 3.3 for the particle size distribution of the soil sample.

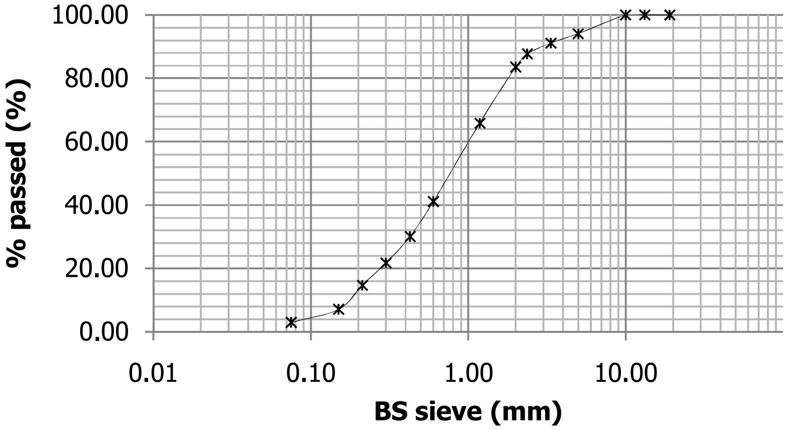

Fig 3.1 Graph of grain size analysis of the black cotton soil

3.3.5 Atterberg Limits

The atterberg limit tests are also known as consistency test (Braja, 1998). They include liquid limit, plastic limit, linear shrinkage and plasticity index tests.

3.3.5.1 Liquid limit test

Test 1(A) B.S 1377 (1990) describe the procedure for the determination of the liquid limit test of a soil sample which was adopted for this work. A 200g of air dried soil sample passing through sieve 425µm sieve was tested. The soil was thoroughly mixed with water on a flat glass plate to a homogenous paste.

The soil paste was then placed in the casagarande apparatus, level off and a groove made by drawing tool through the centre along the diameter of the hinge. By turning the crank at the rate of two revolution per second, the empty shell being lifted and dropped until the two parts of the soil came into contact at the bottom of the groove. The number of blows at which this occur was recorded and some quantity of the soil sample was taken and its moisture content was determined. The liquid limits tests were determine at various moisture content. The moisture content against their respective number of blows was plotted in the semi logarithm graph. The liquid limit was deduced as the moisture content corresponding to 25 numbers of blows.

The same procedure was repeated for the sample with percentage GSA of 4%, 8%, and 12%. The test of the results are given in table 4.1(see appendix)

3.3.5.2 Plastic limit

The proportion of the material passing through sieve with aperture 425µm which was used for the determination of the liquid limit was also used for the determination of the plastic limit. A soil sample of the wet soil was taken and molded between palms of the two hands. The soil sample was rolled and sub divided into two and sub sample into four equal parts. Each of the sample portion formed was then rolled between tips of the fingers and the sub surface of the glass sufficient pressure was then exerted to reduce a diameter of the thread to about

3mm, as specified by the BS 1377 (1990). The rolled soil which formed a thread was rolled until shared in both ways; the plastic limit was recorded as the average of the moisture contents obtained. The procedure was repeated for every successive increment in the concentration of groundnut shell ash (GSA).

The plasticity index (PI) was computed as the numerical difference between the liquid limit (LL) and the plastic limit (PL) as follows:

………………………………………………..(iii)

PI = Plasticity index

LL = liquid limit

PL = plastic limit

Results of the plastic limits and plasticity index as obtained from the procedures described above are given 4.1 table

3.3.3.5.3 Linear shrinkage

150g of the soil sample passing through sieve 425µm BS test sieve was mixed thoroughly on a glass plate with the aid of the pallete knives until the soil mass becomes homogenous paste. The soil mass was subsequently placed in a greased shrinkage mould with slight clearance at the edge. The mould was then slightly jarred to remove air pocket in the mixture.

The mould was then placed in the oven for the water to dry off at about 105˚C-110˚C. the mean length of the dried soil was measured from the length of the top and bottom of the dried samples after cooling. The linear shrinkage of the soil was computed as follows:

▯◦▯*l* …………………………………………….. (iv)

= Linear shrinkage

▯◦ = Change in length

▯*l* = Original length

3.3.6 COMPACTION TEST

The essence of compaction test was to determine the relationship between dry unit weight and molding water content. Factors that influence the degree of compaction are the moisture content, soil type and the compactive effort/ energy per unit volume. Field compaction tests often vary from laboratory tests and in a bid to reduce these differences several compactive efforts are selected in the laboratory that span the range of compactive efforts anticipated in the field, consequently the water content/dry unit weight criteria applies to any reasonable compactive effort.

Two compactive efforts were utilized throughout this work. They are British standard heavy (BSH), West African standard (WAS). The British standard light (BSL) used in previous work yielded positive result and with advent of new technology these types of compactive effort may be encountered in site. The effect of groundnut shell ash (GSA) on the MDD's and OMC's are given in table 4.1. while the graph of dry density versus moisture content was plotted and the maximum dry density (MDD) and optimum moisture content (OMC) was determine for both BSH and WAS compaction test as shown in Appendix A.

3.3.6.1 British Standard Heavy (BSH)

In British standard heavy test, the soil is compacted in a BS mould that has a volume of 1000cm^3. During the laboratory test, the test was conducted according to BS 1377 (1990). The mixed soil sample receives a 27blows of 4.5kg hammer weight at 450mm height in three layers. These tests were conducted for the three percentages 4%, 8%, 12% of ground shell ash (GSA) and the MDD and OMC were determined.

3.3.6.2 West African Standard (WAS)

In West Africans standard test, the soil is compacted in a BS mould that has a volume of $1000cm^3$. During the laboratory test, the test was conducted according to BS 1377 (1990). The mixed soil sample receives a 10blows of 4.5kg hammer weight at 450mm heights in five layers. These tests were conducted for the three percentages 4%, 8%, 12% of ground shell ash (GSA) and the MDD and OMC were determined. The bulk density p_l in Mg/m^3 was calculated for each compacted sample as

$\square 1=\square 1-\square 21000$ ………………………………………………………..(v)

Where

M_l= mass mould and base (g)

M_2= mass of mould and base (g)

And the dry density and P_d in Mg/m^3 is calculated as

$\square\square= 100100+\square$………………………………………………..(vi)

For each percentage of water added to the soil sample, the dry density is plotted against the content and the maximum point on the resultant curves gives the maximum dry density (MDD) on the ordinates axis and optimum moisture content (OMC) on the abscissa.

The procedure was repeated by adding requisite proportion by weight of ground shell Ash to the natural soil sample.

3.3.7 UNCONFINED COMPRESSSIVE STRENGTH (UCS) TESTS

This test was carried out in accordance with British Standards (BS 1990). Unconfined compressive strength (UCS) test were performed on cylindrical specimens 38.1mm in diameter and length of 76.2mm. This ensured testing of soil specimens with length to diameter ratio of 2. Air dried soil – GSA mixtures were compacted at –2%, 0%, +2% and +4% of the optimum moisture content (OMC) and maximum dry density of the BSH and W AS energy levels. After each compaction, the soil was extruded from the mould and sealed in polythene bag to minimize moisture loss, and kept for a period of 48 hours to allow for uniform moisture distribution and curing, at a constant temperature of 25 ± 2ºC. After curing specimens they were placed in a load frame UCS machine driven strain controlled at 0.10%/min until failure occurred. Three specimens were averagely prepared for each test.

The unconfined compressive strength for each sample was deduced from the equation:

…………………………………………………….. (vii)

□*1*□*0* …………………………………………… (viii)

□= □*0(1*− □*1)* …………………………(ix)

F = applied load

A = corresponding average cross-sectional area in mm^2

e = axial strain

L = change in length of specimen as read from deformation chart

L_o = initial length of test specimen in mm

A_o = initial average cross- sectional area of the specimen

e_1 = axial strain for the given load

The results obtained for the different percentages of the GSA are in table 3.3

Table 3.3 Results for Unconfined Compressive Strength for British Standard Compactive Effort

0%	**4%**	**8%**	**12%**

Molding water content	**Unconfined compressive strength (kN/m^2)**	**Molding water content**	**Unconfined compressive strength (kN/m^2)**	**Molding water content**	**Unconfined compressive strength (kN/m^2)**	**Molding water content**	**Unconfined compressive strength (kN/m^2)**
26.24	234.88	18.09	350.79	25.77	204.82	26.04	115.71
28.24	198.76	20.09	237.05	27.77	183.94	28.04	92.17
30.24	154.43	22.09	191.65	29.77	129.42	30.04	89.75
32.24	99.98	24.09	95.05	31.77	99.81	32.04	61.95

Table 3.4 Results for Unconfined Compressive Strength for West African Standard Compactive Effort

0%		**4%**		**8%**		**12%**	
Molding water content	**Unconfined compressive strength (kN/m^2)**	**Molding water content**	**Unconfined compressive strength (kN/m^2)**	**Molding water content**	**Unconfined compressive strength (kN/m^2)**	**Molding water content**	**Unconfined compressive strength (kN/m^2)**
29.67	193.48	29.65	94.91	25.77	150.72	19.60	222.55
31.67	164.09	31.65	77.65	27.77	119.09	21.60	212.99
33.67	84.38	33.65	68.89	29.77	94.57	23.60	198.46
35.67	63.00	35.65	51.88	31.77	62.34	25.60	176.46

3.3.8 HYDRAULIC CONDUCTIVITY (PERMEABILITY) TEST

This was measured using the rigid wall permeameter under falling head condition as recommended by Head (1994). A relatively short sample was connected to a standpipe, which provided the head of water flowing through the sample. Compacted soil – GSA samples at the different GSA contents (0%, 4%, 8%, 12% and 16%) and different molding water contents (-2%, 0%, +2% and +4% of the OMC, respectively) using the BSH and WAS compactive efforts. Specimens were soaked in a water tank for a minimum period of 24 hours to allow for full saturation and the samples were restrained from swelling vertically during saturation. The fully saturated test specimen was then connected to a permeameter liquid (tap water). During permeation, test specimens were free to swell vertically (i.e., no vertical stress was applied). Hydraulic gradient ranged from 5 to 15.Test were only discontinued when hydraulic conductivity readings were steady.

Table 3.5 Results for Hydraulic Conductivity for British Standard Compactive Effort

0%		**4%**		**8%**		**12%**	
Molding water content	**Hydraulic conductivity (m/s)**	**Molding water content**	**Hydraulic conductivity (m/s)**	**Molding water content**	**Hydraulic conductivity (m/s)**	**Molding water content**	**Hydraulic conductivity (m/s)**
26.24	3.66×10^{-9}	18.09	3.09×10^{-9}	21.40	2.32×10^{-9}	26.04	2.14×10^{-9}
28.24	1.88×10^{-10}	20.09	2.61×10^{-9}	23.40	2.45×10^{-10}	28.04	1.45×10^{-9}
30.24	$1. 76 \times 10^{-10}$	22.09	2.36×10^{-9}	25.40	7.9×10^{-11}	30.04	2.45×10^{-10}
32.24	1.30×10^{-10}	24.09	2.11×10^{-10}	27.40	9.99×10^{-11}	32.04	3.12×10^{-10}

Table3.6 Results for Hydraulic Conductivity for West African Standard Compactive Effort

0%	**4%**	**8%**	**12%**

Molding water content	Hydraulic conductivity (m/s)	Molding water content	Hydraulic conductivity (m/s)	Molding water content	Hydraulic conductivity (m/s)	Molding water content	Hydraulic conductivity (m/s)
29.67	1.11×10^{-10}	29.65	2.81×10^{-10}	25.77	1.98×10^{-9}	19.60	2.26×10^{-9}
31.67	9.82×10^{-11}	31.65	7.67×10^{-11}	27.77	2.25×10^{-9}	21.60	1.81×10^{-9}
33.67	3.57×10^{-11}	33.65	1.97×10^{-9}	29.77	6.58×10^{-10}	23.60	9.36×10^{-11}
35.67	1.64×10^{-11}	35.65	3.66×10^{-9}	31.77	2.67×10^{-9}	25.60	3.65×10^{-10}

3.3.9 VOLUMETRIC SHRINKAGE:

The volumetric shrinkage upon drying was measured by extruding cylindrical specimens, compacted using the BSL and WAS energy levels. Air dried soil – GSA mixtures were compacted at – 2%, 0%, +2% and +4% of the optimum moisture content (OMC). The extruded cylindrical specimens were placed on a laboratory bench at a uniform temperature of 29 ± 2ºC for 30 days to dry naturally. This method is considered to be better than the method used by Daniel and Wu (1993) in which compacted cylindrical specimens were made dry in an air-conditioned building. This is because natural drying in the laboratory is considered to duplicate field conditions. Measurements of diameters and heights for each specimen were taken with the aid of a vernier caliper accurate to 0.05mm. The average diameters and heights were used to compute the volumetric shrinkage strain.

Table 3.7 Results for Volumetric Shrinkage Strain for British Standard Compactive Effort

0%	4%	8%	12%

Molding water content	**Volumetric shrinkage strain (%)**	**Molding water content**	**Volumetric shrinkage strain (%)**	**Molding water content**	**Volumetric shrinkage strain (%)**	**Molding water content**	**Volumetric shrinkage strain (%)**
26.24	11.81	18.09	0.27	25.77	2.07	26.04	3.21
28.24	14.05	20.09	2.57	27.77	3.99	28.04	3.29
30.24	14.99	22.09	8.37	29.77	4.47	30.04	8.60
32.24	19.44	24.09	8.75	31.77	7.80	32.04	15.17

Table 3.8 Results for Volumetric Shrinkage Strain for West African Compactive Effort.

0%		**4%**		**8%**		**12%**	
Molding water content	**Volumetric shrinkage strain (%)**	**Molding water content**	**Volumetric shrinkage strain (%)**	**Molding water content**	**Volumetric shrinkage strain (%)**	**Molding water content**	**Volumetric shrinkage strain (%)**
29.67	15.93	29.65	17.97	25.77	8.37	19.60	2.79
31.67	20.72	31,65	20.36	27.77	10.78	21.60	4.91
33.67	23.27	33.65	22.34	29.77	13.66	23.60	6.59
35.67	24.74	35.65	24.14	31.77	15.16	25.60	8.55

3.3.10 Compatibity test

This test was carried out to determine the effect of leachates on treated black cotton soil, the soil sample was compacted in poroctor mould with varying GSA content and subjected to hydrauclic conductivity to allow the leachate to pass through the sample and the result is as follows

Table 3.9 Results for Compatibility test for British Standard Compactive Effort

0%		4%		8%		12%	
Molding water content	**Hydraulic conductivity (m/s)**	**Molding water content**	**Hydraulic conductivity (m/s)**	**Molding water content**	**Hydraulic conductivity (m/s)**	**Molding water content**	**Hydraulic conductivity (m/s)**
26.24	2.87×10^{-10}	18.09	4.32×10^{-9}	21.40	3.22×10^{-9}	26.04	4.56×10^{-9}
28.24	2.12×10^{-10}	20.09	3.54×10^{-9}	23.40	3.13×10^{-10}	28.04	4.45×10^{-9}
30.24	1.99×10^{-10}	22.09	2.36×10^{-9}	25.40	7.9×10^{-11}	30.04	4.12×10^{-10}
32.24	1.48×10^{-10}	24.09	2.11×10^{-10}	27.40	8.98×10^{-11}	32.04	3.98×10^{-10}

Table3.10 Results for Compatibility test for West African Standard Compactive Effort

0%		4%		8%		12%	
Molding water content	**Hydraulic conductivity (m/s)**	**Molding water content**	**Hydraulic conductivity (m/s)**	**Molding water content**	**Hydraulic conductivity (m/s)**	**Molding water content**	**Hydraulic conductivity (m/s)**
29.67	5.67×10^{-9}	29.65	3.65×10^{-9}	25.77	3.21×10^{-9}	19.60	3.76×10^{-9}
31.67	3.67×10^{-10}	31.65	5.98×10^{-10}	27.77	2.99×10^{-9}	21.60	2.22×10^{-9}
33.67	3.57×10^{-10}	33.65	3.31×10^{-9}	29.77	4.67×10^{-10}	23.60	7.98×10^{-11}
35.67	2.59×10^{-10}	35.65	1.98×10^{-9}	31.77	3.32×10^{-9}	25.60	5.75×10^{-10}

CHAPTER FOUR

RESULTS AND DISCUSSIONS

The index properties of the soil sample were determined and the results are presented in the table below:

Table 4.1 Geotechnical Properties of Black Cotton soil with varying GSA Content.

Engineering Properties	Groundnut shell Ash content %			
	0	4	8	12
Liquid Limit, %	96.10	86.90	75.90	72.70
Plastic Limit, %	83.60	76.20	59.80	47.80
Plasticity Index, %	12.50	7.40	16.10	24.90
Linear Shrinkage, %	7.10	8.60	18.50	20.70
Percentage Passing BS No. 200Sieve.	80.59	82.00	81.50	80.00
AASHTO Classification	A-7-6	A-7-6	A-7-6	A-7-6
USCS Classification	CL	CL	CL	CL
Specific Gravity	2.56	2.53	2.51	2.52
MDD Mg/m3				
BSH	1.6	1.72	1.65	1.63
West African Standard	1.53	1.52	1.56	1.69
OMC%				
BSH	28.24	20.09	23.38	28.04
West African Standard	31.67	31.65	27.77	21.60
pH Value	7.20			
Color	Grey			
Dominant Clay mineral	Montimorillonite			

4.1 EVALUATION OF THE EFFECT OF GROUNDNUT SHELL ASH ON BLACK COTTON SOIL.

The physical properties of the soils used are summarized in Table 4.1. The particle Size distribution analysis shows that the soil contains an appreciable quantity of fines 89.00% - 83% (<0.075mm); sand fraction 35% - 42% (< 0.063 – 2 mm). The Atterberg limits show that the liquid limit ranged from 72.1 to 96.1%, the plastic limit from 47.8 – 83.6% and plasticity index from 7.4 to 24.90%. The overall index properties of the soil show that the soils are classified as low plasticity clay CL under Unified Soil Classification System.

The particle size distribution affects the hydraulic conductivity, which is the principal indicator of its containment potential. Low conductivity is likely to be achieved when the soil is well graded because the relative proportions of large and small particle sizes affect the size of voids conducting flow. Daniel (1993) and Benson et al., (1994) suggested that a liner material should have fines content 20 – 30%. This material from the particle size distribution possesses suitable amount of fines and sand fraction required to achieve a hydraulic conductivity less than 1 x 10^{-9} m/s. Atterberg limits are indices of the quantity of clay-sized particles and their mineralogical composition.

Typically, higher liquid limits and plasticity indices are associated with soils having a greater quantity of clay particles or particles having higher surface activity. Soils having higher liquid limits or plasticity indices would have lower hydraulic conductivity (Benson et al.1994). However, Daniel (1993), Rowe et al. (1995) suggested that materials with plasticity index (PI) ≥ 7% would be suitable for a hydraulic barrier. Thus the various soil-GSA mixes used in this study are suitable materials for hydraulic barriers.

4.2 HYDRAULIC CONDUCTIVITY

In a manner of similar natural clays generally hydraulic conductivity decreases with increasing compactive effort, This is in agreement with Acar and Oliveri,(1989) that the increasing compactive effort decreased the frequency of large pores and eliminated the large pore mode. These changes in pore size yielded lower hydraulic conductivity; furthermore with increasing compactive effort, the compaction rammer penetrated the soil surface more resulting in bearing capacity failure under the rammer face. This led to quicker and closer alignment of particles along the failure surface yielding reduced hydraulic conductivity. The hydraulic conductivity also decreased as the molding water content increased. The increasing molding water helped in deflocculating the particle structure, reducing the voids; hence the arrangement of individual particles influenced by molding water content controlled the hydraulic conductivity (Lambe, 1958; Acar and Oliveri,1989).

For the two compactive efforts used and at different molding water contents the hydraulic conductivity decreased with higher GSA content. This was probably due to the increase in the pH value of the molding content, as a result of the partial dissociation of calcium hydroxide. The calcium ion in turn combined with the reactive silica or alumina from the laterite or both when they were present to form insoluble calcium silicates or aluminates or both, blocking the flow of water through the soil voids. The decrease could also have been due to the precipitation of calcium carbonate in the void as the ionized calcium, which reacted with the dissolved carbon dioxide in the water. Furthermore, cementation is supposed to increase with increase in GSA content, thus decreasing hydraulic conductivity. This decrease might also be due to the precipitation of calcium carbonate in the voids as the ionized calcium reacted with the dissolved carbon dioxide in the water.

The results of the minimum hydraulic conductivities, the corresponding moisture content at which the maximum permissible hydraulic conductivity of 1 x 10^{-9} m/s for soil liners were obtained at various compactive efforts and various GSA treatments are summarized in Table 4.2, while the variation of hydraulic conductivity with molding water content for the various mix of soil-GSA content is shown in Fig 4.1 and Fig 4.2. Generally the hydraulic conductivity obtained its lowest value on the wet side of compaction, especially at +2% OMC for most of the specimen. Beyond +2% OMC and before +2% OMC there is generally an increase in hydraulic conductivity values. The increasing molding water content facilitates deflocculating of the particle structure, reducing the void. This is in conformity with other research works (Lambe, 1959; Mitchell et al., 1965; Acer and Oliver; 1989, Garcia – Bengocheaetal,. 1979; Benson and Daniel, 1990; Osinubi and Nwaiwu, 2006). Increasing molding water content from the dry to the wet side effects the hydraulic conductivity. The result obtained for the untreated black cotton sample compacted between -2 to +4% OMC. British Standard Heavy and West African standard gave satisfactory hydraulic conductivity values less than 1×10^{-9}m/s (Benson and Daniel, 1990; Eberemu 2007 and Osinubi and Nwaiwu, 2006; Osinubi and Eberemu, 2009b). These minimum specified values were obtained at molding water contents of 25.38 – 27.38%. The maximum permissible values were obtained at 24.09%. At 8% GSA treatment satisfactory hydraulic conductivity were obtained values indicating that GSA has filled the air voids present in the black cotton. The molding water contents of 25.38- 27.38, at BSH and molding water content of 31.7% at WAS energy level.

Table 4.2 Minimum hydraulic conductivity with corresponding water content for minimum and maximum permissible hydraulic conductivity for the various compactive efforts and GSA content

GSA Treatment (%)	Compactive Effort	Minimum hydraulic conductivity (m/s)	Water Content (%) at minimum hydraulic conductivity	Water content (%) at maximum permissible hydraulic conductivity for soil liners (1 x 10^{-9} m/s)	Optimum moisture Content. (%)
0	British standard Heavy	1.3x 10^{-10}	32.24	-	28.24
	West African Standard	1.64 x 10^{-10}	35.7	29.67	31.67
4	British standard Heavy	2.11x 10^{-10}	24.09	-	20.09
	West African Standard	7.67x 10^{-11}	31.7	29.65	31.65
8	British standard Heavy	9.9 x 10^{-11}	27.4	-	23.38
	West African Standard	6.58x 10^{-10}	29.77	-	27.77
12	British standard Heavy	3.12 x 10^{-10}	32.04	-	28.04
	West African Standard	9.36x 10^{-11}	23.6	25.6	21.6

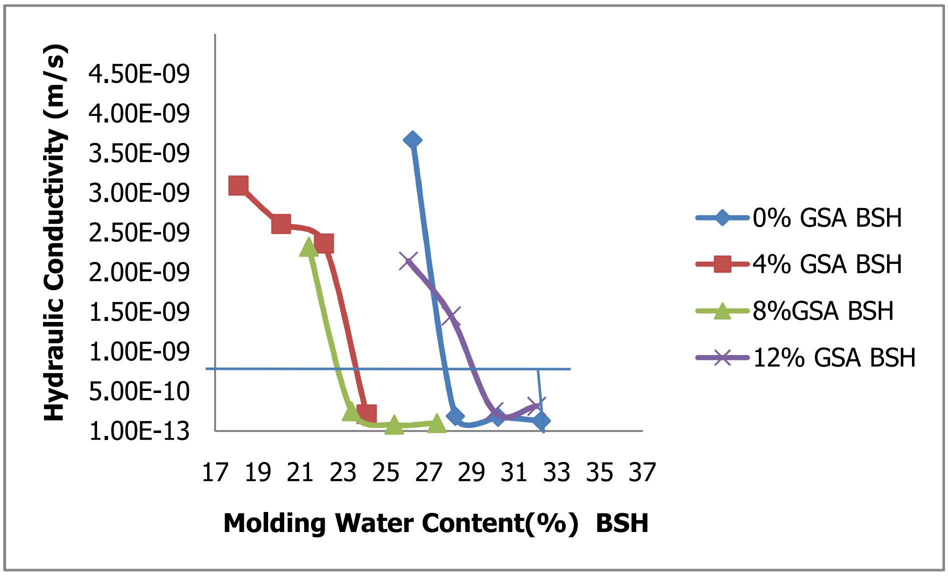

Fig. 4.1.Variation of hydraulic conductivity with Molding Water Content for BSH Compactive Effort

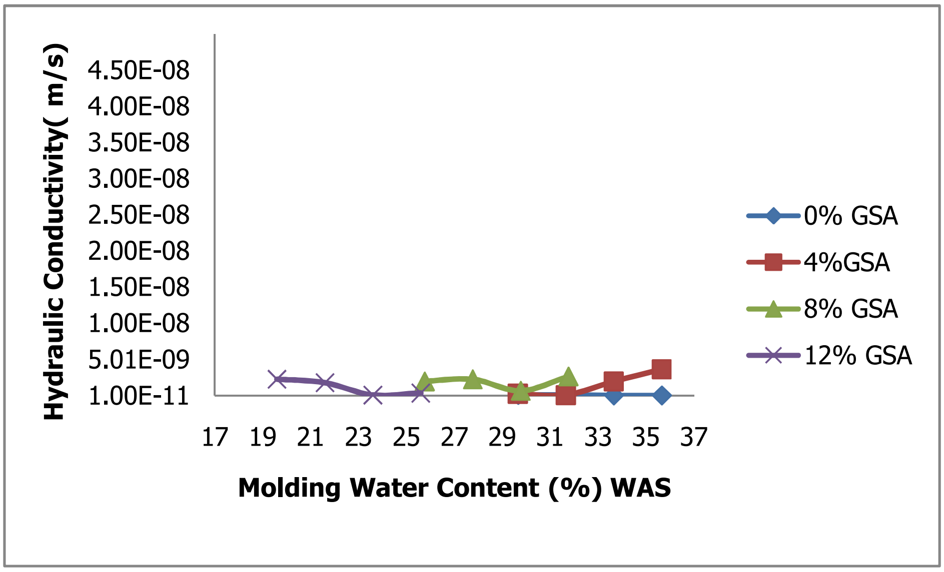

Fig. 4.2 Variation of hydraulic conductivity with Molding Water Content for WAS Compactive Effort

4.3 VOLUMETRIC SHRINKAGE STRAIN

The variation of volumetric shrinkage strain with molding water content for various mix of GSA content is shown in Fig 4.3 and 4.4. In all cases, the volumetric shrinkage strain increased with higher molding water content. These results are consistent with those of Haines (1923) who described the drying process of saturated soils as having two significant stages; the first stage occurring as water leaves the soil without entry of air. Since air is not entering the volume change is equal to the volume of water leaving the soil. The main volume change occurs during the first stage, water surrounding the individual soil particles is removed, allowing the soil particles to move closer together as the water retreats. At some point, the soil particles contact each other, and the drying process slows, as the structure of the soil begins to resist additional volume change. In the second stage, air enters the soil and replaces the water being removed because the particles are in contact. Little change in soil structure or total volume occurs during this stage.

Furthermore, Mitchell (1976) stated that drying shrinkage of fine grained soils depends on particle movement as a result of pore water tension developed by capillary menisci; that if two samples of a given clay are at the same initial water content but different fabrics, the one that is the more deflocculated and dispersed shrinks most. This is because the average pore sizes are smaller, thus allowing greater capillary stresses and because of easier relative movement of particles and particle groups. More so, structure anisotropy on a macro-scale may be reflected by anisotropic shrinkage. For preferred orientation, platy particles parallel to the horizontal direction would have greater vertical shrinkage than lateral shrinkage on drying.

From this study, test results show that as the molding water content increased the volumetric shrinkage strain also increased and this was consistent for all the samples tested. The relationship between compactive effort and shrinkage strain is less clear since no distinct trend was observed. At low compaction water contents, volumetric shrinkage decreased with higher compactive effort.

Generally, the increase in GSA content, affected the volumetric shrinkage strain. As the GSA content increased, the volumetric shrinkage strain reduced. This might be due to increased physico-chemical reactions (i.e. ion exchange).

Table 4.3 Minimum volumetric shrinkage strains with corresponding water content at minimumand maximum permissible volumetric shrinkage at various compactive effort and GSA content

GSA Treatment (%)	Compactive effort	Minimum volumetric shrinkage strain (%)	Water Content (%) volumetric shrinkage strain (%)	Water content (%) at maximum permissible volumetric shrinkage strain (%)	Optimum moisture Content. (%)
0	British standard Heavy West African Standard	- -	-	-	28.24 31.67
4	British standard Heavy West African Standard	0.27 -	18.09 -	20.09 -	28.04 21.6
8	British standard Heavy West African Standard	2.07 -	21.38 -	23.38 -	23.38 27.77
12	British standard Heavy West African Standard	3.2 2.8	26.04 19.6	28.04 -	28.04 21.6

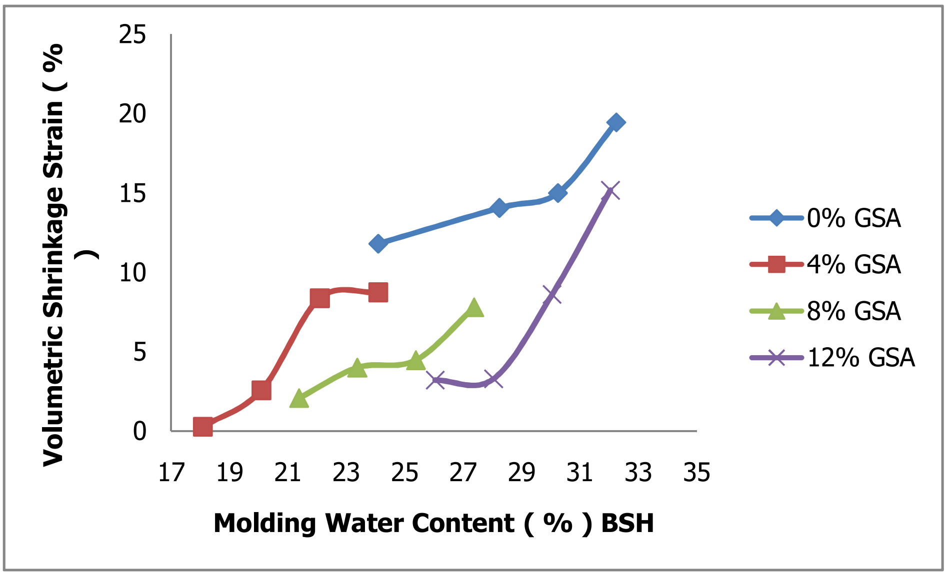

Fig. 4.3.Variation of Volumetric Shrinkage strain with Molding Water Content for BSH Compactive Effort

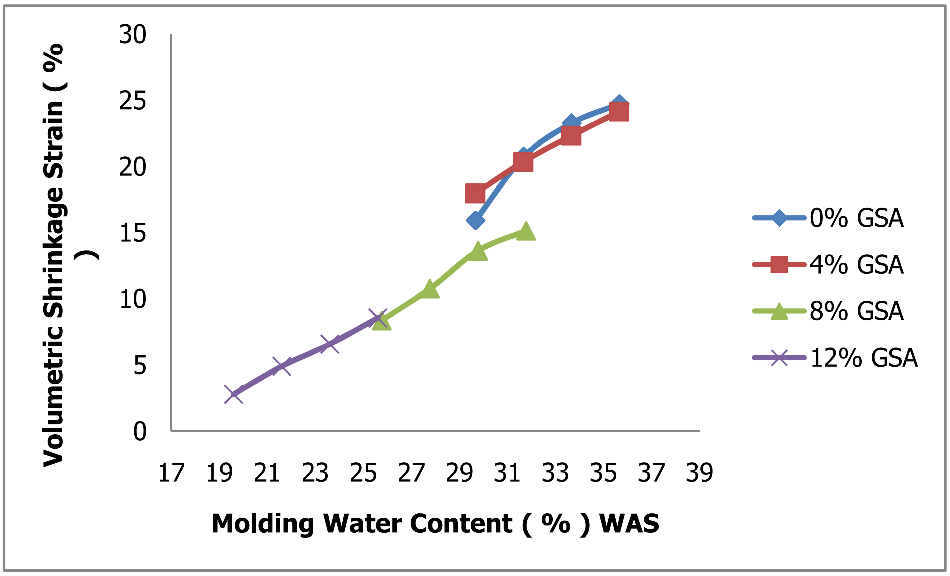

Fig 4.4.Variation of Volumetric Shrinkage strain with Molding Water Content for WAS Compactive Effort

4.4 UNCONFINED COMPRESSIVE STRENGTH

The unconfined compressive strength (UCS) results are summarized in Table 3, while the variation of UCS with molding water content for the various mix of soil-GSA content is shown in Fig 4.5 and Fig 4.6. The UCS reduced with higher molding water content. This was so because the basic factor responsible for the strength of a soil is frictional resistance between soil particles in contact. With increasing molding water content, the soil fabrics were increasingly deflocculated hence the shear strength reduced. Furthermore, increasing water resulted in loss of cementation between the particles leading to loss in strength (i.e. reduced cohesive resistance). From the results obtained in all cases of GSA treatment, increase in GSA content at higher molding water content led to reduced strength. This was because increment in GSA content led to reduction of optimum moisture content thus making more free water available in the soil, and consequently strength values decreased. Furthermore, increase in compaction energy led to increased strength because of closer packing of the soil fabric in agreement with Daniel and Wu (1993), Amadi(2003), Eberemu (2003) and Nwaiwu (2004).

Table 4.4 Maximum UCS with corresponding water content at maximum and minimum permissible UCS for the various compactive effort and GSA content

GSA Treatment (%)	Compactive effort	Maximum unconfined compressive strength (kN/m^2)	Water Content (%) at maximum unconfined compressive strength (kN/m^2)	Water content (%) at minimum permissible unconfined compressive strength for soil liners (200 kN/m^2)	Optimum moisture Content. (%)
0	British standard Heavy West African Standard	234.88 -	26.64 -	- -	28.24 31.67
4	British standard Heavy West African Standard	350.78 -	18.09 -	- -	28.04 21.6
8	British standard Heavy West African Standard	204.82 -	21.38 -	- -	23.38 27.77
12	British standard Heavy West African Standard	- 212.90	- 21.6	- 19.6	28.04 21.6

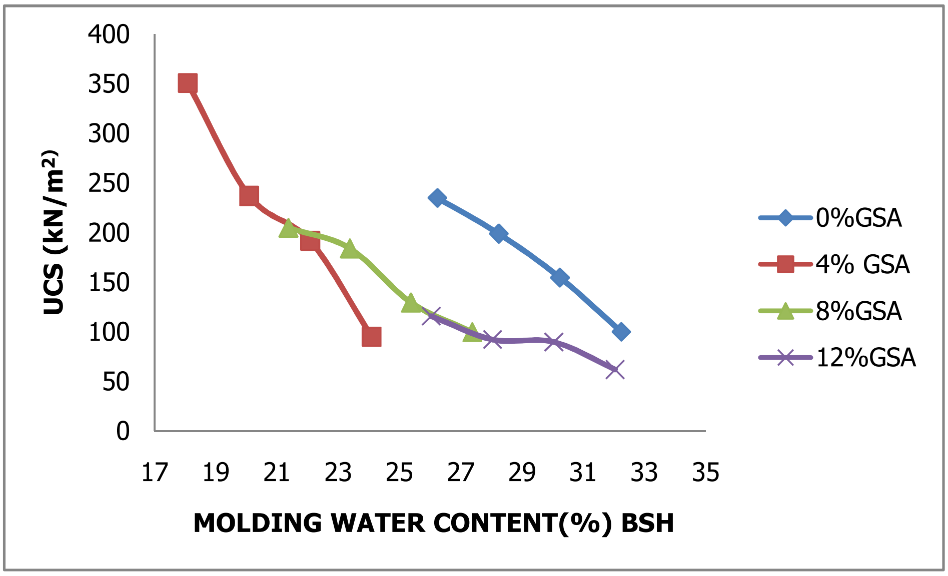

Fig. 4.5.Variation of Unconfined Compressive Strength with Molding Water Content for BSH Compactive Effort

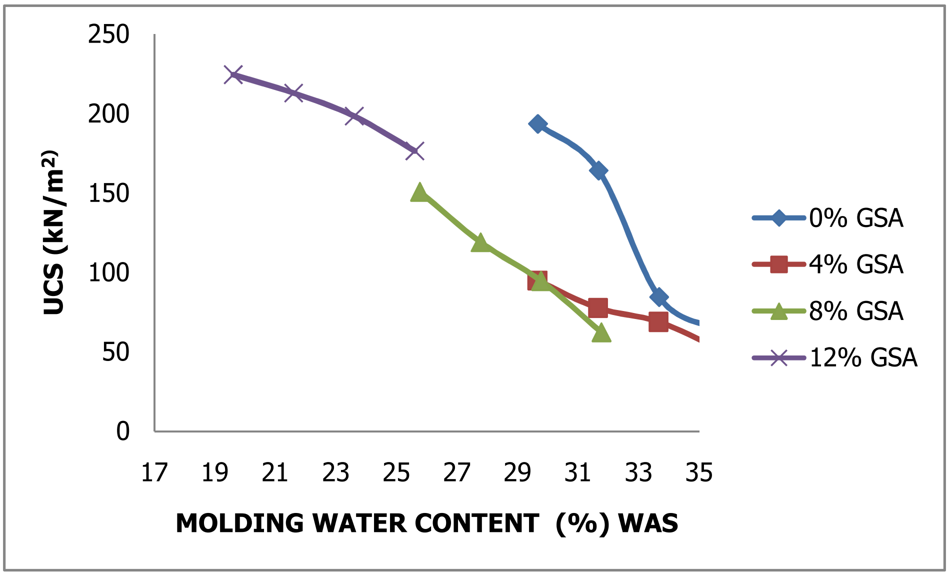

Fig. 4.6.Variation of Unconfined Compressive Strength with Molding Water Content for WAS Compactive effort

4.5 ACCEPTABLE ZONES

Daniel and Benson (1990) described a procedure for determining compaction criteria for soil liners and covers. Three criteria were established first the compacted soils were required to have low hydraulic conductivity, and a maximum of 1 x 10 $^{-9}$ m/s was adopted. A second criterion was that shrinkage cracking caused by desiccation should not be excessive and a maximum permissible volumetric shrinkage strain of 4% was adopted. Thirdly, compacted soils used for liners and cover system must have adequate shear strength not less than 200kN/m^2. Furthermore, the compaction criterion (i.e., water content and dry unit weight) was related to the unconfined compressive strength (> 200 kN/m^2), hydraulic conductivity (< 1 x 10^{-9} m/s) and volumetric shrinkage strain upon drying (< 4%). An acceptable zone was defined for each criterion by superimposition of all three thus producing an overall acceptable zone that satisfied all three criteria was established.

The acceptable zones for shear strength, hydraulic conductivity, and volumetric shrinkage strain for various GSA content, are shown in table 4.5 below

Table 4.5 Acceptable Ranges of Molding Water content at BSH energy level

	GSA Content %			
	0	4	8	12
Engineering Criteria	molding water content range %			
k m/s	28.24 - 32.24	24.09	23.38 -25.38	30.04 - 32.04
UCS kN/m^2		18.09-20.09	21.38	
VSS %		18.09-20.09	23.38	26.04-28.04
OAR		< 24.09	23.38-25.38	
OAR= Overall Acceptable Range				

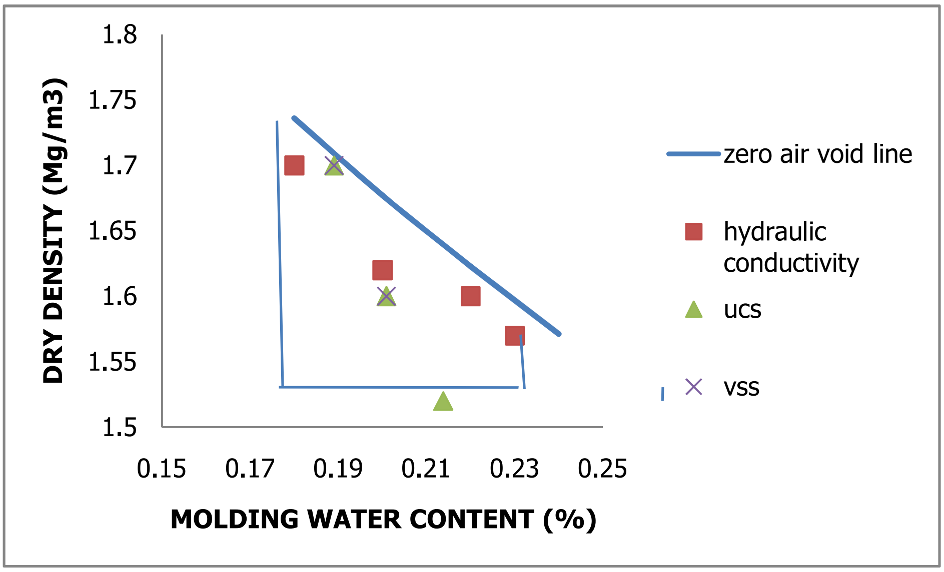

Fig 4.7 Acceptable zone for 4% GSA British Standard Compactive Effort.

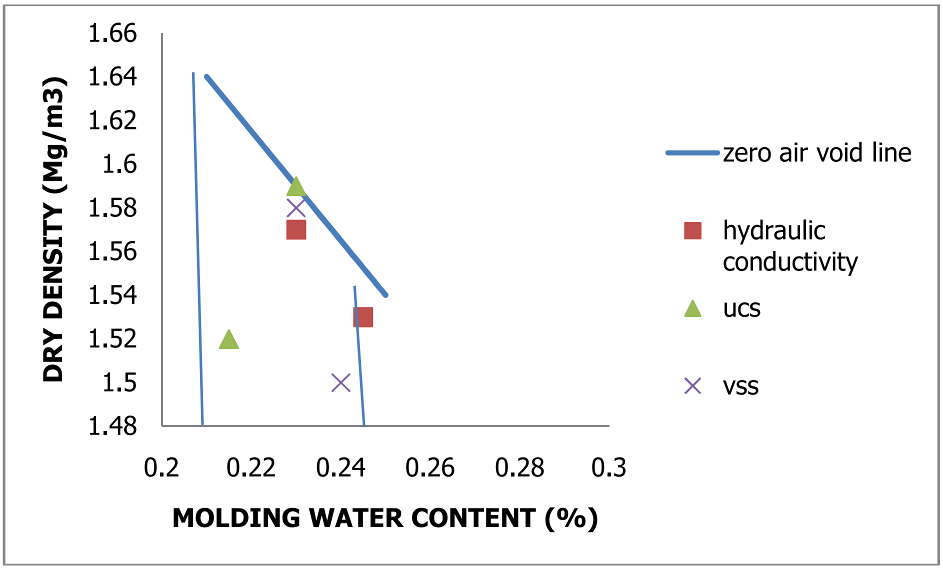

Fig 4.8 Acceptable zone for 8% GSA British Standard Compactive Effort.

Table 4.6 Acceptable Ranges of Molding Water content at WAS Energy Level

Engineering Criteria	GSA Content %			
	0	4	8	12
	Molding water content range %			
k m/s	29.67-35.67	29.65-35.65	29.77 -31.77	23.6 – 25.6
UCS kN/m^2				19.6-21.6
VSS %				19.6
OAR				23.6- 25.6
OAR= Ovarall Acceptable Range				

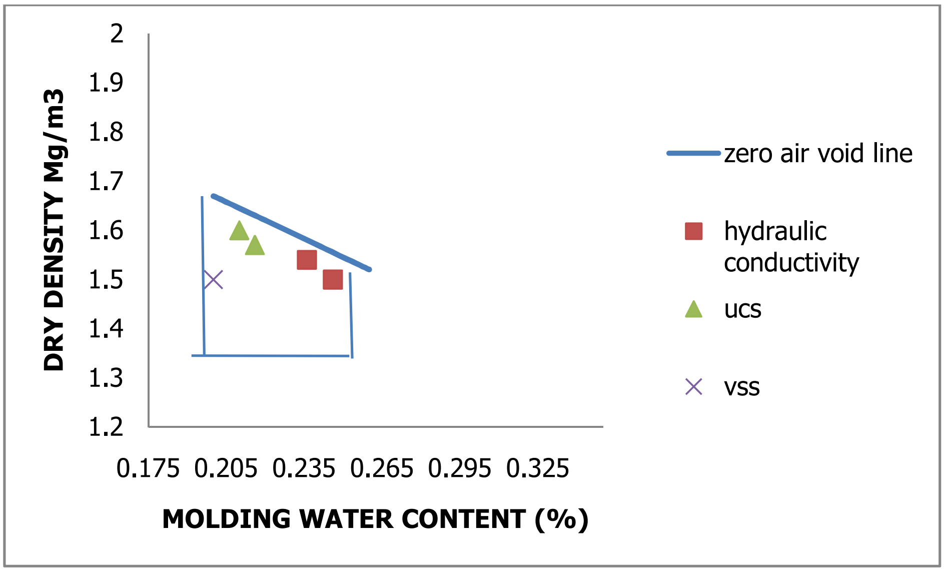

Fig 4.9 Acceptable zone for 12% GSA West African Standard Compactive Effort.

4.6 OVERALL ACCEPTABLE ZONE

The design of liners and cover in waste containment facility involves arriving at a convergence of molding water content of three important design parameters. At this range of molding water content the regulatory specified values of the hydraulic conductivity, unconfined compressive strength and volumetric strain shrinkage must be met. Thus, an overall acceptance zone of molding water content and maximum dry density satisfactory for all the design parameters is produced. The satisfactory treatment level of GSA treated black cotton soil that gave an overall acceptance range for all the three established criteria were achieved at 4% GSA, and 8%for BSH and 12% GSA for WAS. And they were achieved at a molding water content range of6% and < 24.09% and 23.38 -25.38% for BSH respectively, and 23.6 – 25.6% for WAS.

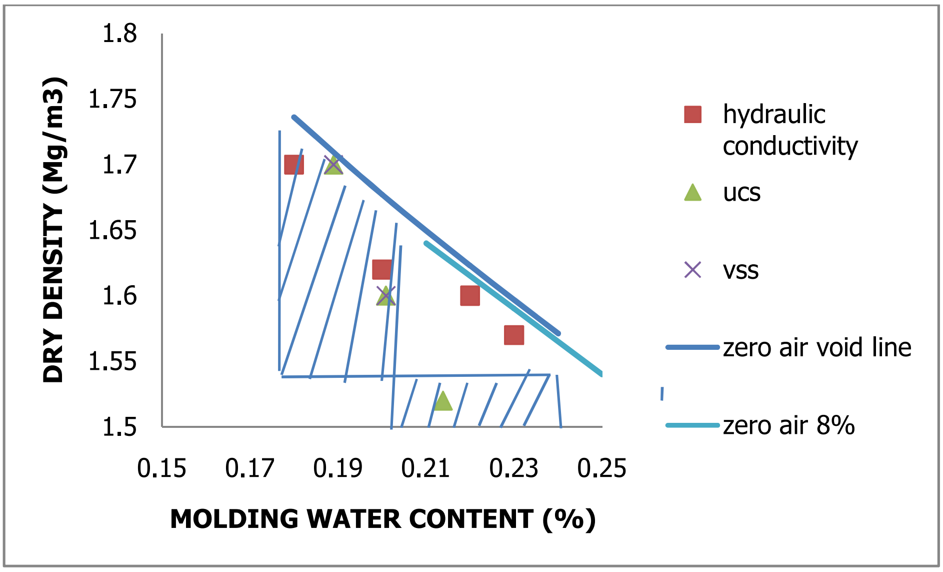

Fig 4.10 Overall Acceptable range for British Standard Compactive Effort.

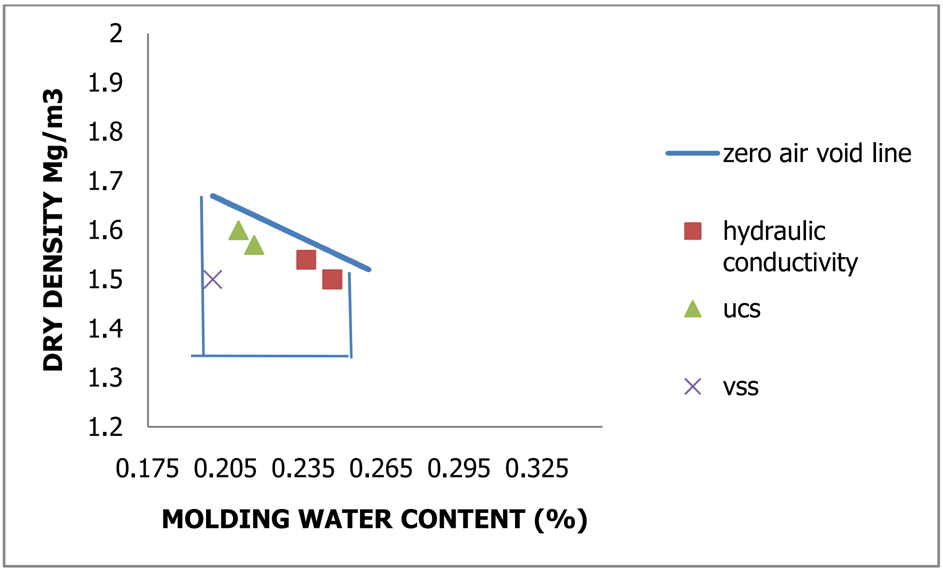

Fig 4.11 Overall Acceptable range for West African Standard Compactive Effort.

CHAPTER FIVE

5.1 CONCLUSION AND RECOMMENDATION

The suitability of ground nut shell ash for treatment of black cotton soil in waste containment facility produced successful results. There were changes in the index properties of the GSA treated black cotton soil specimen. However, the MDD generally increase with an increasing GSA content and suddenly decrease with an increase in GSA content while the OMC decrease with increasing GSA content for both compactive efforts.

Specimens were compacted at -2%, 0% +2% and +4% of the optimum moisture content at the energy levels of British standard heavy and West African standard compactive effort. In other to determine a suitable acceptance zone for the three important parameters (Hydraulic conductivity, Unconfined compressive strength and volumetric shrinkage strain). An assessment to produce a converging MDD and OMC that will produce covers and liner that meets the specification requirements of widely accepted standards of the three important parameters were designed. Hydraulic conductivity produced acceptable results at both BSH and WAS compactive efforts. Generally, a decline of hydraulic conductivity with increasing molding water content and increasing compactive energy level were observed. The increasing molding water helped in deflocculating the particle structure, reducing the voids; hence the arrangement of individual particles influenced by molding water content controlled the hydraulic conductivity (Lambe, 1958; Acar and Oliveri, 1989). For the two compactive efforts used and at different molding water contents the hydraulic conductivity decreased with higher GSA content. This was probably due to the increase in the pH value of the molding content, as a result of the partial dissociation of calcium hydroxide. The calcium ion in turn combined with the reactive silica or alumina from the laterite or both when they were present to form insoluble calcium silicates or aluminates or both, blocking the flow of water through the soil voids. The decrease could also have been due to the precipitation of calcium carbonate in the void as the ionized calcium, which reacted with the dissolved carbon dioxide in the water. Furthermore, cementation is supposed to increase with increase in GSA content, thus decreasing hydraulic conductivity. This decrease might also be due to the precipitation of calcium carbonate in the voids as the ionized calcium reacted with the dissolved carbon dioxide in the water. The result obtained for the untreated black cotton sample compacted between -2 to +4% OMC. British Standard Heavy and West African standard gave satisfactory hydraulic conductivity values less than 1×10^{-9}m/s (Benson and Daniel, 1990; Eberemu 2007 and Osinubi and Nwaiwu, 2006; Osinubi and Eberemu, 2009b). These minimum specified values were obtained at molding water contents of 25.38 – 27.38%. The maximum permissible values were obtained at 24.09%. At 8% GSA treatment satisfactory hydraulic conductivity were obtained values indicating that GSA has filled the air voids present in the black cotton. The molding water contents of 25.38- 27.38, at BSH and molding water content of 31.7%at WAS energy level.

The UCS reduced with higher molding water content. This was so because the basic factor responsible for the strength of a soil is frictional resistance between soil particles in contact. With increasing molding water content, the soil fabrics were increasingly deflocculated hence the shear strength reduced. Furthermore, increasing water resulted in loss of cementation between the particles leading to loss in strength (i.e. reduced cohesive resistance). From the results obtained in all cases of GSA treatment, increase in GSA content at higher molding water content led to reduced strength. This was because increment in GSA content led to reduction of optimum moisture content thus making more free water available in the soil, and consequently strength values decreased. Furthermore, increase in compaction energy led to increased strength because of closer packing of the soil fabric in agreement with Daniel and Wu (1993), Amadi(2003), Eberemu (2003) and Nwaiwu (2004). For the UCS, the result show a general improvement in strength for up to 12% GSA treatment this is largely as a result of the pozzolanic input of GSA which produced stronger bonds. Treated black cotton soil produced improved volumetric shrinkage strain values at both BSH and WAS compactive efforts. But regulatory minimum VSS values were achieved only at 4%, 8% and 12% GSA for BSH, while 12% and GSA treatment produced successful results for WAS compactive effort. Finally, the recommended overall acceptance zone that produced a convergence of the specification requirements of the three most important parameters for the design of liners and covers were achieved at 4% and 8% GSA treatment of black cotton soil at BSH and 12% GSA for WAS compactive effort, at molding water content ranges of < 24.09% and 23.38 – 25.38% for BSH respectively and molding water content range of 23.6 – 25.6 for WAS.

Finally the optimum among the results obtained is at 8%GSA for BSH compactive effort at molding water content of 25.38 that gives the lower hydraulic conductivity of 7.9×10^{-11}m/s.

5.2 RECOMMENDATION

Based on this study, GSA is very good material for improving the engineering properties of black cotton soil in determining the suitability of using compacted black cotton soil treated with ground nut shell ash in hydraulic barrier in municipal landfill, hence further studies should be recommended on different compactive effort. Also the percentages should be increase to see the effect on the engineering properties of black cotton soil. More compatibility test should also be carried out to observe the effect of leachate on treated black cotton soil.

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APPENDIX A

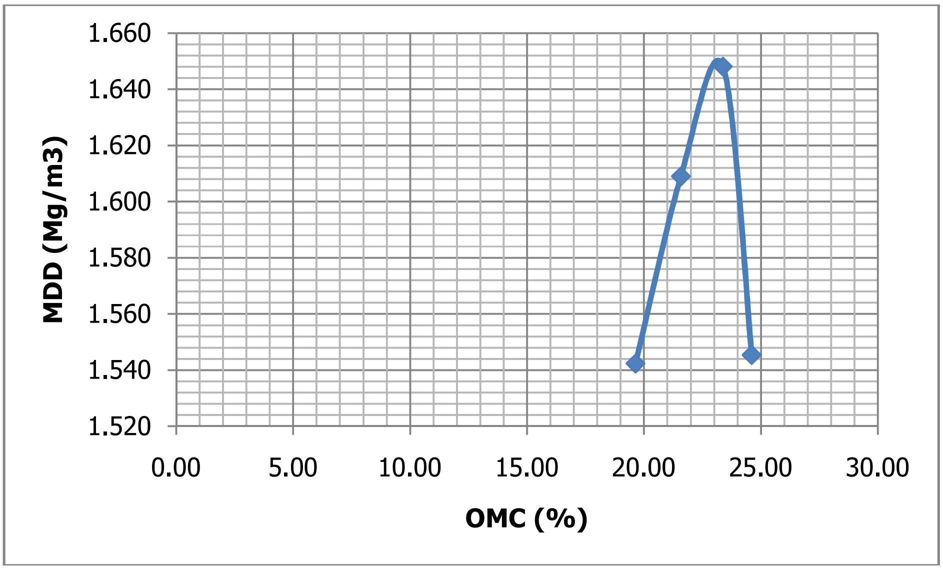


FIG A1 MOISTURE-DENSITY RELATION GRAPH FOR 8% BSH COMPACTIVE EFFORT

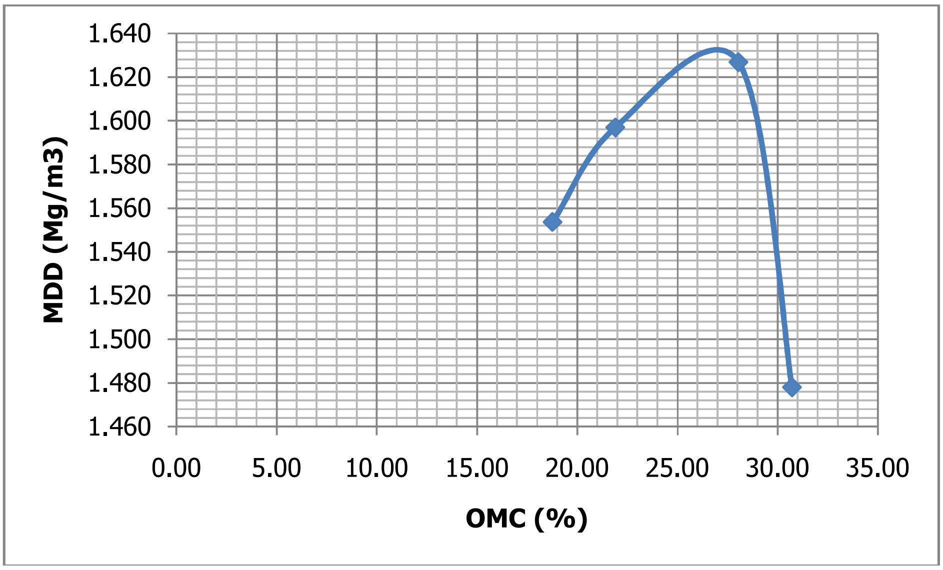


FIG A2 MOISTURE-DENSITY RELATION GRAPH FOR 12% BSH COMPACTIVE EFFORT

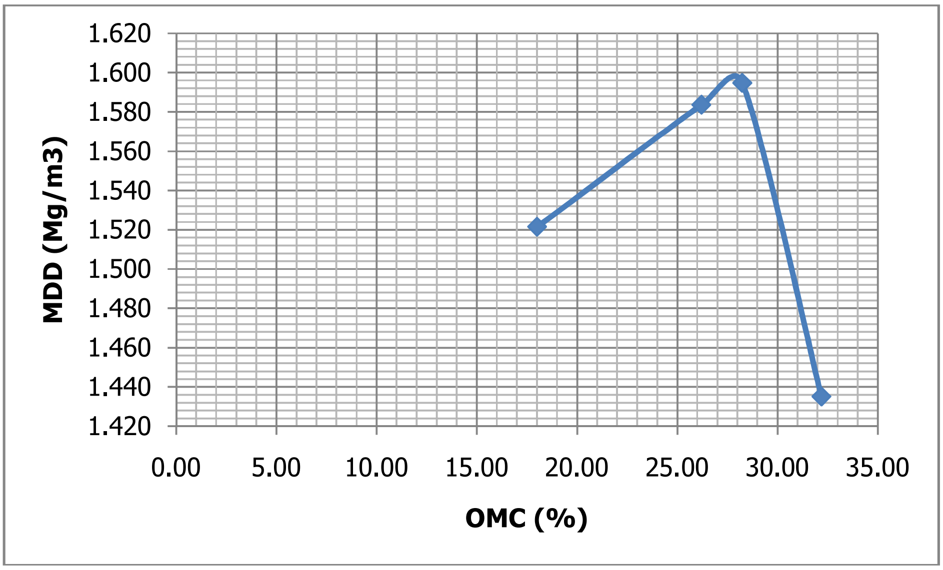


FIG A3 MOISTURE-DENSITY RELATION GRAPH FOR 0% BSH COMPACTIVE EFFORT

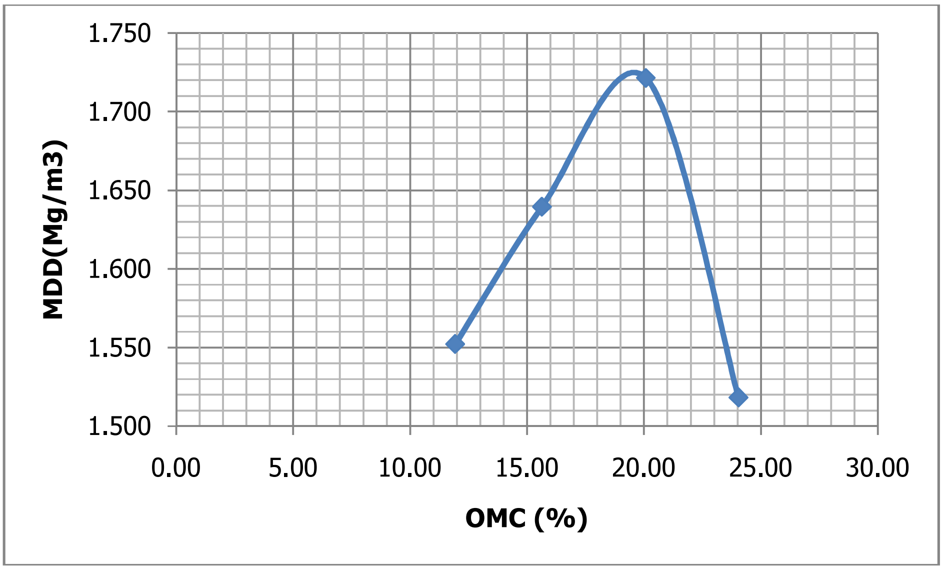


FIG A4 MOISTURE-DENSITY RELATION GRAPH FOR 4% BSH COMPACTIVE EFFORT

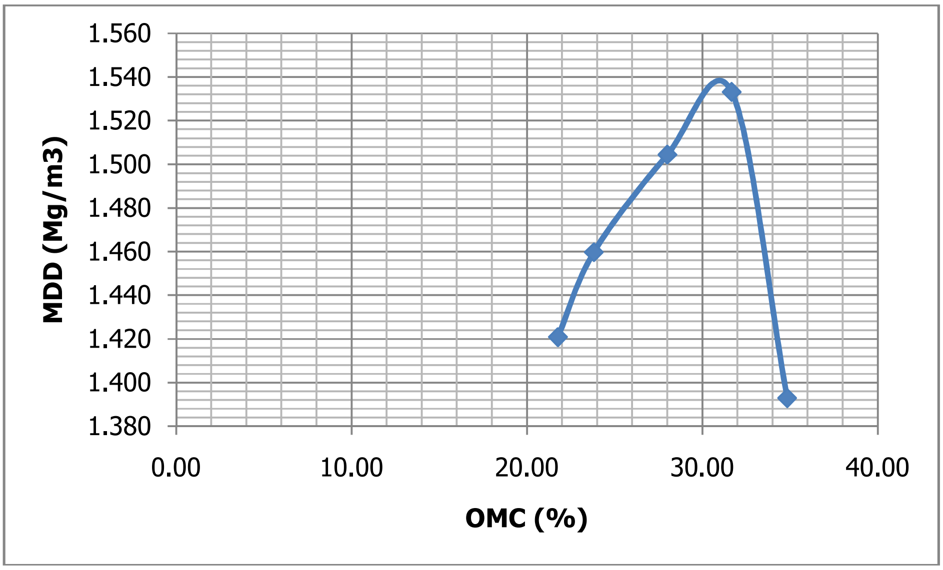


FIG A5 MOISTURE-DENSITY RELATION GRAPH FOR 0% WAS COMPACTIVE EFFORT

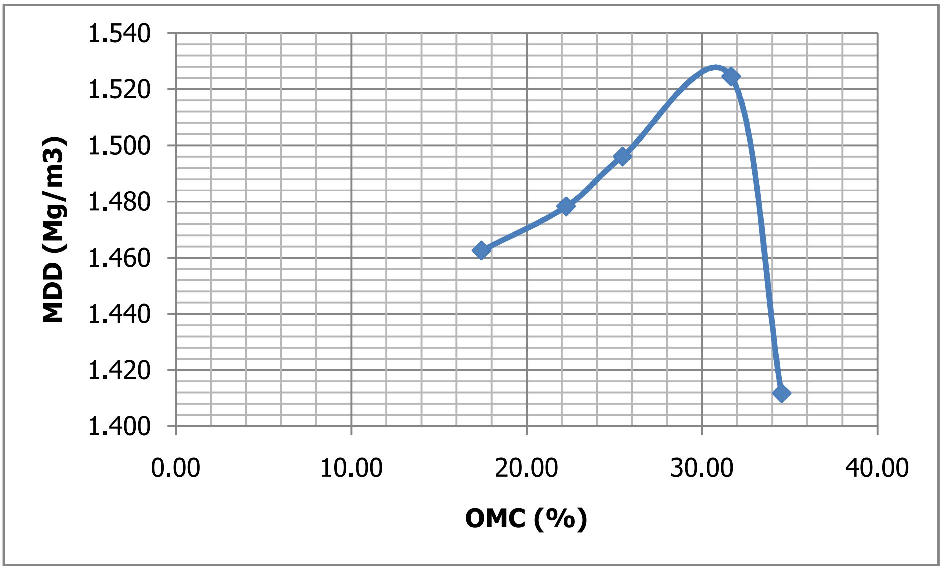


FIG A6 MOISTURE-DENSITY RELATION GRAPH FOR 4% WAS COMPACTIVE EFFORT

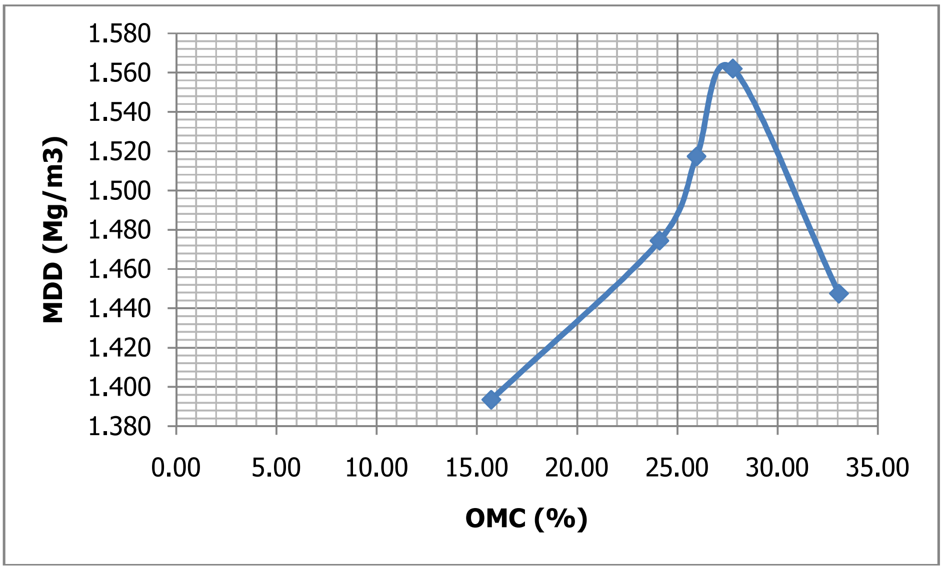


FIG A7 MOISTURE-DENSITY RELATION GRAPH FOR 8% WAS COMPACTIVE EFFORT

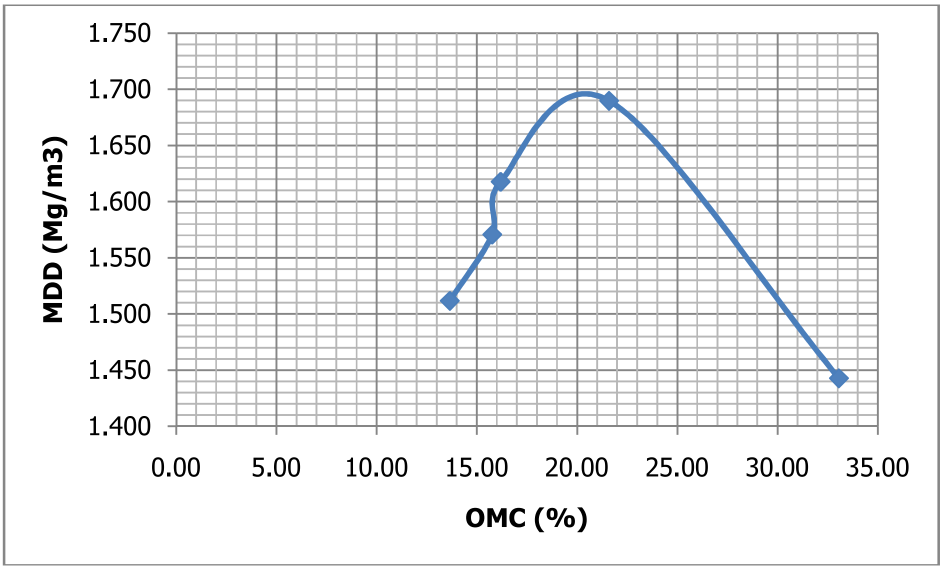


FIG A8 MOISTURE-DENSITY RELATION GRAPH FOR 12% WAS COMPACTIVE EFFORT

APPENDIX B

BAYERO UNIVERSITY KANO

POST GRADUATE PROJECT

INVESTIGATION INTO THE CAUSES OF FLEXIBLE PAVEMENT FAILURES

SIEVE ANALYSIS

Test Conducted at: BUK LAB

Year of Project: 2015 **Project Supervisor:** Dr. A. Y A

Weight of Dry soil taken for sieve analysis (g):		**Weight of dry soil after washing (g):**		
Wgt of Dry soil taken for dry sieve	**170**	**Weig**	**830**	**TP3 BASE**

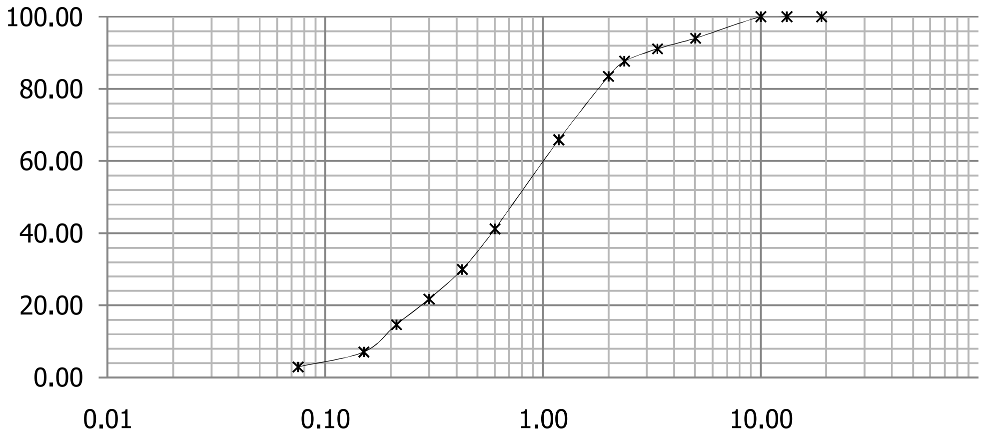
Natural Moisture Content:

Natural Moisture C		
Can No.		
Wgt of Can (g)		
Wgt of Can + wet		
Wgt of Can + dry		
Wgt of water (g)		
Wgt of dry soil (g		
Moisture Content		
	1	

SILT OR CLAY	**SAND**			**GRAVEL**	
	fine	medium	coarse	fine	coarse

Muhammad Nagado Tokari

For Stu For Su



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For S For Su