STABILIZATION OF BLACK COTTON SOIL WITH IRON ORE TAILING

BY

SAMADOU JAHAROU
B. ENG (CIVIL), A.B.U.
M.SC/ENG/2128/2009 – 2010

A THESIS PRESENTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING
FACULTY OF ENGINEERING, AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA

SUPERVISORS
Prof K.J. Osinubi
Dr T.S. Ijimdiya

MARCH 2015

DECLARATION

I hereby declare that this thesis is a research carried out by me in the Department of Civil Engineering, Ahmadu Bello University, Zaria. It has not been accepted in any previous application for a higher degree. All sources of information have been fully acknowledged by means of references.

……………………………………..   …………………………………..
Samadou Jaharou   Date

M.SC./ENG/2128/2009-2010

CERTIFICATION

This thesis titled STABILIZATION OF BLACK COTTON SOIL WITH IRON ORE TAILING carried out by SAMADOU JAHAROU meets the requirement for the award of the degree of Master of Science (Civil Engineering) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

01.04.15
…………………………..…………… ……………………....
Prof. K. J. Osinubi Date
Chairman, Supervisory Committee

……………………………………… ……………………....
Dr. T. S. Ijimdiya Date
Member, Supervisory Committee

……………………………………… ……………………....
Dr. Y. D. Amartey Date
Head of Department

……………………………………… ……………………....
Prof. A. Z. Hassan Date
Dean of Postgraduate School

DEDICATION

I dedicate this work to Almighty Allah for His guidance, blessing and protection throughout this research work and also to my family members for their support and understanding.

ACKNOWLEDGEMENTS

I am grateful to Almighty Allah for giving me the patience to complete this work. I would like to express my deepest and sincere thanks and gratitude to my supervisor Prof. K. J. Osinubi for his unconditional motivation, contributions and advice towards the attainment of this research work. I am also grateful to Dr T. S. Ijimdiya for contributions and guidance in making this research successful. I will like to recognize and acknowledge the guidance and useful contribution of Dr. A. O. Eberemu and Engr. J. Ochepo throughout this research work.

I am also indebted to the Head of Department, Dr. Y. D. Amartey, Postgraduate Coordinator, Dr. J. Sadeeq, Prof. S. P. Ejeh, Dr. O. S. Abejide, Dr. A.T. Olowosulu, Dr. A. Ocholi and Dr. I. Abubakar for their contributions to my success. Furthermore, I will not fail to appreciate the following persons whose contributions assisted in making this project a success, Engr H.S. Samaila, John Sani, Frederick Kigha, Godwin Lazhi, Ishola Kazeem and to the entire staff of soil research laboratory of Civil Engineering, Ahmadu Bello University, Zaria.

ABSTRACT

Results of preliminary investigation of the natural black cotton soil used in the study shows that it belongs to A – 7 – 6 (13) or CH in the AASHTO and Unified Soil Classification System (USCS), respectively. Soils under these groups are highly plastic and of poor engineering benefit. The soil was treated with up to 16% iron ore tailing, IOT (a mining waste) by dry weight of soil and compacted using three energy levels (British Standard light, BSL, West African Standard, WAS and British Standard heavy, BSH). Tests were carried out to determine index properties, compaction characteristics, strength characteristics, durability and microanalysis of specimens. Test results showed an increase in the particle sizes with higher IOT content as particle size distribution curves shifted from the region of fine-grained soils to coarse-grained soil. The liquid limit and plastic limit initially increased from 64.5 and 25.0% for the natural soil to peak values of 71.0 and 34.9 % for 2 and 8% IOT treatments, respectively, and thereafter decreased with higher IOT treatments to 59.9 and 27.5% at 16% IOT content. The linear shrinkage generally reduced with higher IOT treatment from 27.14% for the natural soil to 18.0% at 16% IOT content. Generally, the maximum dry density (MDD) increased while optimum moisture content (OMC) decreased with higher IOT treatment. The 7day unconfined compressive strength (UCS) values for the natural soil are 172.59, 328.38 and 448.83 kN/m^2 when compacted with BSL, WAS and BSH energies, respectively, increased to peak values of 337.77, 487.57 and 821.57 kN/m^2 at 16, 10 and 12% IOT contents, respectively. However, the recorded values did not meet the 1034.25 or 1710 kN/m^2 requirement for adequate lime or cement stabilization, respectively. Similarly, the California bearing ratio (CBR) values (unsoaked) of the compacted natural soil increased from 7.89, 9.82 and 15.03 % to peak values of 16.62, 19.64, and 29.06% at 12, 14 and 12% IOT using BSL, WAS and BSH energies, respectively. For the 24 hour soaked condition the CBR values of 3, 4 and 5 % for the natural soil increased to 5.66, 8.69 and 11.33% for BSL, WAS and BSH compactive energies at 12% IOT treatments. The resistance to loss in strength increased from 10. 81, 11.84 and 13.09 % for the natural soil to peak values of 24.71, 24.73 and 17.18% at 8, 12 and 10 % IOT treatments for BSL, WAS and BSH compactions, respectively. Microanalysis of specimens treated with an optimal 10% IOT and statistical analysis of the results using the analysis of variance (ANOVA) showed that the soil characteristics improved. The results recorded show that although iron ore tailing (IOT) improved the properties of black cotton soil (as demonstrated by its statistically significant effect on soil properties), however, it cannot be used as a stand-alone stabilizer but in admixture stabilization of the soil.

TABLE OF CONTENT

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: LITERATURE REVIEW

CHAPTER THREE: MATERIALS AND METHODS

CHAPTER FOUR: RESULTS AND DISCUSSION

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

LIST OF FIGURES

Comment [KJO1]: Ditto for others

~~——~~**Figure**

Page

Comment [KJO2]: Ditto

LIST OF TABLES

Comment [KJO3]: Correct texts as shown above for the remaining table titles

Formatted

CHAPTER ONE

INTRODUCTION

1.1 Preamble

The stability of structures founded on soil depends to a large extent on the interaction of the said soil with water. Some soils of the tropics (e.g., black cotton soil), absorb large amount of water during the rainy seasons and do not allow easy passage of such water. This consequently results in a large volume increase which drastically reduces during the dry season. This phenomenon has substantial effect on structures founded on such soils. Also, road bases built with soils that are not easily drained are affected by the development of pore water pressures which causes the formation of potholes and, eventually, the total failure of such roads. In an attempt to minimize these effects, such soils are subjected to treatments aimed at either disallowing water into them or allowing easy passage (drainage) of water to prevent pore water build up (Alhassan, 2008).

Problematic soils such as expansive soils are normally encountered in foundation engineering designs for highways, embankments, retaining walls, backfills, etc. Expansive soils are normally found in semi – arid regions of tropical and temperate climate zones and are abundant where the annual evaporation exceeds the precipitation (Chen, 1988; Warren and Kirby; 2004).

Black cotton soil is an expansive soil (Tomlinson, 1999; Osinubi et al., 2010). It is found in the north eastern part of Nigeria, Cameroon, Lake Chad Basin, Sudan, Ethiopia, Kenya and South Zimbabwe. The soil is also found in India, Australia, south west of United States of America (Ola, 1978), South Africa and Israel (Plait, 1953).

Two groups of parent rock materials have been associated with the formation of expansive soils. The first group comprises sedimentary rock of volcanic origin, which can be found in North America, South Africa and Israel (Plait, 1953), while the second group of parent materials are basic igneous rocks found in India, Nigeria and South Western U.S.A. (Medjo and Riskowiski, 2004). Morin, (1971) gives the engineering definition for black cotton soil as dark grey to black soil with a high content of clay, usually over 50 % in which montmorillonite is the principal clay mineral and which is commonly expansive. They have the tendency to expand and shrink with changes in moisture and appreciable plasticity due to the clay fraction.

Black cotton soils are expansive soils also referred to as tropical black clay. They are so named because of their suitability for growing cotton. Black cotton soils have varying colours' ranging from light grey to dark grey and black. The mineralogy of this soil is dominated by the presence of montmorillonite which is characterized by large volume change from wet to dry seasons and vice versa. Deposits of black cotton soil in the field show a general pattern of cracks during the dry season of the year. Cracks measuring 70 mm wide and over 1 m deep have been observed and may extend up to 3m or more in case of deep deposits (Adeniji, 1991). These soils are poor materials to employ for highway or airfield construction because they contain high percentages of plastic clay. In areas where they occur, usually there are no suitable natural gravels or aggregates and most deposits cover significantly large areas that avoiding them is not possible.

Although poor and undesirable for engineering purposes, its properties could be improved to meet standard specification by stabilization processes. Stabilization of the soil with chemical admixtures is a common method of reducing the swell – shrink tendencies of the soil and also makes the soil less plastic (Ola, 1983; Balogun, 1991; Osinubi, 1995; 1999). In traditional practices, stabilizers such as cement, lime, and bitumen, alone or in combination, are used as additives to stabilize soils. However, there is a variety of non-traditional soil stabilization/modification additives available from the commercial sector such as polymer emulsions, acids, lignin derivatives, enzymes, tree resin emulsions, and silicates. To achieve stability, the additive must be incorporated with the soil (Newman and Tingle, 2004).

Researchers (Ola, 1983, Balogun, 1990, Osinubi, 1995, 1999, Osinubi and Medubi, 1998) reported that appreciable improvements in the geotechnical properties of black cotton soils were observed when treated with lime, as well as lime admixed with cement. The need to reduce the rising cost of soil stabilizers and overdependence on industrially manufactured soil improving additives (cement, lime, etc.), has led to intense global research towards economic utilization of wastes for engineering purposes (Oriola and Moses, 2010).

Research works (Mohammedbhai and Baguant, 1990; Osinubi, 1997; Osinubi and Stephen, 2005; Osinubi et al., 2009) in the field of geotechnical engineering focus on the search for cheaper and locally available materials for use in stabilization. A large percentage of such materials are agricultural wastes that produce cementituous compounds on addition of moisture. These studies tried to match the need for safe and environmental disposal of waste, for the society, and the engineer’s need for better and cost effective construction materials (Collins and Ciesiellski, 1993).

Itakpe iron ore deposit, with an estimated reserve of about 200 million tons, was found in 1977 (Ola et al., 2009). The deposit is embedded in the Itakpe Hill near Okene in the north-central Kogi State of Nigeria.

Itakpe iron ore processing plant produces a waste material of about 64 % of its capacity. At a production rate of 4,737 tonnes/day, large quantities of tailings are obtained as waste product of the beneficiated iron ore (Adepoju and Olaleye, 2001). The management of tailings from iron ore mines is an important issue, from the point of view not only of pollution control but also of the conservation of resources (Ghose, 1997).

1.2 Statement of the Problem

Black cotton soils belong to the smectite group, which includes montmorillonite that are highly expansive and are the most troublesome clay minerals when encountered in construction. Primarily, the problem that arises with regard to expansive soils is that their deformations are significantly greater than the elastic deformations and therefore cannot be predicted by classical, elastic or plastic theory. Movement is usually in an uneven pattern and of such a magnitude as to cause extensive damage to the structures and pavements resting on them (Nelson and Miller, 1992).

Black cotton soils pose great threat and dangers to engineering structures because of their expansive characteristics. Expansive soils cause more damage to structures, particularly light buildings and pavements, than any other natural hazards, including earth quakes and floods (Jones and Holtz, 1993).

Though such damages are yet to be quantified in Nigeria, evidence of colossal damages on buildings and road pavements are very obvious in regions of the country especially in the North – eastern part of the country where black cotton soil exists extensively (Osinubi, 1995). Because of the above mentioned problems and because the black cotton soils occupy an estimated area of 104,000 km^2 in the north- eastern part of Nigeria, there is need to further investigate cost-effective ways of stabilizing them.

1.3 Justification for the Study

The rising cost of traditional additives such as cement and lime has motivated the search for cheaper and locally available materials for improving problematic or deficient soils to meet geotechnical engineering requirements in the construction industry. The safe disposal of industrial and agricultural waste products demands urgent and cost effective solutions because of the debilitating effect of these materials on the environment and to the health hazards that these wastes constitute (Oriola and Moses, 2010).

Recent trend in research works in the field of geotechnical engineering and construction materials (Osinubi, 1997; Osinubi, 2000a,b; Cokca, 2001; Medjo and Riskowski, 2004; Moses, 2008; Osinubi and Medubi, 1997 a,b; Osinubi and Eberemu, 2005; Osinubi and Stephen, 2005, 2006a,b; Osinubi et al., 2007a,b; 2008a; Osinubi and Eberemu, 2009) focused more on the search for cheap and locally available materials such as bagasse ash, fly ash, blast furnace slag etc. as stabilizing agents for the purpose of full or partial replacement of traditional stabilizers.

Therefore, the possible use of other locally available industrial and agricultural wastes (such as iron ore tailings) with pozzolanic properties as possible substitutes or as admixtures to main stabilizers to modify/stabilize black cotton soils, will considerably reduce the cost of construction and as well as reduce or eliminate the environmental hazards caused by such wastes.

1.4 Aim and Objectives of the Study

The aim of this research was to evaluate the effect of iron ore tailing (a by-product of mining process) when used to stabilize black cotton soil.

The following specific objectives were designed to be achieved:

1. Determination of the oxide compositions of iron ore tailing and black cotton soil.
2. Determination of the moisture – density relationships of the natural and treated soil using various compactive efforts (i.e., British Standard light, West African Standard and British Standard heavy.)
3. Evaluation of cation exchange capacity (CEC)
4. Determination of the strength and durability properties of the treated soil.
5. Determination of the optimal quantity of iron ore tailing needed to stabilize black cotton soil
6. Microanalysis of optimally treated black cotton soil
7. Statistical analysis of the results using analysis of variance (ANOVA) method

The parameters that were investigated include:

Atterberg limits, compaction characteristics (i.e., dry density and moisture content), unconfined compressive strength (UCS), California bearing ratio (CBR) and durability.

1.5 Scope of the Study

This research was carried out to determine the suitability of iron ore tailing (IOT) as additive for black cotton soil stabilization. Tests were carried out to determine the effect of IOT at various compactive efforts (British Standard light (BSL), West African Standard (WAS) and British Standard heavy (BSH)) on the properties of black cotton soil. All tests were carried out in accordance with procedures outlined in BS 1377 (1990) and BS 1924 (1990).

1.6 Research Methodology

All tests on the natural and stabilized soil were carried out in accordance with BS 1377 (1990) and BS 1924 (1990), respectively. Black cotton soil was treated with IOT in stepped concentrations of 0, 2, 4, 6, 8, 10, 12, 14 and 16 % by dry weight of the soil.

The following tests were carried out:

1. Sieve analysis
2. Atterberg limits
3. Compaction
4. Unconfined compression
5. California bearing ratio
6. Cation exchange capacity
7. Microanalysis of specimens
8. Durability

CHAPTER TWO

LITERATURE REVIEW

2.1 Expansive soils

Expansive soil is a type of clayey soil which expands when it comes in contact with water and shrinks when the water evaporates. This soil is generally found in arid and semi-arid regions of the world. A lot of damages occur on structures founded on this type of soil. The damages normally appear as cracks on buildings, canal beds and linings, pavements, lifting of water supply pipeline and sewerage lines, etc. (Sabat, 2012).

Expansive soils owe their expansive character mainly to the constituent clay mineral. The most important clay mineral, which is the cause for expansive nature is montmorillonite. It has an octahedral sheet sandwiched between two silica sheets. When this mineral is exposed to moisture, water is absorbed between interlayering lattice structures and exert an upward pressure. This upward pressure, known as swelling pressure, causes most of the damages associated with expansive soils. Most of the structural damage by expansive soils results from the differential rather than the total movement of the foundation soil as a result of swelling (Holtz and Hart, 1978).

An example of expansive soils is the black cotton soil which is dark–grey to black in colour. The name originated from India where locations of these soils are favourable for growing cotton. It is also the Nigerian type of expansive soils (Osinubi, 1999).

2.1.1 Origin of black cotton soil

Tropical black clay otherwise known as Canada’s swelling clays, India’s black cotton soil and Kenya black cotton soils can be found all over the world (Chen, 1988).

Black cotton soils are black clays that are produced from the breakdown of basic igneous rocks, where seasonal variation of weather is extreme. Nigerian black cotton soils (BCS) are formed from the weathering of shaly and clayey sediments and basaltic rocks. The Nigerian BCS contains more of the montmorillonite mineral with subsequent manifestation of swell properties and expansive tendencies (Ola, 1983). Black cotton soils are confined to the semi-arid regions of tropical and temperate climatic zones and are abundant where the annual evaporation exceeds the precipitation (Chen, 1988; Warren and Kirby; 2004),

Balogun (1991) reported that black cotton soils occur in continuous stretches as superficial deposits and are typical of flat terrains with poor drainage. The absence of quartz in the clay mineralogy enhances the formation of fine-grained soil material, which is impermeable and waterlogged. Other conditions favouring the formation of black cotton soils are evaporation exceeding precipitation, poor leaching, alkaline conditions and retention of magnesium and calcium in the soil (Ola, 1983).

2.1.2 Mineralogical and chemical composition of black cotton soil

Ola (1983) showed that the Nigerian black cotton soils contains about 70 % montmorillonite and 30 % kaolinite and the predominance of this montmorillonite is due to the weathering of the basic constituents. The swell and shrink characteristics of the soil are largely due to montmorillonite mineral while kaolinite is likely responsible for high strength value because of its inability to swell with absorbed water.

The montmorillonite clay structure consists of layer sheet formed and stacked one above the other and the bonding between successive layers is by van der Waals forces and by cation that may be present to balance charge deficiencies in the structure. These bonds are however, weak and easily separated by cleavage or adsorption of water and other liquids. There is an extensive isomorphous substitution for aluminium and silicon with its lattice which gives the clay a net negative charge resulting in the water absorbing tendencies and an attraction for hydroxyl ions and water molecules to the clay surface (Nelson and Miller, 1992). On the other hand, kaolinite is a relatively inactive clay mineral. Its structure is made of repeating layers of elemental silica-gibbsite sheets in 1:1 lattice (Das, 1998).

2.2 Iron Ore Tailing

Tailings are the discarded material resulting from the concentration of ore during beneficiation operations. Tailings are characterized by fine particle size and varying mineralogical and chemical composition (Aleshin, 1978).

The iron ore extracted from the mines are beneficiated to separate out the valuable mineral content. The prime function of beneficiation of iron ore is to improve the iron (Fe) content and to decrease the Alumina / Silica ratio for smooth blast furnace operations. The left over residue of the iron ore after the beneficiation which usually constitutes of fine particles mixed in a slurry form, known as tailings are needed to be disposed of in the tailings pond for containment. Tailings contain all other constituents of the ore but the extracted metal, among them heavy metals and other toxic substances that are either added to the tailings in the milling process or available with the ore before that (ICOLD, 2003). Therefore, tailings are the waste silica and quartz particles, as well as fine-grained ore that are unable to be recovered within the existing concentration processes.

The Itakpe iron ore deposit in Nigeria which has a total estimated reserve of about 182.5 million metric tonnes consists mainly of quartzite with magnetite and haematite and the Itakpe project was designed to treat a minimum of 24,000 tons of ore per day and operate 300 days per year (Ajaka, 2009). The deposit contains a mixture of magnetite and hematite with ratio varying throughout the deposit. The ore consists of coarse, medium and fine grained particles. The fine ores are located mainly in the eastern part of the deposit and in thin layers, while the coarse and medium ores are relatively mixed. However, the coarse ore predominates in the north and west of the central layers while the medium one does in the centre of the central layers. The average iron content of the ore deposit was determined to be approximately 35% (Ola et al., 2009).

The disposal of tailings is a major environmental problem, which is becoming more serious with increasing extraction of lower grade deposits. The tailings are usually transported and deposited as slurry of high water content into a massive pond for containment, which are generally called as tailing ponds / tailing dams (CPCB, 2007). Tailings embankments are susceptible to rapid erosion, cutting down and complete breaching (Toland, 1977). The creation of artificial tailings ponds creates environmental problems of air and water pollution, deforestation and has impacts on agriculture and forestry. Of particular concern is direct discharge of tailings into rivers. Another cause of surface water pollution is the discharge of supernatant effluent into water courses.

In certain mines where ores have high sulfur content, drainage from mine workings and waste heaps can become highly acidic and can contain high concentrations of dissolved heavy metals. This acid mine drainage (AMD) can have a pH of 3 or lower; sulphate levels of 800–1,800 milligrams per litre (mg/l) depending on the contents of the ore. Effluent from tailings ponds may contain concentrations of chromium of several milligrams per liter, chemicals used in flotation and other metal concentration processes could create toxicity problems (World Bank Group, 1998). In the sedimentary deposit mining areas the water table and aquifers are damaged and thus the availability of water from these sources reduces. Tailings must be managed to optimize human safety and environmental protection that is the reason why intensive research and development efforts are being intensified in finding cost-effective solutions in utilizing these industrial wastes.

2.3 Soil Stabilization

Soil stabilization is the alteration of one or more soil properties, by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties. Earlier, soil improvement has been in the qualitative sense only, but more recently, it has also become associated with quantitative values (compressive strength, shearing strength, load bearing quality, adsorption softening and reduction in strength) of strength and durability, which are related to performance (Amu et al., 2005). Soils may be stabilized to increase strength and durability or to prevent erosion and dust generation. Soil stabilization deals with the physical, physico-chemical and chemical methods to make the stabilized soil to serve its purpose as pavement component material (Koteswara, 2011).

According to Johnson et al. (1988) stabilization infers improvement in both strength and durability. Osinubi and Katte (1991) referred to soil stabilization as the alteration or control of any soil property. It covers not only the increase or decrease of any soil property, but also the variation of any property with changes in environmental condition, namely moisture or pressure.

Primarily, the objectives of stabilization are to improve soil strength, to decrease permeability and water absorption and to improve bearing capacity and durability under cyclical conditions such varying moisture content (Akinmade, 2008).

Soil stabilization has been used in the building of roads, aircraft runways, earth dams and embankment in erosion control (Diamond, 1975; Kawamura and Diamond, 1975) and in reduction of frost heaving.

2.3.1 Mechanical stabilization

This is the process of altering soil properties by changing the gradation through mixing with other soils, densifying the soils using compaction energies, or undercutting the existing soils and replacing them with granular material. In the field, hand–operated vibrating plates and motorized vibratory rollers of various sizes are very efficient in compacting sand and gravelly soils. Large falling weights have been used to dynamically compact loose granular fills (Markwick, 1944).

The objective of mechanical compaction is the improvement of the engineering properties of the soil mass, and the several advantages which are obtained through compaction are as follows (O' Flaherty, 1988):

i. Reduction in settlement due to reduced void ratio

ii. Increase in soil strength

iii. Reduction in shrinkage.

2.3.2 Chemical stabilization

Soil stabilization using chemical admixtures is the oldest and most widespread method of ground improvement. Chemical stabilization is mixing of soil with one of or a combination of admixtures of powder, slurry, or liquid for the general objectives of improving or controlling its volume stability, strength and stress-strain behavior, permeability, and durability (Winterkorn and Pamukçu, 1990).

Traditional stabilizers such as Portland cement, lime and bitumen are used to stabilize soil. However, there are a variety of non-traditional additives available from the commercial sector such as polymer emulsions, acids, lignin derivatives, enzymes, tree resin emulsions, and silicates.

Inorganic salts such as sodium chloride and calcium chloride have long been used in stabilization. Their chief function is to reduce plasticity and facilitate densification (Gillot, 1987; Yamanouchi, 1975; Habercom, 1978; Balogun, 1991).

2.3.2.1 Cement stabilization

Soil which is stabilized with cement is known as cement-soil. The chemical reaction between cement and soil during hydration process will produce binding force.

Cement stabilization is suitable for inorganic soil (Bergado et al., 1996). However, high early strength cement is more effective than the Portland cement (Hammond, 1961).

The Portland Cement Association (1970) has indicated that nearly all types of soils can be stabilized with cement. In general, gravels require about 10 % by weight of cement, sand requires about 7 to10 %; silts about 12 to 15 % and clays about 12 to 20 % by weight of cement (Gillot, 1987). When soils are sandy, mixing of cement and soil can be carried out at or slightly about optimum moisture content but with clayey soils mixing is most readily achieved with moisture slightly below optimum (Akinmade, 2008).

2.3.2.2 Lime stabilization

Lime reacts with medium, moderately fine and fine-grained soils to produce decreased plasticity, increased workability, reduced swelling, and increased strength. The main reactions include cation exchange, flocculation and pozzolanic reactions (Nelson and Miller, 1992).

Eades and Grim (1960) found that there exists a chemical reaction between lime and pure clay minerals (kaolinite, illite and montmorillonite) with accompanying increase in bearing value. The quantity of lime needed to effectively treat a soil to develop increased strength varies with the type of clay mineral present. Akawwi and Al-Kharabsheh (2002) reported that the swelling and shrinkage potential of soils are affected by mineralogical constituents and surrounding environment.

The optimum amount of lime for maximum strength gain in stabilizing soil with lime according to Eades and Grim (1960) is 4 - 6 % for kaolinite, about 8 % for illite and montmorillonite. Ola (1978) reported a linear relationship between the strength of lime – stabilized black cotton soil and up to 10 % lime content.

2.3.2.3 Bitumen stabilization

This method enhances the strength of the soil by making it waterproof, forms binding among the soil particles and maintain low moisture content of soil. Bitumen stabilization of any soil can only be feasible if the plasticity index of the soil lies between 6 and 10 %, if otherwise; it may become difficult to stabilize such soils with bitumen, due to the non-pulverizing of the soil (Yoder and Witczak, 1975). Gillot, (1987), Osinubi and Bajeh (1994) as well as Osinubi (2000b, 2001b) reported that bituminous soil stabilization has been most successfully employed in the stabilization of non-cohesive or mildly cohesive soils particularly in warm dry climates where the soil has low moisture content.

2.3.2.4 Agricultural and/or industrial waste stabilization

Previous researches have revealed that the soils could be stabilized effectively using bitumen, lime or cement. Balogun (1991) reported that stabilization of black cotton soil, with lime for example, was not adequate to meet the requirements of the conventional specification for use of the soil in road and highway construction. Similarly, Ibrahim (1983) found that high percentage of cement would be required to stabilize black cotton soil effectively.

The rising cost of conventional soil stabilizers coupled with the need to reduce the cost of waste disposal as well as the need for the economical utilization of industrial and agricultural waste have prompted an investigation into the stabilizing potential of wastes for beneficial engineering purposes. Fly ash is one of the most plentiful and industrial by-products. It is generated in vast quantities as a by-product of burning coal at electric power plants (Senol et al., 2006).

Fly ash generated by coal combustion based power plants typically fall within the ASTM fly ash classes C and F (Reyes and Pando, 2007). Yudhbir and Honjo (1991) stated that the pozzolanic fly ashes can be advantageously made use of to improve the geotechnical properties of black cotton soils.

Studies have been carried out on the beneficial use of agricultural and industrial waste for construction purposes in the Department of Civil Engineering, Ahmadu Bello University, Zaria. Akinmade (2008) and Osinubi et al. (2009b; 2011) reported that locust bean waste ash has a good potential in improving some of the geotechnical properties of the soil.

Osinubi and Stephen (2005; 2006a,b; 2007), Osinubi and Ijimdiya (2009), Osinubi and Mustapha (2005; 2008), Osinubi and Eberemu (2006), Osinubi et al., (2007a,b; 2009a,b) focused on the use of bagasse ash as possible stabilizers/admixtures for the stabilization of expansive soils. Stephen (2006) studied the potential of bagasse ash as stabilizer on black cotton soil, while Moses (2006) and Osinubi et al. (2008a, b) admixed bagasse ash with lime and cement in stabilizing black cotton soil.

. Sayah (1993) and Zaman et al. (1992) reported the effectiveness of cement kiln dust in stabilizing highly expansive clay soils. The use of cement kiln dust in stabilization of clays has been shown to improve the unconfined compressive strength and reduce the plasticity index using dust with low loss on ignition (LOI). On the other hand, adding cement kiln dust with high LOI resulted in relatively lower unconfined compressive strengths and higher plasticity indices (Bhatty et al., 1996).

2.4 Pozzolanas

Pozzolans are defined as siliceous and aluminous materials which themselves possess little or no cementitious value but will, in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (Robert, 1993).

2.4.1 Properties of pozzolanas

The chemical composition of pozzolanas can be roughly summarized as follows:

Silica + Alumina + Iron Oxide – Not less than 70 percent

Other Oxides and Alkalis – Not more than 15 percent

Loss on ignition – Not more than 15 percent

The ASTM C618 – 78 specifications for pozzolanas is given in Table 2.1

Table 2.1: Properties of pozzolanas

Property	**Class N**	**Class F**	**Class C**

Chemical Properties			
$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	70	70	50
SO_3 (Max %)	4	5	5
MgO (Max %)	5	5	5
Loss on ignition	10	2	6
Physical Properties			
Moisture content (%)			
Fineness (%) on sieve No. 200 (mm)	3	3	3
Pozzolanic Activity	85	85	85
Index with OPC at 28 days (%)			
Pozzolanic Activity Index with lime	75	75	75
at 7 days	5.5	5.5	5.5

Source: ASTM C618-78

2.4.2 Fineness of pozzolanas

An essential physical property of a cementing material that affects its affinity for water is its fineness. The activity of pozzolanas is increased by fine grinding. ASTM C618-78 specification requires that the percentage passing sieve No. 200 ≥ 85% (Lea, 1956, Smith, 1992).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Black cotton soil

The soil sample used in this study was obtained near Baure village in Deba Local Government Area (LGA) of Gombe State. It was collected as disturbed sample, excavated from depth not less than 0.5 m so as to avoid any organic material. The samples were packaged in sealed plastic bags for use in laboratory. The collected soil sample was air-dried and pulverized into particles passing BS No. 4 (4.75 mm aperture) sieve before laboratory tests were carried out.

Morin (1971) reported that the Lake Chad Basin is the only extensive lacustrine deposit of black cotton soil in Africa. The black cotton soils of north eastern Nigeria were laid during the tertiary and quaternary periods of the Chad formation and are composed of a sequence of lacustrine and fluviatile clays and sands of Pleistocene age. Figure 3.1 shows the geology of the black cotton soil of the Northern Eastern Nigeria.

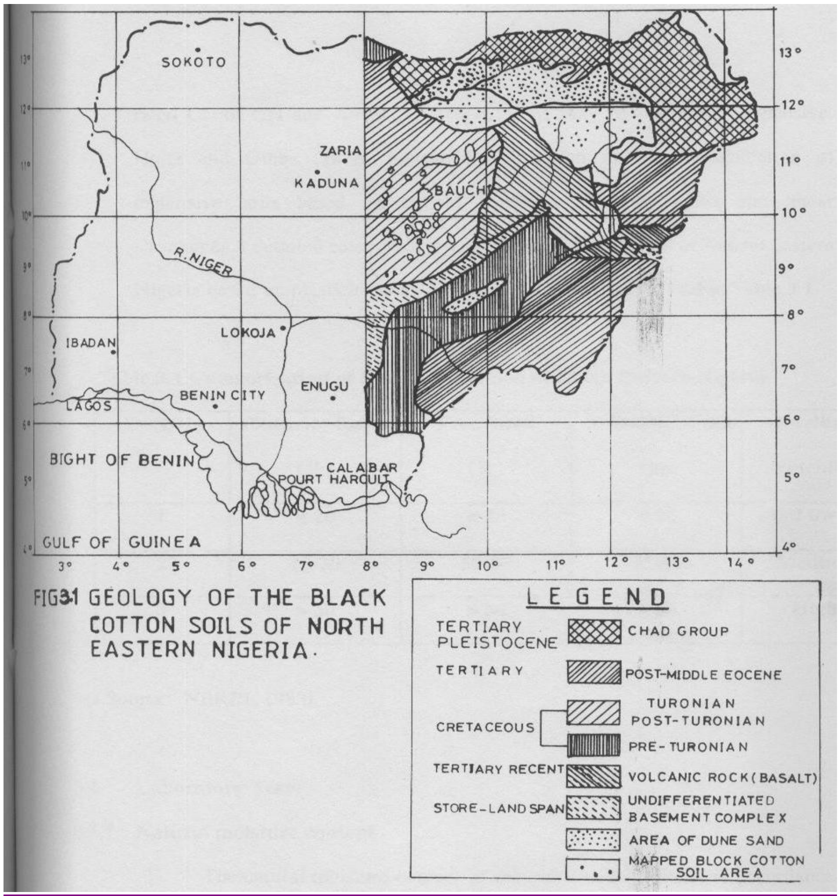

Fig 3.1: Geology of the Black Cotton Soil of the Northern Eastern Nigeria. (After Ola, 1983)

3.1.2 Iron ore tailing

Iron ore tailing was obtained from the National Iron Ore Mining Company (NIOMCO) waste deposit in Itakpe in Okene Local Government Area of Kogi State of Nigeria. The iron ore tailing sample was passed through BS No. 200 sieve before laboratory tests were carried out.

3.2 Methods

3.2.1 Moisture content

The natural moisture content of the black cotton soil (BCS) was determined in accordance with BS 1377 (1990) Part 2; Test 1(A). A weighing container was cleaned and weighed to the nearest 0.01g. Freshly crumbled sample was loosely placed in the weighed container. The container with sample was weighed to the nearest 0.01g and placed in a thermostatically controlled oven and dried at temperature 105-110^{0}C for 24 hours. The dried sample and container were then weighed to the same accuracy.

Moisture content was determined using the equation

$$W = \frac{M_2 - M_3}{M_3 - M_1} \times 100\% \qquad (3.1)$$

W - Moisture content (%)

M_1 - mass of container (g)

M_2 - mass of container + wet soil (g)

M_3 - mass of container + dry soil

Three different tests were carried out from which average natural moisture content was determined.

3.2.2 Specific gravity

The determination of specific gravity was carried out according to BS 1377 (1990) test (B) for fine–grained soils. The density bottle and the stopper were weighed to the nearest 0.01g (m_1). The air-dried soil was transferred into the density bottle, and the bottle, content and the cover were weighed as m_2. Water was then added just enough to cover the soil, the solution is gently stirred to remove any air bubble. The bottle was then completely filled up and covered. The covered bottle was then wiped dry and the whole weighed to the nearest 0.01g (as m_3). The bottle was subsequently emptied and filled completely with water, wiped dry and weighed to the nearest 0.01g (m_4). The specific gravity is calculated using eqn. (3.2)

$$G_S = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_1)} \qquad (3.2)$$

The procedure was repeated to obtain three values from which the average specific gravity of the modified BCS and IOT were determined.

3.2.3 Particle size distribution

The particle size distribution of the natural soil was determined using both sedimentation analysis and dry sieving of the coarse fraction as specified by BS 1377 (1990) for cohesive soils. The soil sample (200 g) was soaked for 24 hours and washed through BS No. 200 sieve. The materials retained was oven-dried for 24 hours and sieved by agitating it through a range of sieves from sieves No. 7 or 2.4 mm sieve and downwards. The mixture that passes through sieve No. 200 was poured into a 1000 ml measuring cylinder then 25 ml of sodium hexametaphosphate (commercial grade) was added and stirred thoroughly, then hydrometer is immerse gently and readings were taken at intervals stipulated by BS 1377; 1990 Part 2.

3.2.4 Atterberg limits

The Atterberg limits test included the determination of liquid limits, plastic limits and plasticity indices of the natural and modified soil samples. They were also conducted in accordance with Test 1(A) B S 1377 (1990) Part 2 for the natural soil and BS 1924 (1990) for the stabilized soils.

3.2.4.1 Liquid limit

Test 1(A) B.S 1377 (1990) describes the procedure for the determination of liquid limit test of a soil which was adopted for this work. In this test, 200 g of the sample material passing BS No. 40 sieve (425 µm aperture) was placed on a clean glass plate. The soil was thoroughly mixed with water on this flat glass plate, using palette knife and spatula to form a homogenous paste. A proportion of the paste was placed in Casagrande apparatus and level parallel to the base of the chip and divided by drawing the grooving tool through the paste along diameter passing the centre of the hinge. The crank was turned to lift-drop the cup at the rate of 2 revs per second, noting the number of blows (falls) that would make the bottom two parts of the groove come together. . The liquid limit tests were determined at various moisture contents from drier states to the wetter states. The moisture content was plotted against the respective number of blows on the semi logarithm paper. The liquid limit was deduced as the moisture content corresponding to 25 blows.

3.2.4.2 Plastic limit

A portion of the soil/soil–IOT mixes used for the liquid limit test was retained for the determination of plastic limit. A small portion of the soil sample was put on a flat glass plate and mixed thoroughly enough to be shaped into a small ball. The ball was then moulded between fingers and then rolled on the glass plate with palm of hand into thread of about 3mm diameter when the thread crumbles by shearing. The crumbled threads were immediately put in weighing pan for moisture content determination. The same test was performed for each of the modified soils.

3.2.4.3 Plasticity index

Having determined the values of the liquid limit and the plastic limit of the soil, plasticity Indices of the natural and modified soil samples were derived using equation

$$PI = LL - PL \tag{3.3}$$

where,

PI = Plasticity Index

LL= Liquid Limit

PL= Plasticity Limit

3.2.5 Linear shrinkage

The test was performed according to BS 1377 (1990), Test 5, by mixing 125 g of soil passing sieve with 425 µm aperture with water to obtain a homogenous paste. Water mixed with the soil sample was in the same amount as the moisture content corresponding to the liquid limit. The sample was put in shrinkage mould and vibrated gently in order to expel trapped air in the mixture. The soil in the mould was levelled using spatula and then air dried at 60^0C until the soil shrinks clear off the mould before oven-drying at 105 to 110^0C to establish a clear and complete shrinkage. After cooling, the sample length was measured using ruler. The linear shrinkage was determined from the equation:

$$\text{Linear Shrinkage} = \frac{(\text{Initial length - Dried length})}{\text{Initial Length}} \times 100\ \% \tag{3.4}$$

This test was carried out for all the soil samples considered.

3.2.6 Free swell

This test was carried out according to United State Bureau of Reclamation (USBR) method (Holtz and Gibbs, 1959). Some 10 g of soil passing sieve with aperture 425 µm was oven dried and allowed to cool in a desiccator. The sample was then slowly poured into 100 cc measuring cylinder to which water was added to the 100 cc mark. The content was then shaken to obtain a homogenous mixture and should be allowed to settle for at least 24 hours before the final level was recorded. Free swell was determined from the equation:

$$\text{Free Swell} = \frac{\text{Final Volume - Initial Volume}}{\text{Inital Volume}} \times 100\% \qquad (3.5)$$

3.2.7 Cation exchange capacity

The test was carried out in accordance with the procedures given by International Soil and Reference Information Center, ISRIC (1998). Some quantity of the natural soil was sieved through the 2 mm screen and 10g of the sieved sample was put into a 100 ml plastic beaker. About 40 ml of ammonium acetate (1N at pH7) was added and stirred using a glass rod and left over night. The sample was then filtered with a light suction using a 55 mm Butcher funnel. The soil was leached with 250 ml of Ammonium acetate (NH_4Ac) until no test for calcium could be obtained in the effluent solution. To test for calcium, diluted Sodium hydroxide (NaOH), few drops of each of 1N NH_4Cl and 10 % ammonium oxalate were added to 10 ml of the leachate in a test tube and heated to near boiling point. The presence of calcium was indicated by a white precipitate or turbidity. As long as calcium was detected, the process was repeated until there was no trace of it.

The calcium-free soil was then leached with neutral 1N ammonium chloride NH_4Cl four times and once with 0.25 N of the acid. The electrolyte was then washed out using 150-200 ml of isopropyl alcohol.

Chloride in the leachate was tested for using silver nitrate (0.1N AgN0_3) till its trace was negligible, and the soil was left to drain thoroughly. A 10% percent acidified NaCl was added little by little to the ammonium saturated soil until 250 ml had passed through the sample, allowing each portion to pass through the sample before adding the next portion. The leachate was transferred in quantities to flask for titration. To it, 25 ml of 1N NaOH was added, and 60 ml of the solution distilled into 50mL of 2%H_3BO_3. Ten drops of bromocresol green-mythel was added. The colour changed from bluish green to pink at the end of the titration. Blank titration was run on the reagents to correct titration figure for the reagents and the milliequivalents of ammonium in 100g of soil was calculated. The NH_4-borate was titrated with a standard acid 0.1N HCl in the blank titration. The cation exchange capacity was calculated using eq. (3.6):

$$\frac{(Titre - B) * NA * 100}{weight\ of\ soil} \qquad (3.6)$$

where

B = Blank

NA = Normality of acid

This same procedure was then repeated for each of the sample treated with IOT.

3.2.8 Compaction

Compaction tests on the soil samples were carried out in accordance with BS 1377 (1990) Part 4:3:3 using the British Standard light (BSL) and British Standard heavy (BSH) energies.as well as West African Standard (WAS) described in Nigerian General Specifications (1997). For the BSL, 3 kg of soil sample was thoroughly mixed with 8 % of water (and the water is added at 8 % for each of the compactions). The wet soil was then placed in 1000 mm^3 mould and compacted in three equal layers; each layer receiving 27 blows of 2.5 kg rammer, falling through a height of 300 mm. At the end of the compaction, extension collar on the mould was removed and the top of the soil trimmed to level by means of a straight edge. The weight of the mould and the soil sample were measured. The weight of the mould and base had earlier been measured.

In the case of the BSH compactor, test mould of the same capacity was filled in five layers and alternately compacted with 4.5kg rammer falling from 300mm up to 27 blows per layer. The same procedure was followed to determine moisture content. The WAS compactive, effort was derived from a 4.5 kg rammer falling through 300 mm height, 10 times on five layers of the soil and trimmed to level with the mould.

3.2.8.1 Maximum dry density

The bulk and dry density in (Mg/m^3) was obtained for each of the soil samples using equation:

$$\rho = \frac{m_2 - m_1}{1000} \qquad (3.7)$$

The dry density was also calculated using the equation:

$$\rho_d = 100\rho/(100 + w) \qquad (3.8)$$

where,

ρ - Bulk density (Mg/m^3)

m_1 - Mass of empty mould and base (g)

m_2 - Mass of mould, soil and base (g)

W - Moisture content (%)

ρ_d - Dry density.

The values of the dry densities as obtained from eqn. (3.8) were plotted against their respective moisture contents and the maximum dry density (MDD) was deduced as the maximum point on the resultant curves

3.2.8.2 Optimum moisture content

Optimum moisture content, the amount of water content corresponding to maximum dry density of the sample read from the MDD/moisture content graph.

3.2.9 Unconfined compressive strength

The unconfined compressive strength (UCS) tests were performed on the soil samples according to BS 1377; 1990 Part 7 using the British Standard light (BSL), West African Standard (WAS) and British Standard heavy (BSH) energy levels. The natural air dried soil sample/the stabilized soil samples were compacted in 1000 cm^3 moulds at their respective optimum moisture contents using the three energy levels described earlier. The predetermined quantities of soil, iron ore tailing and water obtained from moisture-density relationship were thoroughly mixed. Three samples for various percentages of soil iron ore tailing mixes were extruded from the moulds and trimmed into a cylindrical specimen of 38.1 mm diameter and 76.2 mm length. Each specimen was cured by sealing in a polythene bag for 7, 14 and 28 days with another set of samples cured for 7days and soaked in water for another 7 day for durability assessment.

At the elapsed day of curing, the specimens were then placed centrally on the lower platen of a compression testing machine and a compressive force was applied to the specimen with a strain control at 0.10 % mm. Record was taken simultaneously of the axial deformation and the axial force at regular interval until failure of the sample occurred. The UCS of the sample was determined at the point on the stress–strain curve at which failure occurred. The UCS was calculated from the following equation:

$$Compressive\ \text{strength} = \frac{\text{Failure load}}{\text{Surface Area of Specimen}} \qquad (3.9)$$

3.2.10 California bearing ratio

The California bearing ratio (CBR) test was carried out as a measure of strength of the natural and stabilized soil. The aim of the CBR test was to determine the relationship between force and penetration. The CBR is expressed by the force exerted by the plunger by the depth of its penetration into the specimen. The tests were carried out in conformity with the B.S. 1377 (1990), B.S. 1924 (1990) and the Nigerian General Specifications (1997).

For the British Standard light (standard Proctor) compaction, 5 kg of the natural or stabilised soil sample were mixed at respective optimum moisture content in 2360 cm^3 mould, at the three compactive efforts. The mixture was then compacted in 3 equal layers in the CBR mould, with 62 blows of the 2.5 kg rammer was applied to each layer for BSL. For the WAS, the samples were compacted in five layers with 25 blows from the 4.5 kg rammer and for the BSH, the sample received 62 blows in 5 layers from the 4.5 kg rammer. The extension collar was removed and the top of the compacted sample trimmed carefully and waxed. The samples were kept in the humidity room at a temperature of 20 ± 2°C and 100 % relative humidity for 6 days. Durability assessment of CBR specimens entailed immersion of the 6 days cured specimens in water for about 24 hours before testing; this is in accordance with the Nigerian General Specifications (1997). The specimens were then transferred to the CBR testing machine. The plunger was then made to penetrate the specimen at a uniform rate. The dial reading indicating, forces were taken each at 0.25 mm interval of penetration until the maximum of 7.50 mm was attained or alternatively until failure was reached. The bottom of the specimens was also tested in like manner. The CBR curves were plotted using the values obtained from the tests. The CBR was calculated at the penetration of 2.50 mm and 5.0 mm as:

$$\text{CBR} = \frac{\text{Measured load}}{\text{Standard load}} \times 100\% \qquad (3.10)$$

where standard load = 13.24 kN of 2.5 mm penetration

= 19.96 kN of 5.0 mm penetration

However, where the values are within 10 % of each other, the mean value of the two readings was considered, otherwise the higher value was recorded as the CBR of the specimen

3.2.11 Durability

The durability assessment (under adverse field conditions) of the soil sample was determined by resistance to loss in strength when immersed in water. It was expressed as the ratio of UCS of the specimen cured for 7 days and soaked for another 7 days to the UCS of the specimen cured for 14 days:

$$\text{Resistance to loss in strength (\%)} = \frac{\text{UCS(7 day cured + 7 day soaked)}}{\text{UCS(14 day cured)}} \times 100\% \qquad (3.11)$$

3.2.12 Analysis of variance

The problem of analyzing quality of estimated regression line can be handled by analysis of variance (ANOVA). This procedure subdivides the total variations in independent variables into meaningful components that are observed and treated in a systematic manner. Let our experimental data be in the form (x_i, y_i) in n-numbers of experiments and the regression line is estimated then (Montgomery, 2001)

$$S_{yy} = bS_{xy} + SSE \qquad (3.12)$$

where,

b = slope of underlying straight line of relationship.

An alternative and perhaps more informative formulation is

$$\sum_{i=1}^{n}(y_i - \bar{y})^2 = \sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2 + \sum_{i=1}^{n}(y_i - fc)^a \qquad (3.13)$$

By using the above formula, the total experimental data are partitioned into two components with corrected sum of squares of y that makes the best fit line of regression to establish whether results of experiments fall within acceptable limits or confidence level.

This partitioning shall be represented symbolically as:

$$SST = SSR + SSE \tag{3.14}$$

where,

SSR = the regression sum of squares which reflects variation in the parallel values of the model i.e. a postulated straight line.

SSE = the second component, the sum of squares of errors, reflecting variation about the regression lines.

Suppose that we have to test the following hypothesis

HQ: $\beta = 0$,

HI: $\beta \neq 0$,

Where the null hypothesis indicates that the model is $\mu_y \backslash x = a$. That means *Y* results from chance or random fluctuations which are independent of values of *x*. Under the null hypothesis it can be shown that SSR/o^2 and SSE/σ^2 are values of chi-squared variables with 1 and (n-2) degrees of freedom respectively. This implies that SST/a^2 is also a value of a chi-squared variable with *n*-1 degrees of freedom.

For the above hypothesis testing, let calculate

$$f = \frac{SSR/1}{SSE/(n-2)} - \frac{SSR}{s^2} \tag{3.15}$$

We should note that HQ is rejected as the level of significance, “when the null hypothesis is rejected. That is, when the F-statistic exceed the critical value, $fQ_{(l,n - 2)}$, we conclude that there is a significant amount of variation in the response accounted for by the postulated straight line function. If the F-statistic is smaller we reject, we conclude that the data did not reflect sufficient evidence to support the model postulated”. The computed results from this analysis are presented by means of table of analysis of variance. It is customary to refer to the various sums of squares divided by their respective degrees of freedom as the mean squares.

3.2.13 Microanalysis

Microanalysis of specimens treated with optimal concentration of IOT was carried out using a scanning electron microscope (SEM) to examine the structural arrangement. The natural soil and soil sample that gave the optimum blend for the BSL compactive effort were prepared and cured for 7 days and 28 days then a section of it was viewed using the scanned electron microscope.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Properties of Materials Used in the Study

4.1.1 Black cotton soil

Preliminary tests conducted on the natural properties of the black cotton soil revealed that the soil has low moisture content of 15.2 %. The index properties are summarized in Table 4.1. The particle size distribution is shown in Fig. 4.1. The soil belongs to the CH group in the Unified Soil Classification System (ASTM, 1992) or A-7-6 (13) soil group of the AASHTO soil classification system (AASHTO, 1986). The soil is greyish black in colour (from wet to dry states) with a liquid limit of 64.5 %, plastic limit of 25 % and plasticity index of 39.5 %.

The soil has a free swell of about 85 %, soaked California bear ratio (CBR) values of 3, 4 and 5 % for British Standard light, West African Standard and British Standard heavy compaction energies, respectively, and unconfined compressive strength (UCS) values of 238.03, 346.98 and 458.37 kN/m^2 for the three energy levels, respectively. The soil was found to be highly plastic and fell below the standard recommendation for most geotechnical construction works especially highway construction in agreement with the findings reported by Butches and Sailie (1984) as well as Osinubi and Medubi (1997a). Detailed test results are given in Tables A4.2 – A4.11 in Appendix A.

Table 4.1: Properties of the natural soil

Property	Quantity
Percentage Passing BS No. 200 sieve	74.7
Natural Moisture Content, %	15.2
Liquid Limit, %	64.5
Plastic Limit, %	25.0
Plasticity Index, %	39.5
Linear Shrinkage, %	27.1
Free Swell, %	85.0
Specific Gravity	2.42
AASHTO Classification	A-7-6 (13)
USCS	CH
Maximum Dry Density, Mg/m^3	
British Standard light	1.38
West African Standard	1.52
British Standard heavy	1.59
Optimum Moisture Content, %	
British Standard light	28.5
West African Standard	18.5
British Standard heavy	16.5
Unconfined Compressive Strength, kN/m^2	
British Standard light	
West African Standard	238.03
British Standard heavy	346.98
California Bearing Ratio (Soaked), %	458.37
British Standard light	
West African Standard	3
British Standard heavy	4
Colour	5
Dominant clay mineral	Greyish black
	Montmorillonite

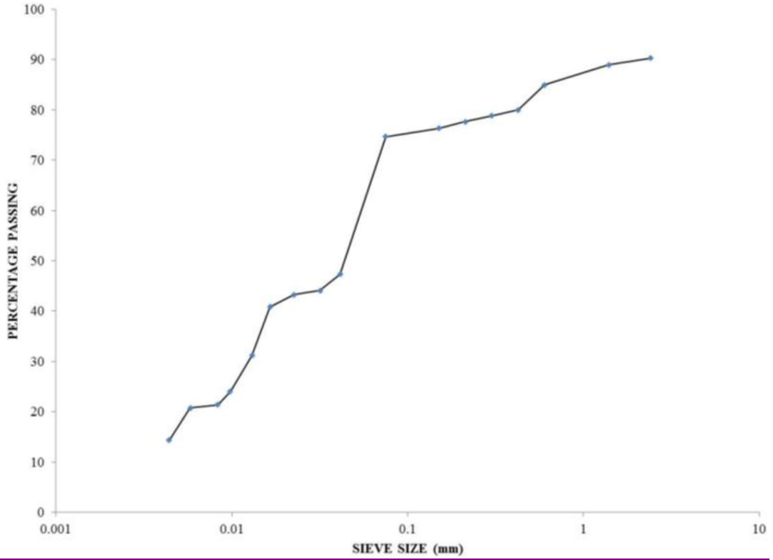

Fig. 4.1: Particle size distribution curve for the natural soil

4.1.2 Iron ore tailing

The specific gravity of the iron ore tailing (IOT) was found to be 3.76. The high content of silicon and iron oxides in IOT provided the required improvement in the stabilization process. Table 4.3 shows the summary of the oxide composition of IOT

Table 4.2: Oxide composition of iron ore tailing

Oxide	**Concentration (%)**
CaO	0.607
SiO_2	45.64
Fe_2O_3	47.70
Al_2O_3	3.36
MnO	0.067
TiO_2	0.240
K_2O	0.607
P_bO	0.415
Na_2O	0.405
MgO	0.393
LOI	3.0

4.1.3 Cation exchange capacity

The primary factor that determines cation exchange capacity (CEC) is the clay and organic matter of the soil (Hamza, 2008).The variation of cation exchange capacity of black cotton soil with iron ore tailing (IOT) content is shown in Fig. 4.2. Cation exchange capacity increased from 0 to 10% IOT content and then reduced with higher IOT content up to 16%. The peak value of 42.2 Cmol/kg at 10% IOT might be considered as optimum for the black cotton soil – iron ore tailing mixture.

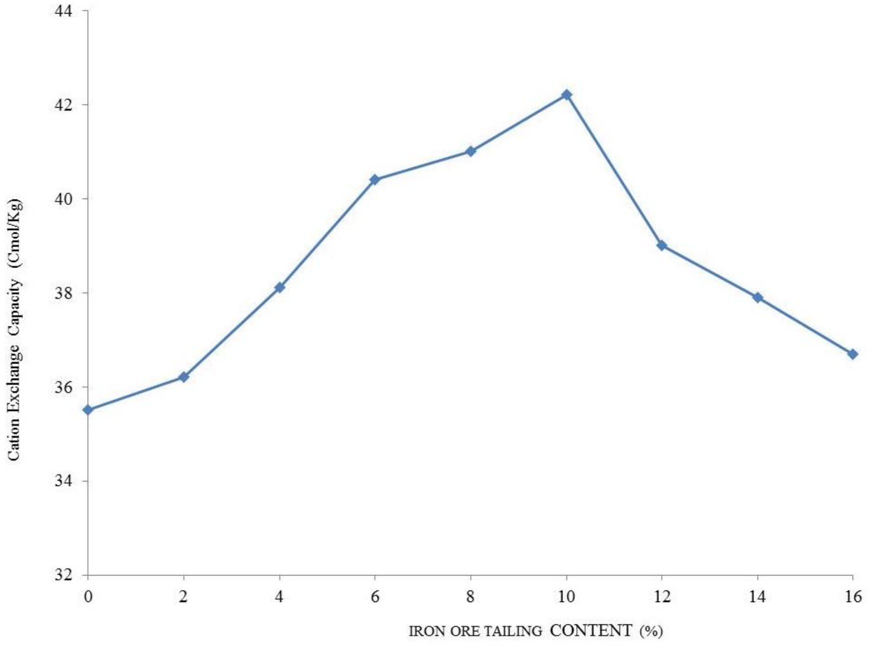

Fig. 4.2: Variation of cation exchange capacity of black cotton soil with iron ore tailing content

The increase in CEC of the black cotton soil was probably due to the increased pH of the soil by the IOT that has a little calcium hydroxide content which supplied free Ca^{2+}

required for the cation exchange between the clay mineral particles and additive. The detailed results are given in Table A4.6 of Appendix A.

An analysis of variance (ANOVA) test on the CEC result shows that the effect of IOT on black cotton soil was statistically significant ($F_{CAL} = 238.52 > F_{CRIT} = 4.49$) . The detailed test results are given in Table B4.1 of Appendix B.

4.2 Sieve Analysis

4.2.2 Wet sieving

The particle size distribution from hydrometer test for the natural and treated black cotton soil samples are shown in Fig. 4.3. A reduction in the percentage of fines with increasing IOT content can be noticed. It was observed that there was a slight reduction in the silt fraction of the soil from 14.33 % for the natural soil to 0 % at 16 % IOT content. This reduction may not be unconnected with the agglomeration and flocculation of the clay particles and a result of ion exchange at the surface of the clay particles; as the excess Ca^{2+} in IOT reacted with the lower valence metallic ions in the clay structure. Detailed test results are given in Table A4.4(a) of Appendix A.

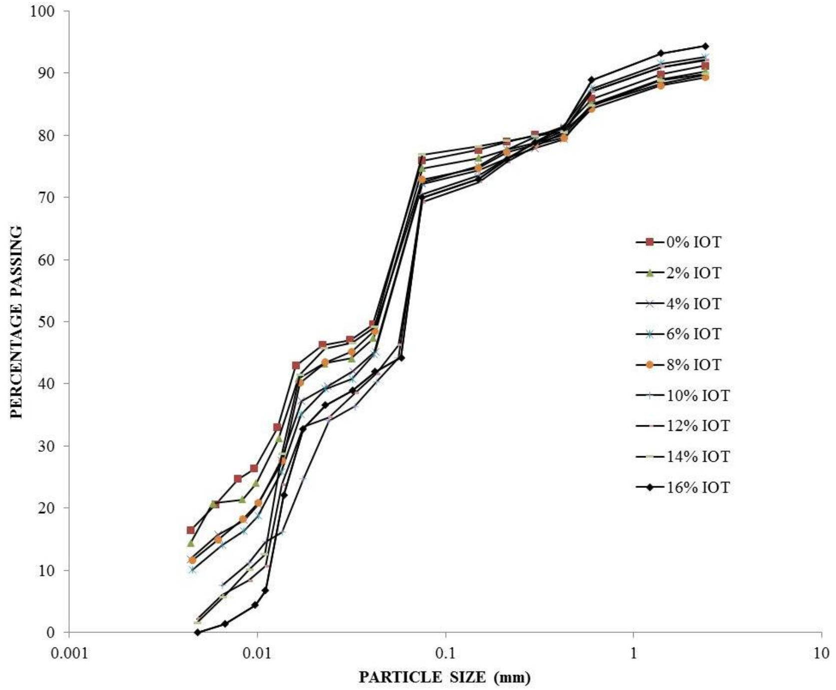

Fig. 4.3: Particle size distribution curves for black cotton soil – iron ore tailing mixtures(Wet sieving)

4.2.3 Dry Sieving

4.2.3.1 Using optimum moisture content from British Standard light compaction

The particle size distribution of the modified soil using optimum moisture content from BSL compaction is shown in Fig. 4.4. A reduction in the percentage of fines with increasing IOT content was noticed.

The reduction in clay content was due to the hydration of IOT which acted as a nucleus to which soil particles adhered. With increase in IOT content the quantity of free silt and clay progressively reduced and coarser materials were formed in agreement with Kedzi (1979), Osinubi (1995) and Sani (2012). Detailed test results are given in Table A4.4 (b) of Appendix A.

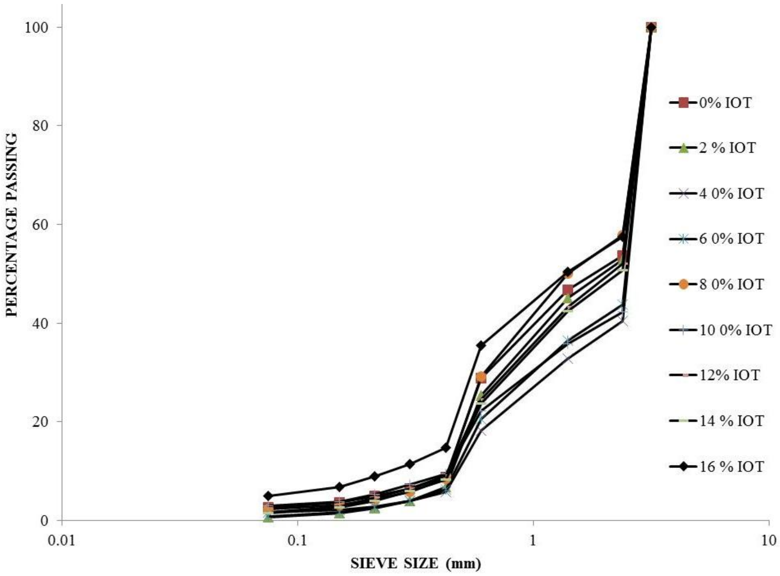

Fig. 4.4: Particle size distribution curves for black cotton soil – iron ore tailing mixtures (BSL compaction)

4.2.3.2Using optimum moisture content from West African Standard compaction

The particle size distribution of the modified soil using optimum moisture content from WAS compaction is shown in Fig. 4.4. A reduction in the percentage of fines with increasing IOT content was noticed.

The reduction in clay content was due to the hydration of IOT which acted as a nucleus to which soil particles adhered. With increase in IOT content the quantity of free silt and clay progressively reduced and coarser materials were formed in agreement with Kedzi (1979), Osinubi (1995) and Sani (2012). Detailed test results are given in Table A4.4 (b) of Appendix A.

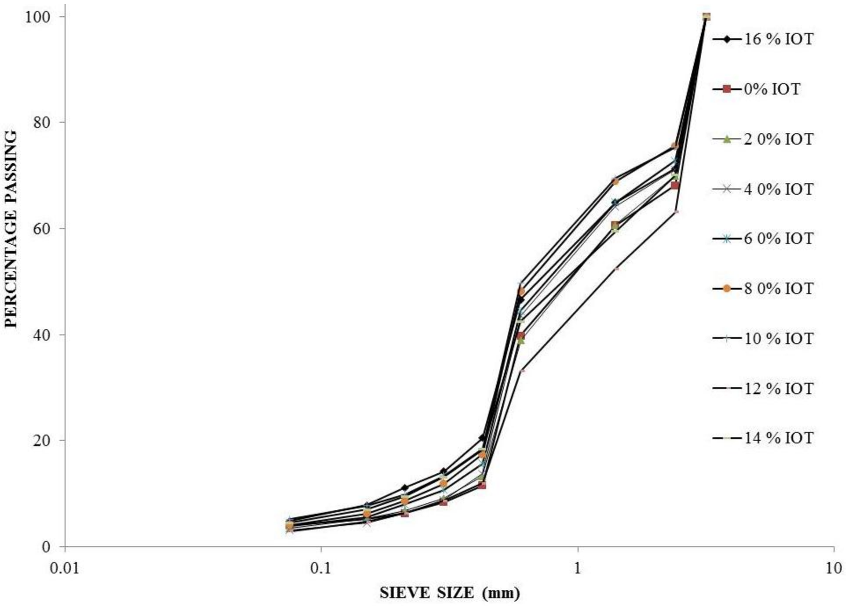

Fig. 4.5: Particle size distribution curves for black cotton soil – iron ore tailing mixtures (WAS compaction)

4.2.3.3 Using optimum moisture content from British Standard heavy compaction

The particle size distribution for BSH compaction are shown in Fig. 4.6. There was a reduction in the percentage of fines with increased in IOT content as shown on the curves. A little change is noticed in the coarser sizes. The IOT content caused the soil - IOT mixture to flocculate and agglomerate more and hence the mixture got coarser enabling the clay particle to form pseudo silt sizes. The results are consistent with the findings reported by Osula (1991), Obeahon (1993) and Oyelakin (2011). Detailed test results are given in Table A4.4 (d) of Appendix A.

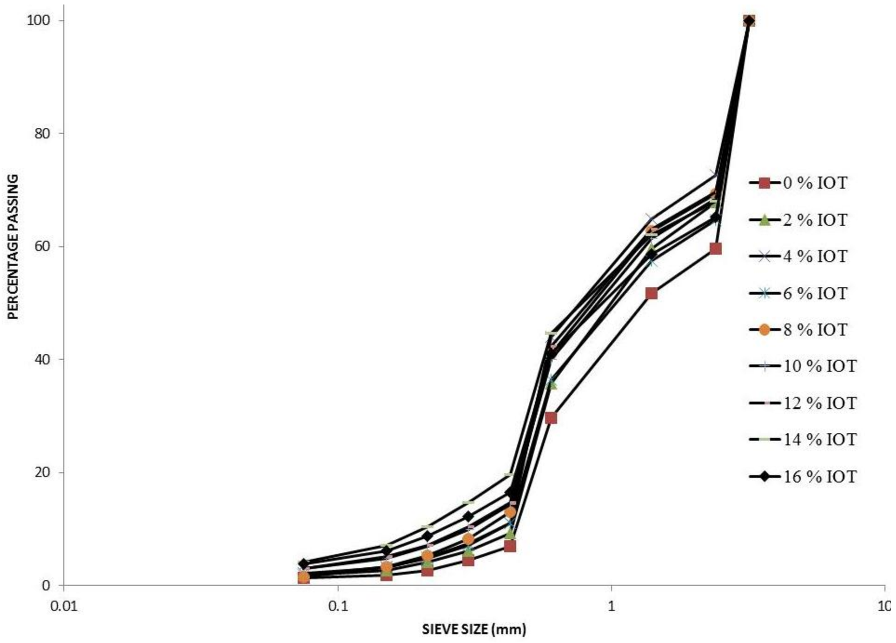

Fig. 4.6: Particle size distribution curves for black cotton soil – iron ore tailing mixtures (BSH compaction)

4.3 Atterberg Limits

4.3.1 Liquid limit

The variation of liquid limit (LL) of the black cotton soil with iron ore tailing content is shown in Fig.4.7. An initial increase in liquid limit with addition of IOT was observed. The liquid limit increased from 64.5 % for the natural black cotton soil to 71 % at 2% IOT content and thereafter steadily decreased to 59.9 % at 16% IOT content. The initial increase in the liquid limit value could be due to pozzolanic substances in the IOT that required more amount of water for hydration to go to completion while the reduction might be the result of agglomeration and flocculation of the clay particles. Detailed test results are given in Table A4.5 of Appendix A.

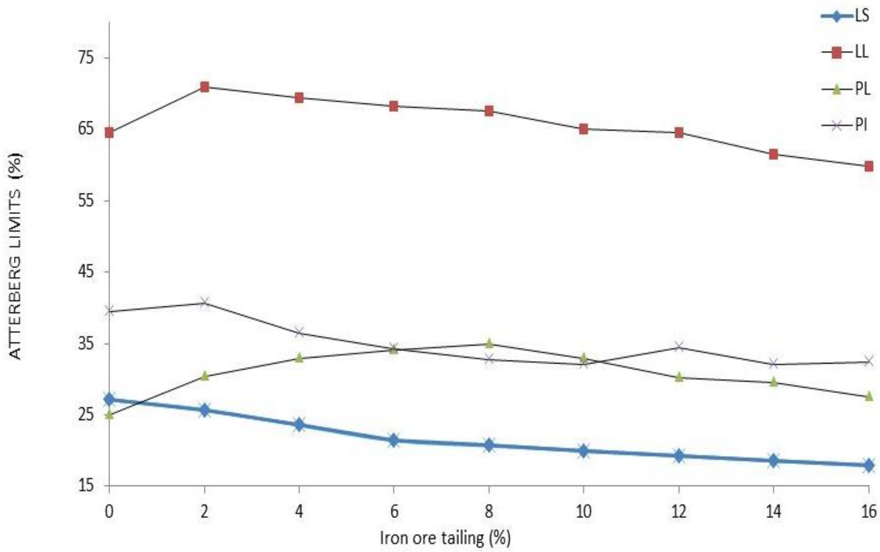

Fig. 4.7: Variation of Atterberg limits of black cotton soil with iron ore tailing content

The analysis of variance (ANOVA) test results (see Table 4.3) shows that the effect of the IOT on the liquid limit of black cotton soil was statistically significant (F_{CAL} = 693.0489> F_{CRIT} = 4.49). Detailed test results are given in Table B4.2 (a) of Appendix B.

Table 4.3 : Results of one - way analysis of variance for Atterberg limits of black cotton soil - iron ore tailing mixtures

Property	**Source of variation**	**Degree of freedom**	**F_{caL}**	**P_{-value}**	**F_{crit}**	**Remark**
Liquid	IOT	1	693.05	1.33E-14	4.49	F_{CAL}> F_{CRIT},

Limit						Significant effect
Plastic Limit	IOT	1	117.53	8.83E-09	4.49	$F_{CAL} > F_{CRIT}$, Significant effect
Plasticity Index	IOT	1	165.37	7.5E-10	4.49	$F_{CAL} > F_{CRIT}$, Significant effect
Linear Shrinkage	IOT	1	41.33	8.33E-06	4.49	$F_{CAL} > F_{CRIT}$, Significant effect

4.3.2 Plastic limit

The variation of the plastic limit of black cotton soil with iron ore tailing content is shown in Fig. 4.7. Plastic limit increased from a value of 25 % for the natural black cotton soil to a peak value of 34.9 % at 8% IOT content. Thereafter, it reduced with higher IOT content to 27.5 % at 16 % IOT content. This trend is in conformity with the findings reported by Alhassan (2006) and Mustapha (2006). Detailed test results are given in Table A4.5 of Appendix A.

The analysis of variance (ANOVA) test results (see Table 4.3) shows that the effect of IOT on the plastic limit of the treated black cotton soil was statistically significant ($F_{CAL} = 117.43 > F_{CRIT} = 4.49$) Detailed test results are given in Table B4.2(b) of Appendix B.

4.3.3 Plasticity index

The variation of the plasticity index of black cotton soil with iron ore tailing content is shown in Fig. 4.7. There was an initial slight increase in the plasticity index value from 39.5 % for the natural soil to 40.59 % at 2 % IOT content. Thereafter, the value decreased to 42.4 % at 16 % IOT content. Detailed test results are given in Table A4.5 of Appendix A.

The one-way analysis of variance (ANOVA) test results (see Table 4.3) shows that the effect of IOT on the plasticity index of the treated black cotton soil was statistically significant ($F_{CAL} = 165.36 > F_{CRIT} = 4.49$). Detailed test results are given in Table A4.2 (c) of Appendix B.

4.3.4 Linear shrinkage

The variation of the linear shrinkage of black cotton soil with iron ore tailing content is shown in Fig. 4.7. Generally, the linear shrinkage of black cotton soil reduced with higher IOT treatments from 27.14 % for the natural soil to 16.2 % at 16 % IOT content. This trend is in conformity with the findings reported by Ola (1991), Osinubi (1995, 1999) and Azige (2012). Detailed test results are given in Table A4.5 of Appendix A.

The analysis of variance (ANOVA) test results (see Table 4.3) shows that the effect of IOT on the linear shrinkage of black cotton soil was statistically significant ($F_{CAL} = 41.32 > F_{CRIT} = 4.49$). Detailed test results are given in Table A4.2(d) of Appendix B.

4.4 Compaction Characteristics

4.4.1 Maximum dry density

The variation of the maximum dry density (MDD) of black cotton soil with iron ore tailing content for the three compactive efforts is shown in Fig. 4.8. The MDD values increased with higher iron ore tailing content and compactive effort.

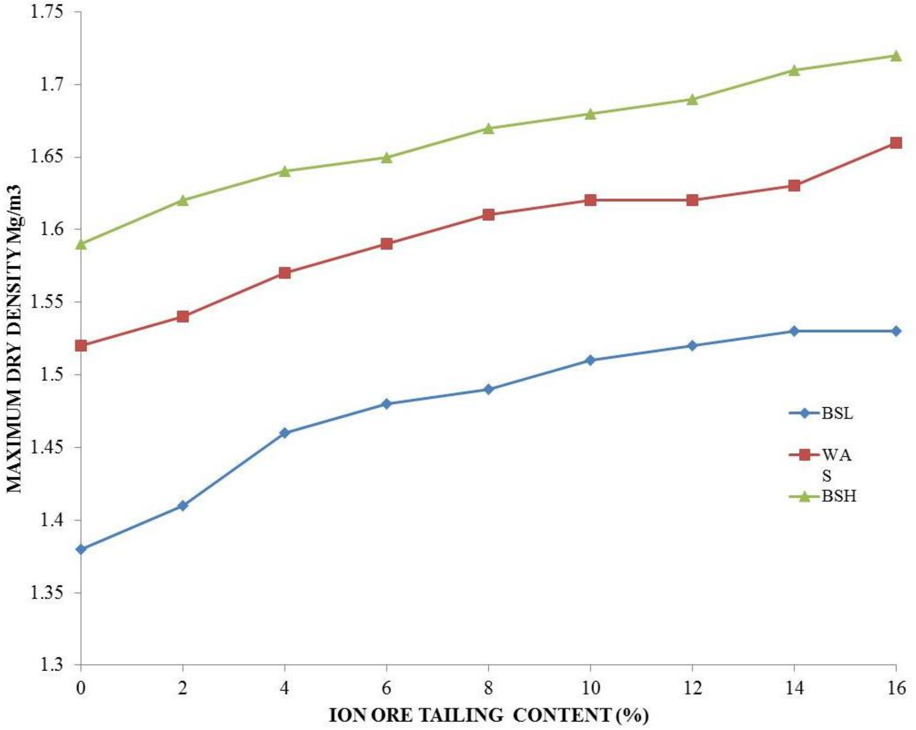

Fig. 4.8: Variation of maximum dry density of black cotton soil with iron ore tailing content

Maximum dry density values increased from 1.38, 1.52 and 1.59 Mg/m^3 for the natural black cotton soil compacted with BSL, WAS and BSH energies, respectively, to 1.53, 1.66 and 1.72 Mg/m^3, respectively, at 16 % IOT content. The increase in MDD for the BSL, WAS and BSH compactive efforts is in conformity with the trend of increasing MDD/decreasing OMC. This is as a result of IOT occupying the void within the soil matrix in addition to the flocculation and agglomeration of the clay particle due to exchange of ions (Osinubi, 2000 a; Moses, 2008; Oriola and Moses, 2010). Detailed test results are given in Table A4.7 of Appendix A.

Results of one way analysis of variance for compaction characteristics of black cotton soil – iron ore tailing mixtures are summarised in Table 4.4. The results shows that the effect of IOT on the maximum dry density was statistically significant for BSL ($F_{CAL} = 12.75 > F_{CRIT} = 4.49$), WAS (($F_{CAL} = 12.30 > F_{CRIT} = 4.49$) and BSH ($F_{CAL} = 12.04 > F_{CRIT} = 4.49$) compactions. Detailed test results are given in Table B4.3a - c of Appendix B.

Results of two-way analysis of variance (ANOVA) for compaction characteristics of iron ore tailing-compactive effort are summarised in Table 4.5. The results show that the effect of the iron ore tailing and compactive effort on the maximum dry density was statistically significant ($F_{CAL} = 74.85 > F_{CRIT} = 2.59$) for IOT and ($F_{CAL} = 900.04 > F_{CRIT} = 3.63$). The effect of compactive effort was more significant than that of iron ore tailing. Detailed test results are given in table B4.8 of Appendix B.

Table 4.4: Results of one-way analysis of variance for compaction characteristics of black cotton soil - iron ore tailing mixtures

Property		**Source of variation**	**Degree of freedom**	**$F_{calulated}$**	**P_{-value}**	**$F_{critical}$**	**Remark**
BSL	MDD	IOT	1	12.76	0.0025	4.49	$F_{CAL} > F_{CRIT}$, Significant effect
	OMC	IOT	1	69.60	3.21E-07	4.49	$F_{CAL} > F_{CRIT}$, Significant effect
WAS	MDD	IOT	1	12.30	0.0029	4.49	$F_{CAL} > F_{CRIT}$, Significant effect

	OMC	IOT	1	18.11	0.0006	4.49	$F_{CAL} > F_{CRIT}$, Significant effect
BSH	MDD	IOT	1	12.05	0.0032	4.49	$F_{CAL} > F_{CRIT}$, Significant effect
	OMC	IOT	1	8.62	1.23E-09	4.49	$F_{CAL} > F_{CRIT}$, Significant effect

Table 4.5: Results of two-way analysis of variance for compaction characteristics of iron ore tailing - compactive effort

Property	**Source of variation**	**Degree of freedom**	**$F_{calulated}$**	**P_{-value}**	**$F_{critical}$**	**Remark**
MDD	IOT	8	74.85106	3.24E-11	2.591096	$F_{CAL} > F_{CRIT}$, Significant effect
	COMPACTIVE EFFORT	2	900.0426	3.63E-17	3.633723	$F_{CAL} > F_{CRIT}$, Significant effect
OMC	IOT	8	54.73333	3.58E-10	2.591096	$F_{CAL} > F_{CRIT}$, Significant effect
	COMPACTIVE EFFORT	2	1499.893	6.28E-19	3.633723	$F_{CAL} > F_{CRIT}$, Significant effect

4.4.2 Optimum moisture content

The variation of optimum moisture content of black cotton soil with IOT for BSL, WAS and BSH compactive efforts is shown in Fig. 4.9. Optimum moisture content (OMC) values decreased from 28.5, 18.5 and 11.5 % for the natural black cotton soil compacted with BSL, WAS and BSH energies, respectively, to minimum values of 22.0 14.0 and 11.5 % at 16, 14 and 14 % IOT contents, respectively.

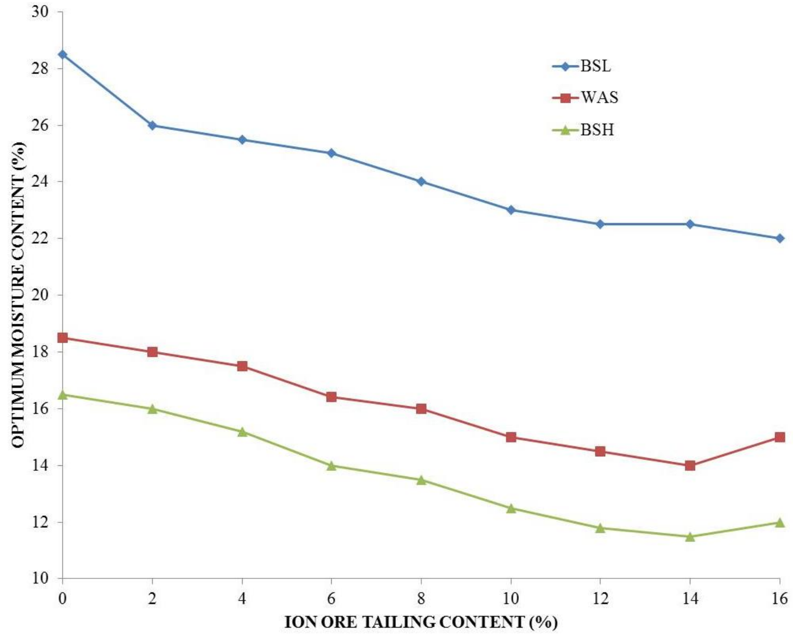

Fig. 4.9: Variation of optimum moisture content of black cotton soil with iron ore tailing content

The decrease in OMC values were probably due to self –desiccation in which all the water was used, resulting in low hydration. When no water movement to or from soil-IOT paste is permitted, the water is used up in the hydration reaction, until too little is left to saturate the solid surfaces and hence the relative humidity within the paste decreases. The process described above might have affected the reaction mechanism of IOT treated black cotton soil (Osinubi and Stephen, 2007, Moses, 2008).

Furthermore, the cause for the reduction in the OMC values can also be explained as follows: the cation exchange between additives and expansive soil decreases the thickness of electric double layer and promotes the flocculation. The flocculation of the solid particles implies that the water-additives–soil mixtures can be compacted with lower water content, and the optimum water content is reduced (Bose, 2012).

The observed decrease of OMC values with higher compactive efforts was because it was easier to breakdown flocculated aggregates, destroy shear planes and eliminate large pores, at higher compactive efforts (Osinubi, 1999). Detailed test results are given in Table A4.9 of Appendix A.

Results of one way analysis of variance for compaction characteristics of black cotton soil – iron ore tailing mixtures given in Table 4.4 show that the effect of IOT on the optimum moisture content of black cotton soil was statistically significant for BSL ($F_{CAL} = 69.59 > F_{CRIT} = 4.49$), WAS ($F_{CAL} = 18.11 > F_{CRIT} = 4.49$) and BSH ($F_{CAL} = 8.61 > F_{CRIT} = 4.49$) Detailed test results are given in Table B4.4 (c) of Appendix B.

Results of two-way analysis of variance (ANOVA) for compaction characteristics of iron ore tailing-compactive effort are summarised in Table 4.5. The results show that the effect of the iron ore tailing and compactive effort on the optimum moisture content was statistically significant ($F_{CAL} = 54.73 > F_{CRIT} = 2.59$) for IOT and ($F_{CAL} = 1499.89 > F_{CRIT} = 3.63$). The effect of compactive effort was more significant than that of iron ore tailing. Detailed test results are given in table B4.9 of Appendix B.

4.5 Strength Characteristics

4.5.1 Unconfined compressive strength

The main test recommended for use for determining required amount of additive to be used in the stabilization of soils is the unconfined compressive strength

(UCS) test (Singh, 1991). It is an important factor in the evaluation of the design criteria for the use of soil as a pavement material (Ola, 1983).

4.5.1.1 7 days curing period

The UCS of specimens compacted at the energy levels of the BSL, WAS and BSH and cured for 7 days are shown in Fig. 4.10. Generally, UCS values increased with higher compactive effort and IOT content.

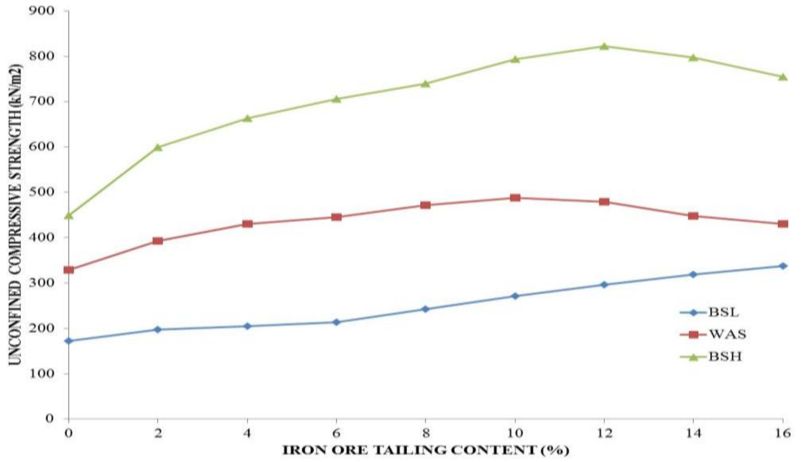

Fig. 4.10 Variation of unconfined compressive strength (7 days curing period) of black cotton soil with iron ore tailing content

For BSL compaction, UCS values increased from 172.59 kN/m^2 for the natural black cotton soil to 337.77 kN/m^2 at 16 % IOT. The compaction carried out using WAS energy showed that UCS value increased from 328.36 kN/m^2 for the natural soil to a peak value of 487.57 kN/m^2 at 10 % IOT content and thereafter reduced to 429.99 kN/m^2 at 16 % IOT treatment. With respect to BSH compaction, UCS values increased from 488.83kN/m^2 for the natural black cotton soil to 821.57kN/m^2 at 12 % IOT content and thereafter reduced to 754.94kN/m^2 at 16 % IOT content. The increase in UCS values could be attributed to ion exchange at the surface of clay particles. The Ca^{2+} in the additives reacted with the lower valence metallic ions in the clay microstructure which resulted in agglomeration and flocculation of the clay particles (Moses and Saminu, 2012). Detailed test results are given in Table A4.9 of Appendix A.

Results of analysis of variance (ANOVA) for strength characteristics of black cotton soil – iron ore tailing mixtures are given in Table 4.6. For BSL, WAS and BSH compactions the results show that the effect of IOT on unconfined compressive strength (7 days curing period) was statistically significant for BSL (F_{CAL} = 154.49.39 > F_{CRIT} = 4.49), WAS (F_{CAL} = 661.26 > F_{CRIT} = 4.49) and BSH (F_{CAL} = 309.15 > F_{CRIT} = 4.49) compactive efforts. Detailed test results are given in Table B4.5 of Appendix B.

Results of two-way analysis of variance (ANOVA) for strength characteristics of iron ore tailing-compactive effort are summarised in Table 4.7. The results show that the effect of the iron ore tailing and compactive effort on the unconfined compressive strength (7 days curing period) was statistically significant (F_{CAL} = 6.48 > F_{CRIT} = 2.59) for IOT and (F_{CAL} = 198.75 > F_{CRIT} = 3.63). The effect of compactive effort was more significant than that of iron ore tailing. Detailed test results are given in table B4.10a of Appendix B.

Table 4.6: Results of analysis of variance for unconfined compressive strength of black cotton soil - iron ore tailing mixtures

Comment [KJO4]: Table should not be broken

Property		**Source of variation**	**Degree of freedom**	**$F_{calulated}$**	**P_{-value}**	**$F_{critical}$**	**Remark**
BSL	7 Days	IOT	1	154.5	1.23E-09	4.49	Significant effect
	14 Days	IOT	1	319.01	5.43E-12	4.49	Significant effect
	28 Days	IOT	1	296.09	9.59E-12	4.49	Significant effect
	7+7 Days	IOT	1	48.97	3E-06	4.49	Significant effect
WAS	7 Days	IOT	1	661.26	6.90E-12	4.49	Significant effect
	14 Days	IOT	1	781.09	5.22E-15	4.49	Significant effect
	28 Days	IOT	1	228.53	6.80E-11	4.49	Significant effect
	7+7 Days	IOT	1	63.28	5.97E-07	4.49	Significant effect
BSH	7 Days	IOT	1	309.15	6.90E-12	4.49	Significant effect
	14 Days	IOT	1	264	9.59E-12	4.49	Significant effect
	28 Days	IOT	1	307.23	7.24E-12	4.49	Significant effect
	7+7 Days	IOT	1	171.08	5.84E-10	4.49	Significant effect

7, 14 and 28 days - Curing periods
7 + 7 days – 7 days cured + 7 days soaked

Table 4.7: Results of Two-way analysis of variance for unconfined compressive strength of iron ore tailing - compactive effort

Comment [KJO5]: Table should not be broken

Property	**Source of variation**	**Degree of freedom**	**$F_{calulated}$**	**P_{-value}**	**$F_{critical}$**	**Remark**
UCS 7	IOT	8	6.484655	0.000779	2.591096	$F_{CAL} \geq F_{CRIT}$,

DAYS						Significant effect
	COMPACTIVE EFFORT	2	198.7564	5.02E-12	3.633723	$F_{CAL} \geq F_{CRIT}$, Significant effect
UCS 14 DAYS	IOT	8	9.585109	7.91E-05	2.591096	$F_{CAL} \geq F_{CRIT}$, Significant effect
	COMPACTIVE EFFORT	2	125.6755	1.65E-10	3.633723	$F_{CAL} \geq F_{CRIT}$, Significant effect
UCS 28 DAYS	IOT	8	19.62054	6.84E-07	2.591096	$F_{CAL} \geq F_{CRIT}$, Significant effect
	COMPACTIVE EFFORT	21	201.0831	4.59E-12	3.633723	$F_{CAL} \geq F_{CRIT}$, Significant effect
UCS 7 + 7 DAYS	IOT	8	41.33723	2.99E-09	2.591096	$F_{CAL} \geq F_{CRIT}$, Significant effect
	COMPACTIVE EFFORT	2	56.21174	5.81E-08	3.633723	$F_{CAL} \geq F_{CRIT}$, Significant effect

4.5.1.2 14 days curing period

The UCS of specimens compacted at the energy levels of the BSL, WAS and BSH and cured for 14 days are shown in Fig. 4.11.The UCS values increased with higher IOT content and compactive effort.

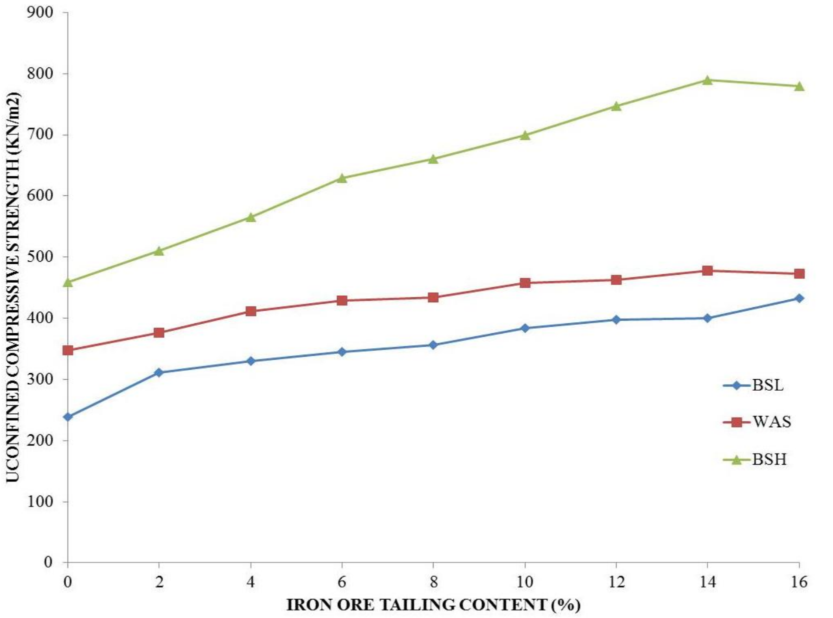

Fig. 4.11: Variation of unconfined compressive strength (14 days curing period) of black cotton soil with iron ore tailing content

For BSL compaction the UCS values increased from 238.03 kN/m^2 for natural black cotton soil to 432.16 kN/m^2 at 16 % IOT. The compaction carried out using WAS and BSH energies showed that UCS increased from 346.98 and 458.37 kN/m^2 for natural soil to peak values of 478.1 and 789.23 kN/m^2 , respectively, at 14 % IOT content. Detailed test results are given in Table A4.9(a) of Appendix A.

This increase in compressive strength with curing period can be attributed to time dependent strength gain of the pozzolanas.

Results of analysis of variance (ANOVA) for strength characteristics of black cotton soil – iron ore tailing mixtures are given in Table 4.6. For BSL, WAS and BSH compactions the results show that the effect of IOT on the unconfined compressive strength (14 days curing period) was statistically significant for BSL (F_{CAL} = 319.01 > F_{CRIT} = 4.49, WAS (F_{CAL} =781.09 > F_{CRIT} = 4.49, BSH (F_{CAL} = 263.99 > F_{CRIT} = 4.49). Detailed test results are given in Table A4.5 (d, e and f) of the Appendix.

Results of two-way analysis of variance (ANOVA) for strength characteristics of iron ore tailing-compactive effort are summarised in Table 4.7. The results show that the effect of the iron ore tailing and compactive effort on the unconfined compressive strength (14 days curing period) was statistically significant (F_{CAL} = 9.58 > F_{CRIT} = 2.59) for IOT and (F_{CAL} = 125.67 > F_{CRIT} = 3.63). The effect of compactive effort was more significant than that of iron ore tailing. Detailed test results are given in table B4.10b of Appendix B.

4.5.1.3 28 days curing period

The UCS of specimens compacted at the energy levels of the BSL, WAS and BSH and cured for 28 days are shown in Fig. 4.12. Generally, UCS values increased with higher compactive effort and IOT content.

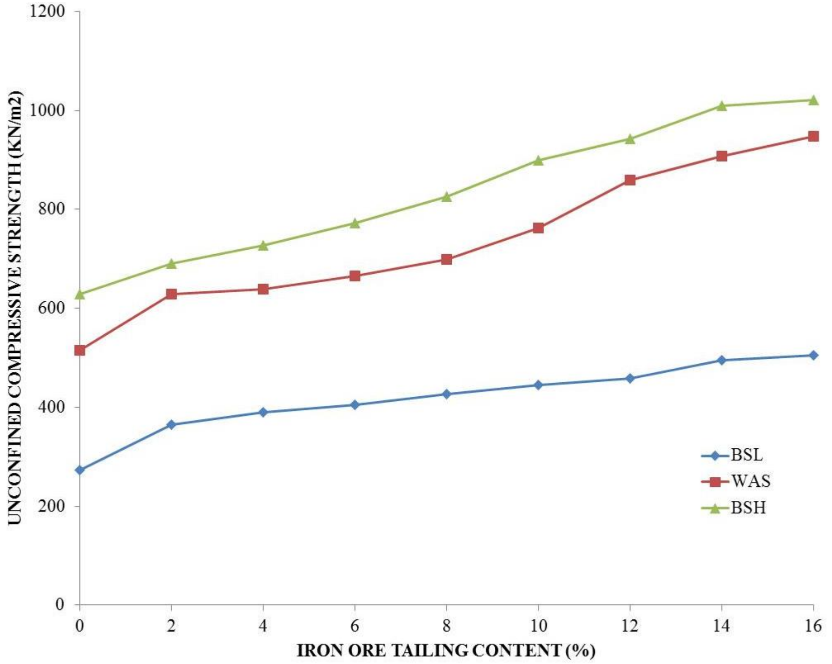

Fig. 4.12: Variation of unconfined compressive strength (28 days curing period) of black cotton soil with iron ore tailing content

For BSL, WAS and BSH compaction, UCS values for 28 days curing period increased from 273.24, 514.45 and 627.81kN/m^2 for the natural black cotton soil to 504.91, 1009.31, 947.68 and 1009.31kN/m^2 respectively at 16 % IOT content.

The increase in strength could be due to the presence of iron oxide (goethite) which dehydrates with time to yield higher strength in agreement with Nixon and Skipp, (1957), Little (1967) and Osinubi (2001a). The trend of increased compressive strength with curing period can also be attributed to time dependent strength gain action of the pozzolanas (Osinubi and Moses, 2013). Detailed test results are given in Table A4.9(c) of the appendix A.

Results of analysis of variance (ANOVA) for strength characteristics of black cotton soil – iron ore tailing mixtures are given in Table 4.6. For BSL, WAS and BSH compactions the results show that the effect of IOT on the unconfined compressive strength (28 days curing period) was statistically significant for BSL ($F_{CAL} = 296.09 > F_{CRIT} = 4.49$), WAS ($F_{CAL} = 228.52 > F_{CRIT} = 4.49$), BSH ($F_{CAL} = 307.22 > F_{CRIT} = 4.49$). Detailed test results are given in Table B4 .5 (g, h and i) of Appendix B.

Results of two-way analysis of variance (ANOVA) for strength characteristics of iron ore tailing-compactive effort are summarised in Table 4.7. The results show that the effect of the iron ore tailing and compactive effort on the unconfined compressive strength (28 days curing period) was statistically significant ($F_{CAL} = 19.62 > F_{CRIT} = 2.59$) for IOT and ($F_{CAL} = 201.08 > F_{CRIT} = 3.63$). The effect of compactive effort was more significant than that of iron ore tailing. Detailed test results are given in table B4.10c of Appendix B.

4.5.1.47 days curing and 7 days soaking periods

The UCS of specimens compacted at the energy levels of the BSL, WAS and BSH and cured for 7 days curing and 7 days soaking periods are shown in Fig 4.13. UCS values increased with higher compactive effort and IOT content.

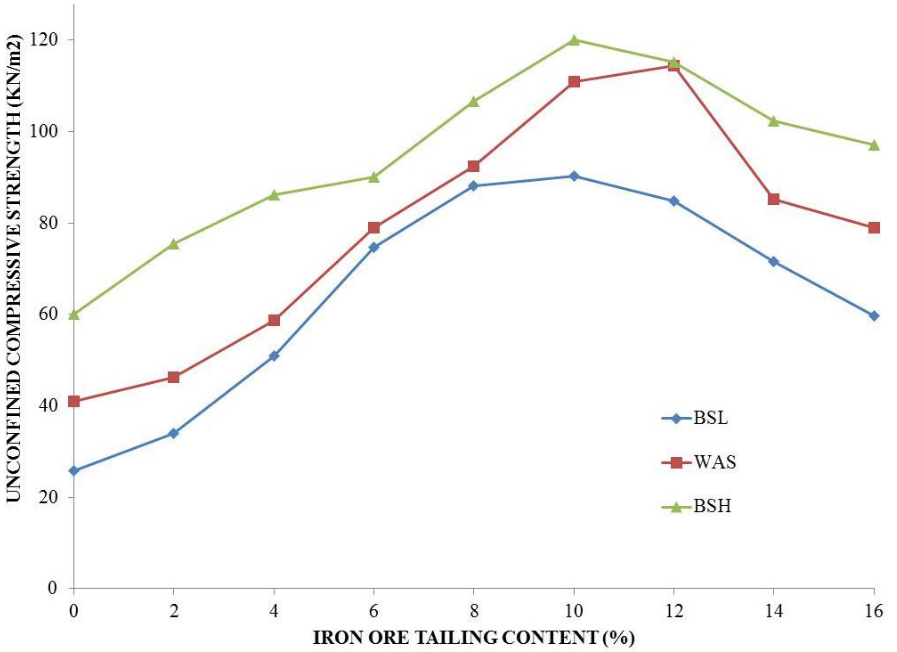

Fig. 4.13: Variation of unconfined compressive strength (7 days curing + 7 days soaking) of black cotton soil with iron ore tailing content

UCS values for specimens compacted at the energies of the BSL, WAS and BSH, increased from 25.72, 41.08 and 60.02 kN/m^2 for the natural black cotton soil to peak values of 90.37, 115.14 and 120.03 kN/m^2 at 10, 12 and 10 % IOT respectively and then reduced to minimum values of 59.70, 78.90 and 97.05 kN/m^2 at 16 % IOT treatment. It is pertinent to note here that the UCS values for the soaked specimens are too low compared to those obtained for 7 and 14 days curing periods; which is probably due to the ingress of water that resulted in loss of strengths. Detailed test results are given in Table A4.9(d) of Appendix A.

Results of analysis of variance (ANOVA) for strength characteristics of black cotton soil – iron ore tailing mixtures are given in Table 4.6. For BSL, WAS and BSH compactions the results show that the effect of IOT on the unconfined compressive strength (7 days curing + 7 days soaking periods) was statistically significant for BSL ($F_{CAL} = 48.96 > F_{CRIT} = 4.49$), WAS ($F_{CAL} = 63.27 > F_{CRIT} = 4.49$) and BSH ($F_{CAL} = 171.08 > F_{CRIT} = 4.49$). Detailed test results are given in Table B4.5 (j, k and l) of Appendix B.

Results of two-way analysis of variance (ANOVA) for strength characteristics of iron ore tailing-compactive effort are summarised in Table 4.7. The results show that the effect of the iron ore tailing and compactive effort on the unconfined compressive strength (7 days curing and 7 days soaking periods) was statistically significant ($F_{CAL} = 41.33 > F_{CRIT} = 2.59$) for IOT and ($F_{CAL} = 56.21 > F_{CRIT} = 3.63$). The effect of compactive effort was more significant than that of iron ore tailing. Detailed test results are given in table B4.10d of Appendix B.

4.6 California Bearing Ratio

California bearing ratio (CBR) is an important parameter that indicates the strength and bearing ability of a soil, which will assist the designer in recommending or rejecting the soil as suitable for base or sub-base for a flexible road pavement.

4.6.1 Unsoaked California bearing ratio

The variation of California bearing ratio (unsoaked condition) with iron ore tailing content for specimens compacted at the energy levels of the BSL, WAS and BSH is shown in Fig. 4.14. For BSL, WAS and BSH compactions, unsoaked CBR values increased from 8, 10 and 15 % for the natural black cotton soil to peak values of 29, 20 and 17 % were recorded at 12, 14 and 12 % IOT content, respectively.

Detailed test results are given in Table A4.10(a) of Appendix A.

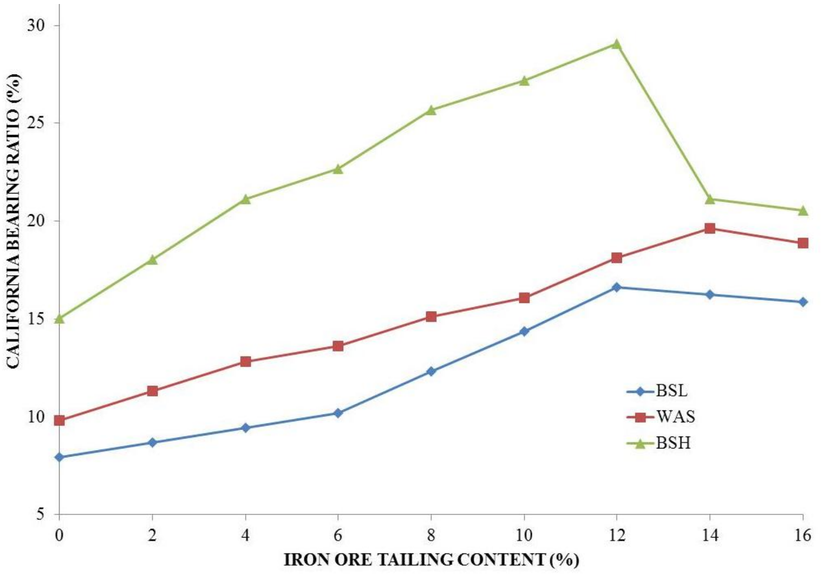

Fig. 4.14: Variation of California bearing ratio (unsoaked condition) with iron ore tailing content

The Nigerian General Specifications (1997) recommends that a CBR value of 180 % should be attained in the laboratory for cement stabilization. However, an unsoaked CBR value of 80 % is required for bases and soaked value of 30 % for sub-bases both when compacted at optimum moisture content and at 100 % West African Standard compaction (Gidigasu and Dogbey, 1980; Gidigasu, 1982; Osinubi, 2001a). The CBR values recorded for the IOT stabilized soil at the three compactive efforts are lower than those prescribed by Nigerian General Specifications (1997). It implies that IOT cannot be used as a ‘stand alone’ additive.

Results of analysis of variance (ANOVA) for unsoaked CBR of black cotton soil – iron ore tailing mixtures are given in Table 4.8. For WAS and BSH compactions the results show that the effect of IOT on the unsoaked CBR was statistically significant for WAS ($F_{CAL} = 10.69 > F_{CRIT} = 4.49$) and BSH ($F_{CAL} = 36.88 > F_{CRIT} = 4.49$). Detailed test results are given in Table B4.6(a, b andc) of Appendix B.

Results of two-way analysis of variance (ANOVA) for California bearing ratio of iron ore tailing-compactive effort are summarised in Table 4.9. The results show that the effect of the iron ore tailing and compactive effort on the unsoaked CBR was statistically significant ($F_{CAL} = 7.75 > F_{CRIT} = 2.59$) for IOT and ($F_{CAL} = 52.67 > F_{CRIT} = 3.63$). The effect of compactive effort was more significant than that of iron ore tailing. Detailed test results are given in table B4.11 of Appendix B.

Table 4.8: Results of one-way analysis of variance for California bearing ratio of black cotton soil-iron ore tailing mixtures

Property		**Source of Variation**	**Degree of Freedom**	**F_{CAL}**	**P-value**	**F_{CRIT}**	**Remark**
BSL	Unsoaked	IOT	1	4.16	0.0582	4.49	No Significant effect
	Soaked	IOT	1	4.10	0.0598	4.49	No Significant effect
WAS	Unsoaked	IOT	1	10.70	0.0048	4.49	Significant effect
	Soaked	IOT	1	0.79	0.3863	4.49	No Significant effect
BSH	Unsoaked	IOT	1	36.88	1.61E-05	4.49	Significant effect
	Soaked	IOT	1	0.17	0.6857	4.49	No Significant effect

Table 4.9: Results of two - way analysis of variance for California bearing ratio of iron ore tailing - compactive effort

Property	**Source of variation**	**Degree of freedom**	**$F_{calulated}$**	**P_{-value}**	**$F_{critical}$**	**Remark**
UNSOAKED CBR	IOT	8	7.74834	0.000284	2.591096	$F_{CAL} \geq F_{CRIT}$, Significant effect

	COMPACTIVE EFFORT	2	52.6748	9.13E-08	3.633723	FCAL> FCRIT, Significant effect
SOAKED CBR	IOT	8	9.516362	8.27E-05	2.591096	FCAL> FCRIT, Significant effect
	COMPACTIVE EFFORT	2	65.63648	1.94E-08	3.633723	FCAL> FCRIT, Significant effect

4.6.2 Soaked California bearing ratio

The variation of California bearing ratio (24 hours soaking period) with iron ore tailing content for specimens compacted at the energy levels of the BSL, WAS and BSH is shown in Fig. 4.15. It was observed that with higher IOT content and

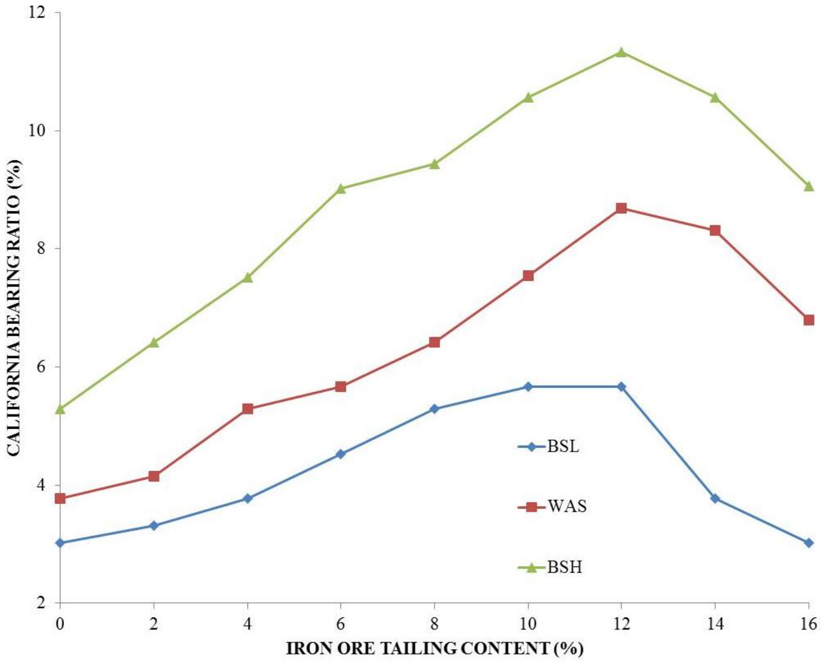

Fig. 4.15: Variation of California bearing ratio (24 hours soaking period) with iron ore tailing content

compactive effort, CBR values increased to peak values of 6, 9 and 11 % for BSL, WAS and BSH compaction respectively at 12 % IOT content. The recorded soaked CBR values did not meet the 30 % requirement for sub-bases both when compacted at optimum moisture content and at 100 % West African Standard compaction. Detailed test results are given in Table A4.10(b) of Appendix A.

Results of analysis of variance (ANOVA) for CBR (soaked for 24 hours) of black cotton soil – iron ore tailing mixtures are given in Table 4.8. For BSL, WAS and BSH compactions the results show that the effect of IOT on the soaked CBR was not statistically significant for BSL ($F_{CAL} = 4.10 < F_{CRIT} = 4.49$), WAS ($F_{CAL} = 0.79 < F_{CRIT} = 4.49$) and BSH ($F_{CAL} = 0.16 < F_{CRIT} = 4.49$). Detailed test results are given in Table B4.6(d, e and f) of Appendix B.

Results of two-way analysis of variance (ANOVA) for California bearing ratio of iron ore tailing-compactive effort are summarised in Table 4.9. The results show that the effect of the iron ore tailing and compactive effort on the soaked CBR was statistically significant ($F_{CAL} = 9.51 > F_{CRIT} = 2.59$) for IOT and ($F_{CAL} = 65.63 > F_{CRIT} = 3.63$). The effect of compactive effort was more significant than that of iron ore tailing. Detailed test results are given in table B4.12 of Appendix B.

4.7 Microanalysis

Microstructure of specimens before and after treatment with optimal concentration of IOT were observed on the Scanning Electron Microscope (SEM). The objectives were to obtain a SEM micrograph to investigate the bond formation, the surface texture, the mineral structure and geometry of the element due to the curing and iron ore tailing-soil interaction (Saravut et al., 2012).

4.7.1 7 days curing period micrographs for British Standard light compaction

The micrographs of UCS specimens of the natural soil and 10 % IOT treated black cotton soil cured for 7 days are shown on Plates 4.1 and 4.2, respectively.

Comment [KJO6]: It is better to place the plates beside each other for comparative purpose.

The micrograph of the natural soil after 7 days curing shows that the soil was cohesive because almost no significant reaction might have occurred during the curing period.

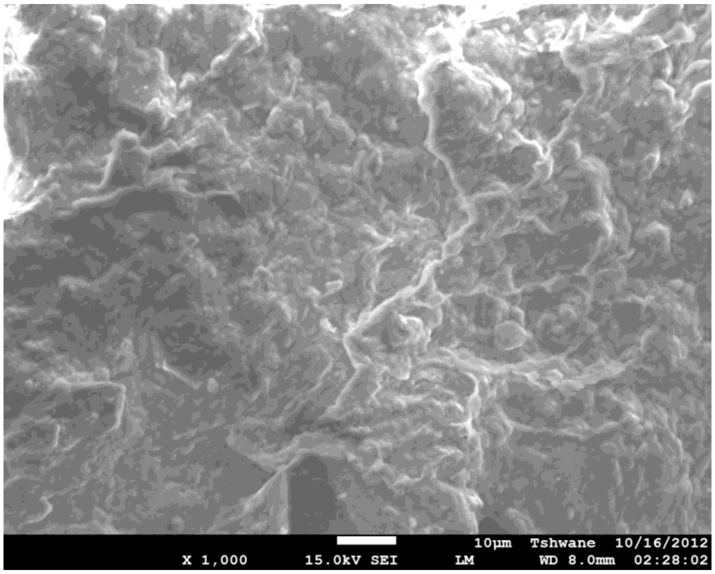

Plate 4.1: Micrograph of natural black cotton soil (7 days curing)

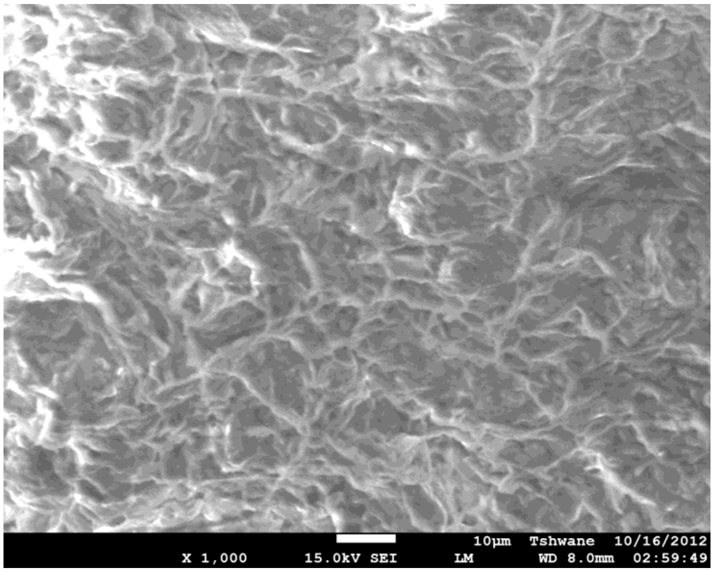

Plate 4.2: Micrograph of black cotton soil - 10 % iron ore tailing mixture

(7 days curing)

As IOT was added to the soil there was a slight reduction in the cohesiveness of the soil due to the cation exchange reaction which forced the weakly bonded ions in the clay structure to be substituted by the more active and higher valent cations and this led to the flocculation and liberation of water bonded at the outer layers (Asma and Dariusz, 2013).

4.7.2 28 days curing period micrographs for British Standard light compaction

The micrographs of UCS specimens of the natural and 10 % IOT treated black cotton soil cured for 28 days are shown on Plates 4.3 and 4.4, respectively. The micrograph of UCS specimens of the natural soil cured for 28 days is not significantly different from that of specimen cured for 7 days although their structural particle arrangements appear to be different. This could be attributed to lesser inter-surface activity that might have taken place during curing.

Comment [KJO7]: It is better to place the plates beside each other for comparative purpose.

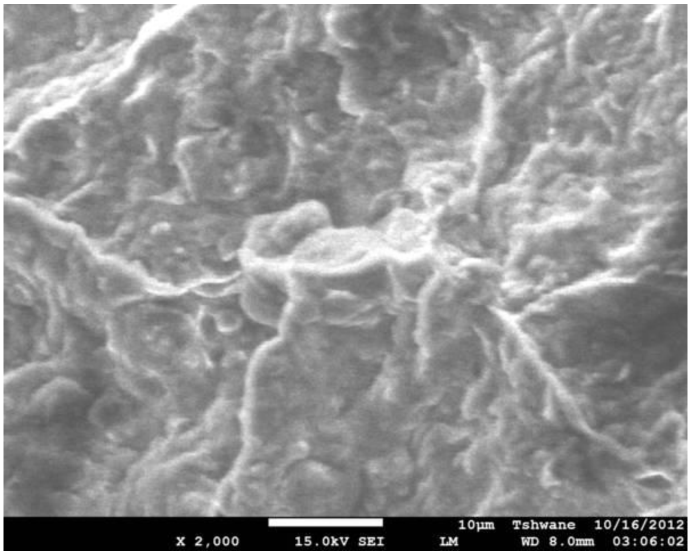

Plate 4.3: Micrograph of natural black cotton soil (28 days curing)

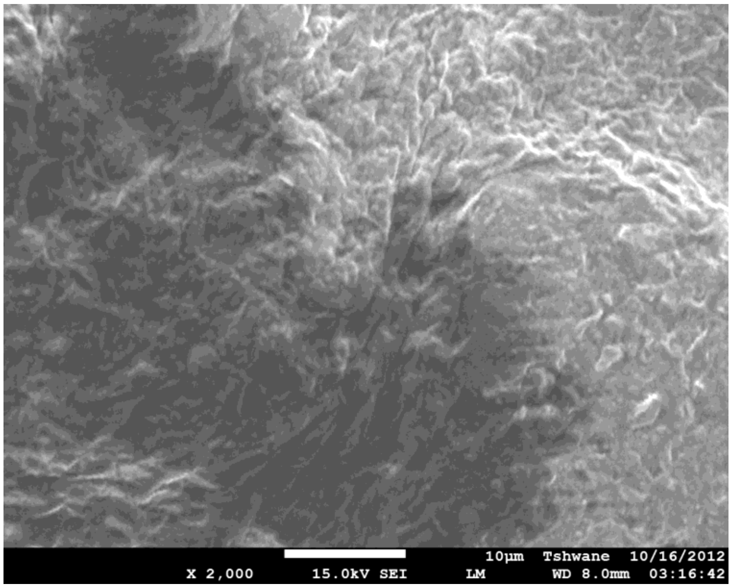

Plate 4.4: Micrograph of black cotton soil - 10 % iron ore tailing mixture
(28 days curing)

The micrograph of black cotton soil – 10 % IOT mixture cured for 28 days gives a better view of how the sample became coarser than those of specimens cured for 7 days. A complete reaction of the soil-iron ore tailing mixture might have taken place with complete cation exchange and the gain in full strength after 28 days (Sani, 2012).

4.8 Durability

In order to simulate the worst condition that could occur in the field, durability was evaluated by the immersion of specimens in water to determine resistance to loss in strength which is more acceptable for tropical regions like Nigeria (Ola, 1974). The resistance to loss in strength was determined as the ratio of the unconfined compressive strength of specimen cured for 7 days, and later immersed in water for 7 days, to those cured for 14 days. Conventionally, an allowable 20% loss in strength is recommended for a specimen cured for 7 days and immersed in water for 4 days (Ola, 1974; Osinubi, 1998a; 1999).

The variation of resistance to loss in strength.of black cotton soil with iron ore tailing content for BSL, WAS and BSH compactions is shown in Fig. 4.16. For BSL, WAS and BSH compactions, resistance to loss in strength increased from 10.81 % (i.e., loss in strength of 89.19 %), 11.84 % (i.e., loss in strength of 88.16%) and 13.09 % (i.e., loss in strength of 86.91%) % for the natural black cotton soil to peak values of 24.71% (i.e., loss in strength of 75.29 %), 24.73 % (i.e., loss in strength of 75.27 %) and 17.18 % (i.e., loss in strength of 82.82 %) at 8, 12 and 10 % IOT contents, respectively.

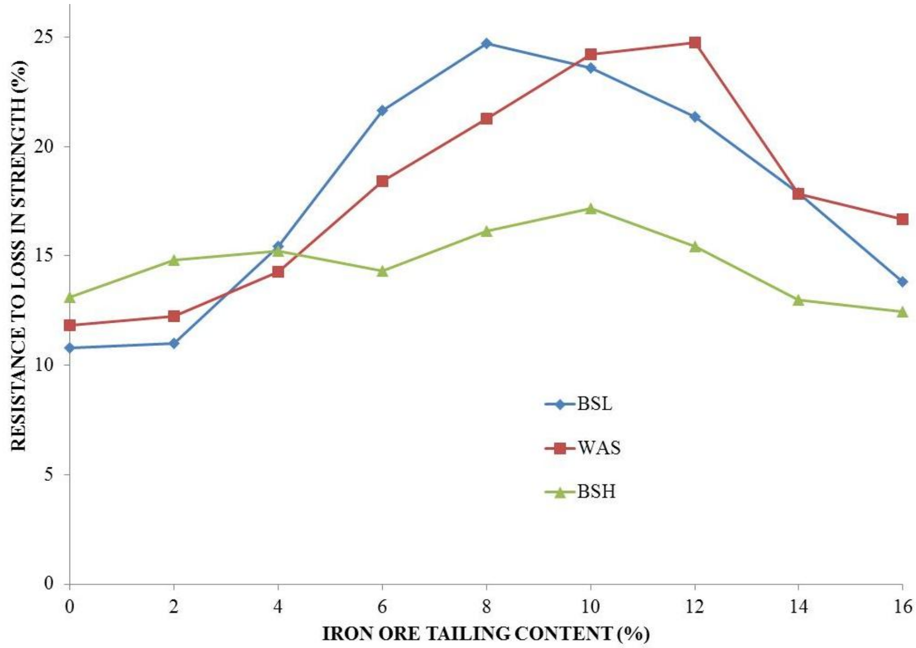

Fig. 4.16: Variation of resistance to loss in strength.of black cotton soil with iron ore tailing content

The recorded peak resistance to loss in strength value of 24.73 % is above 20 % as required maximum. This implies that the IOT stabilized black cotton soil sample did not meet the minimum durability requirement for use in pavement construction. Detailed test results are given in Table A4.11 of Appendix A.

Results of analysis of variance (ANOVA) for durability of black cotton soil – iron ore tailing mixtures are given in Table 4.10. For BSL, WAS and BSH Compactions the results show that the effect of IOT on the durability was statistically significant for BSL ($F_{CAL} = 14.86 > F_{CRIT} = 4.49$) , WAS ($F_{CAL} = 16.92 > F_{CRIT} = 4.49$) and BSH ($F_{CAL} = 12.13 > F_{CRIT} = 4.49$) compactive efforts. Detailed test results are given in Table B4.7 of Appendix B.

Table 4.10: Results of analysis of variance for durability of black cotton soil - iron ore tailing mixtures

Property	**Source of Variation**	**Degree of Freedom**	**F_{CAL}**	**P-Value**	**F_{CRIT}**	**Remark**
BSL	IOT	1	14.87	0.0014	4.49	Significant effect
WAS	IOT	1	16.93	0.0008	4.49	Significant effect
BSH	IOT	1	12.13	0.0031	4.49	Significant effect

Table 4.11: Results of two - way analysis of variance for durability of iron ore tailing-compactive effort

Property	**Source of variation**	**Degree of freedom**	**$F_{calulated}$**	**P_{-value}**	**$F_{critical}$**	**Remark**
RESISTANCE TO LOSS IN STRENGTH	IOT	8	5.653084	0.00163	2.591096	$F_{CAL} > F_{CRIT}$, Significant effect
	COMPACTIVE EFFORT	2	4.581997	0.026713	3.633723	$F_{CAL} > F_{CRIT}$, Significant effect

Results of two-way analysis of variance (ANOVA) for durabilty of iron ore tailing-compactive effort are summarised in Table 4.11. The results show that the effect of the iron ore tailing and compactive effort on the durabity was statistically significant ($F_{CAL} = 5.65 > F_{CRIT} = 2.59$) for IOT and ($F_{CAL} = 4.58 > F_{CRIT} = 3.63$). The effect of compactive effort was more significant than that of iron ore tailing. Detailed test results are given in table B4.13 of Appendix B.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The preliminary investigation conducted on the natural black cotton soil collected at Baure, in Deba L.G.A of Gombe State shows that it falls under A-7-6 (13) classification for AASHTO (1986) and CH according to Unified Soil Classification System (ASTM, 1992). The natural soil has low moisture content of 15.17 %, liquid limit of 64.5 %, plastic limit of 25 %, plasticity index of 39.5 %, linear shrinkage of 27.14 %, free swell of 85 %, and specific gravity of 2.42. These values indicate that the soil is of high plasticity with about 74.7 % of the soil particles passing the BS. No 200 sieve.

The gradation of the black cotton soil improved as the iron ore tailing (IOT) content increased. The Atterberg limits showed that the liquid limit increased from 64.5 % of the natural at 0 % IOT to 71 % at 2 % IOT content then decreased to 59.9 % at 16 % IOT content. Plastic limit increased from a natural soil value of 25 % to a peak value of 34.9 % at 8 % IOT content and then reduced to 27.46 % at 16 % IOT content. The plasticity index reduced from the natural soil value of 39.5 % to 32.44 % at 16 % IOT content.

The maximum dry density (MDD) of black cotton soil increased with higher IOT content and compactive efforts from 1.38, 1.52 and 1.59 Mg/m^3 for the natural soil when compacted using British Standard light (BSL), West African Standard (WAS) and British standard heavy (BSH) energies, respectively, to 1.53, 1.66 and 1.72 Mg/m^3, at 16 % IOT content.

The optimum moisture content (OMC) values decreased from 28.5, 18.5 and 16.5% for the natural black cotton soil to minimum values of 22, 14 and 11.5 % at 16, 14 and 14% IOT contents when compacted at the energy levels of the BSL, WAS and BSH, respectively.

The 7 day unconfined compressive strength (UCS) values for BSL, WAS and BSH compactive efforts recorded for the natural black cotton soil were 172.59, 328.36 and 448.83 kN/m^2, respectively. The UCS values of the treated soil increased to 337.77, 479.44 and 821.57 kN/m^2 at 16, 12 and 12 % IOT content, respectively, for the three energy levels considered. These did not meet the 1710 kN/m^2 prescribed by Road Note 31 for economic range of ordinary Portland cement stabilization.

The soaked CBR values of 3, 4 and 5 % for the natural black cotton soil compacted with BSL, WAS and BSH energies, respectively, increased to peak values of 6, 9 and 11 %, respectively, when treated with 12 % IOT. None of the recorded peak CBR values for the three energy levels meets the minimum requirement of 15 % prescribed by the Nigerian General Specifications, section vi, clause 6201 for subgrade materials compacted at the BSL energy level.

The resistance to loss in strength of black cotton soil increased from 10.81, 11.84, and 13.09 % for the natural soil to peak values of 24.71, 24.73 and 17.18 % for BSL, WAS and BSH compaction energies at 8, 12, and 10 % IOT contents, respectively. The recorded peak resistance to loss in strength of value (75.29 %) fell short of the acceptable conventional 80 % accepted as maximum resistance to loss in strength.

Based on the foregoing, an optimal 10 % iron ore tailing treatment of black cotton soil when compacted with British Standard heavy energy can be used as sub base material in road construction.

5.2 Recommendation

Based on the results obtained in this study:

1. An optimal 10 % iron ore tailing content can be used to improve the properties of black cotton soil when compacted with BSH energy.
2. Iron ore tailing (IOT) cannot be used as a stand-alone stabilizer but should be used as admixture in lime or cement stabilization of black cotton soil.

REFERENCES

Comment [KJO8]: Correct as shown for Journals, Books, Proceedings and Theses

AASHTO (1986). *Standard Specifications for Transport Materials and Methods of Sampling and Testing*. 14th Edition, American Association of State Highway and Transport Officials (AASHTO), Washington, D.C

Adeniji, F. A. (1991) "Recharge function of vertisolic vadose Zone in sub-sahelian Chad Basin". *Proc. Ist Inter. Conf. On Arid Zone Ideology Hydrology and Water Resources*, Maduguri, pp. 331 – 348

Adepoju, S. O. and Olaleye, B. M., (2001). "Gravity concentration of silica sand from Itakpe iron-ore tailings by tabling operation". *Nigerian Journal of Engineering Management*. Vol. 2, No. 2, pp. 51-55.

Ajaka, E. O. (2009). "Recovering fine iron minerals from Itakpe iron ore process tailing", ARPN *Journal of Engineering and Applied Sciences*, Vol. 4, No. 9, pp. 17-28

Akawwi, E. and Al-Kharabsheh, A. (2002)."Lime stabilization effects on properties of expansive soils in Amman, Jordan". *Electronic Journal of Geotechnical Engineering*. www.ejge.com/2000 ppr0020.

Akinmade, O. B., (2008). *Stabilization of Black Cotton Soil Using Locust Bean Waste Ash*.. Unpublished M.Sc thesis, Civil Engineering Department, Ahmadu Bello University, Zaria.

Alhassan, M. (2008). *"*Potentials of rice husk ash for soil stabilization*."* Assumption University *Journal of Technology* Vol. 11, No. 4, pp.246-50

Alhassan, M. (2006). *Effect of Bagasse Ash on Lime Modified Laterite*. Unpublished M.Sc.Thesis Civil Engineering Department, Ahmadu Bello University, Zaria

Aleshin, E. (1978), "Power plant fly ash as a source of alumina." *Proceedings of the 6th Mineral Waste Utilization Symposium*, 2-3 May, Bureau of Mines and IIT Research Institute Chicago, Illinois pp. 334-339.

Amu, O.O., Fajobi, A.B. and Oke, B.O. (2005), "Effect of eggshell powder on the stabilizing potential of lime on expansive clay soil" *Journal of Applied Science*., Vol. 5, No. 8, pp. 1474-1478

Asma, M. and Dariusz, W. (2013), “Effect of lime stabilization on the strength and microstructure of clay”, IOSR *Journal of Mechanical and Civil Engineering* (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 6, Issue 3 (May. - Jun. 2013), PP 87-94 www.iosrjournals.org

ASTM (1992). *Annual Book of Standards* Vol. 04.08, American Society for Testing and Materials, Philadelphia.

ASTM C618-78(1978). *“Specification for Fly Ash and Raw Calcined Natural Pozzolana for use as a Mineral Admixture in Portland Cement Concrete”*.American Society for Testing and Materials, Philadelphia

Azige, P. (2012). “*Locust Bean Waste Ash Modification of Black Cotton Soil using Cement Kiln Dust as an Activator”*.Unpublished M.Sc. Thesis, Ahmadu Bello University, Zaria, Nigeria.

Balogun, L. A. (1991). “Effect of sand and salt additives on some geotechnical properties of lime stabilized Black Cotton Soil”. *The Nigeria Engineer*, Vol. 26 No., 15 – 24.

Balogun, L.A (1990). “Foundation investigation and design techniques for residential buildings on expansive black cotton soils. ” *The Nigerian Engineer*. Vol. 20, No. 2, pp. 34-41.

Bell, F. G. (1989). “Lime stabilization of clay soil.” *Bulletin of the Int. Assoc. of Engineering Geology*, Paris, No39, pp. 67-74.

Bergado, D. T., Anderson, L. R., Miura, N., Balasubramaniam, A. S., (1996), *“Soft ground improvement in lowland and other environments”*, New York: ASCE Press.

Bhatty, J. I., Bhottacharja, S., and Tordes, H. A., (1996) *“Use of cement kiln dust in stabilizing clay soils”* Portland Cement Association, Skokie Illinois, USA.

Bose B. (2012) “Geo-engineering properties of expansive soil stabilized with fly ash”, *Electronic Journal of Geotechnical Engineering*, Vol. 17 pp. 1339-1353

BS 1377 (1990). *Method of Testing Soil for Civil Engineering* British Standard Institute (BSI) London.

BS 1924 (1990). *Method of Tests for Stabilized Soils.British Standard Institute* (BSI) London.

Comment [KJO9]: Ditto for this and other references

Butches, F. and Sailie, E. L (1984) "Swelling behaviour of tropical black clays." *Proceedings of the 8th Regional Conference for Africa on Soil Mechanics and Foundation Engineering*, Harare. 81 – 86.

Chen, F. H. (1988). *Foundations on Expansive Soils.* Elsevire Scientific Publishing Company, Amsterdam.

Cokca, Erdal (2001) *"*Use of Class F Ashes for the Stabilization of an Expansive Soils*".Jounal of Geotechnical Engrg.* Vol. 127 No. 7, pp. 568-573.

Collins, R. J. and Ciesiellski, S. K. (1993) *"Recycling and use of waste materials or by products in highway construction."* Vols. 1 and 2. Pp 568-578.

CPCB, (2007), "*Comprehensive industry document on iron ore mining*". Parivesh Bhawan, East Arjuin Nagar, New Delhi, pp4-10

Das, B. M. (1998). *Principles of Geotechnical Engineering.* 4th Edition, PWS, Publishing Division of International Thomas Publishing Company, New York.

Diamond, S. (1975). "*Soil stabilization for erosion control.*" JHRP L36-50H, Final Rep., JHRP 75-20, Purdue and Indiana State Publication 47.

Eades, J. L., and Grim, R. E., (1960), "The reaction of hydrated lime with pure clay minerals in soil stabilization.", *U. S. Highway Research Board Bulletin*, Vol. 262, pp. 51-63

Ghose, M.K. (1997), *"*Environmental management for disposal of spoils and tailings from mines*', Env. And Ecology* 15(1), 206-210.

Gidigasu, M. D. (1982). "Importance of material selection, construction control and field performance studies in developing acceptance specification for laterite paving gravels." *Solos and Rocha, Rio de Janeiro*, Brazil. Vol. 5 No1

Gidigasu, M.D. and Dogbey, J.L.K. (1980). "Geotechnical characteristics of laterized decomposed rocks for pavement construction in dry sub-humid environment." *Proc. 6th Southeast Asian Conf. on Soil Engrg.* Taipei, Vol. 1. pp. 492-506

Gilliot, J. E. (1987). *Clay in Engineering Geology*. Elsevier Publishing Company, Amsterdam.

Habercom, G. E. (1976). *Soil Stabilization.* (A Bibliography with Abstracts). National Technical Information Service Biblio. 221pp.

Hammond, R., (1961), *"Laterite soil engineering.*", Amsterdam: Elsevier Scientific publishing Company.

Hamza, M. A. (2008), "Understanding soil analysis data", *Resource Management Technical Report 327*, pp. 32-34

Holtz, W. G. and Hart, S. S., (1978) "Home construction on shrinking and swelling soils", *special publication 11, American Society of Civil Engineers*, pp. 1-18

Holtz, W. G. and Gibbs, H. J. (1956). "Engineering properties of expansive clays." *ASCE Transaction*, Vol. 121 No 1, Paper 2814.

Ibrahim, A. (1983). "Black cotton soil in road pavement design, construction and performance." In S. A. Ola (ed.) *Tropical Soils of Nigeria in Engineering Practice*, A. A. Balkema, The Netherlands, Rotherdam, pp. 260-278.

ICOLD, (2003*)," International Commission on Large Dam report 151",* Boulevard Haussmann, 75008, Paris, France.

ISRIC (1998). "*World soil information*" International Soil and Reference Information Center.

Johnson,W. A., Herrin, M., Davidson, T. D. and Handy, L.R. (1988) *Soil stabilization in : Highway Design Reference Guide*, edited by Woods, K. B and Ross, S. S. MC Graw –Hill Book Company. New York.

Jones B. K and Holtz W. G (1993). *"Expansive Soil, the hidden Disaster*". American Society of Civil Engineering (43 No. 8pp 78 – 79).

Kawamura ,M. and Diamond, S. (1975). "Stabilization of clays soils against erosion loss." *JHRP-75-4, Tech. Paper*, Purdue and Indiana State Highway Commission.

Kedzi, A. (1979). *Stabilized Earth Roads.* Elsevier, Amsterdam, pp 327.

Koteswara, R. D., (2011), "The efficacy of reinforced technique on the fly ash stabilized expansive soil as a subgrade embankment for highways*". Int. Journal of Eng. Sc. And Technol. (IJEST)*, Vol. 3 No.2, pp. 776

Lea, F.M. (1956). *The Chemistry of Cement and Concrete*, Edward Arnold Publishers. London

Little A.L (1967) "The use of tropically weathered soil in the construction of earthdams." *Proc. Of 3rd Asian Reg. Conf. Soil Mech & Foundation Engrg*., Haifa, Israel, Vol.1, pp 35-41.

Markwick, A. H. D. (1944)."*The basic principles of soil compaction and their application.*" Institute of Civil Engineering, London, Road Engineering Div., Road Paper No. 16.

Medjo .E. and Riskowiski, G. (2004*). "*A procedure for processing mixtures of soil, cement and sugar cane bagasse*."* Agricultural Engineering International *Journal of Scientific Research and Development Manuscript BC 990*, Vol. III, pp. 1-6.

Mohammedbhai, G. T. G. and Bagant, B. T. (1990) *"*Possibility of using bagasse ash and other furnace residue as partial substitute for cement in Maritius*." Revue Agricole et Sulclriere de l'lle Maurice*, Vol. 64, No 3 pp.1-10.

Montgomery, D., (2001) "*Design and Analysis of Experiments*", 5th edition, 2001, New York: John Wiley & Sons, 2001

Morin, W. J. (1971). *"*Properties of African tropical black clay soils.". *Proceedings 5th Regional Conference for Africa on Soil Mechanics and Foundation Engineering* Luanda, Vol. 1, pp. 51-59.

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

Moses, G.. (2006), *"Stabilization of Black Cotton Soil with ordinary Portland Cement using Bagasse Ash as Admixture*". M.Sc. Thesis, Department of Civil Engineering, Ahmadu Bello University, Zaria

Moses G. K. and Saminu A. (2012*), "*Cement kiln dust stabilization of compacted black cotton soil*", Electronic Journal of Geotechnical Engineering* Vol. 17, pp. 875-836.

Mustapha, A.M. (2006)."*The Effect of Bagasse Ash on Cement Stabilized Laterite".*Unpublished M.Sc. Thesis, Ahmadu Bello University, Zaria, Nigeria.

Nelson, D. and Miller, J. (1992). Expansive Soils Problems and Practice in *Foundation and Pavement Engineering.* John Wiley and Sons, Inc., New York.

Newman, K. and Tingle, J. S., (2004), “Emulsion Polymers for soil stabilization”, *2004 FAA Worlwide Airport Technology Transfert conference*, Atlantic city, New Jersey, USA.

Nigerian General Specifications (1997). *Roads and Bridges*. Federal Ministry of Works, Abuja, Nigeria.

Nixon.I.K and Skipp.H.O.(1957). “Airfield construction on overseas soils and laterite.” *Proc. of British Inst. Civil Engrg.*,London,United Kingdom.Vol.8,pp.253-292.

Obeahon S. O. (1993). *The Effect of Elapse Time After Mixing on the Properties of Modified Laterite*. Unpublished M. Sc. Thesis Civil Engineering Department Ahmadu Bello University Zaria.

O’Flaherty. C.A (1988). *Highway Engineering*. Vol. 2, Edward Arnold, London. U.K

Ochepo, J. (2008), *“The Effect of Elapsed Time on the Geotechnical Properties of Black Cotton Soils Stabilized with Lime-Bagasse Ash Admixture”,* Unpublished M.Sc. Thesis, Department of Civil Engineering, Ahmadu Bello University, Zaria.

Ola, S. A., Adeleke, A. O., Usman, G. A., Odunaike, A. A., Kollere, S. M., and Ajiboye, P. O., (2009), “Study on the magnetic concentration of Nigerian Itakpe sinter concentrate to a Midrex-grade concentrate”, *Maejo Int. J. Sci. Technol.* 2009, 3(03), 400-407.

Ola S.A. (1983).*’’*The geotechnical properties of black cotton soils of North Eastern Nigeria*.’’* In: S.A Ola(ed). *Tropical Soils of Nigeria in Engineering Practice.* Balkema, Rotterdam, pp. 260-178.

Ola, S. A. (1974) “Need for estimated cement requirement for stabilizing lateritic soil.” *Journal of Transporationt Div., ASCE*, Vol. 17,No 8, pp. 379-388.

Ola, S. A. (1978) *“*The geology and geotechnical properties of the black cotton soils of North Eastern Nigeria*.” Engineering Geology*, Vol. 12, pp. 375-391.

Oriola, F. and Moses G., (2010).Groundnut Shell Ash Stabilization of Black Cotton Soil. *EJGE*.Vol.15.,P415-428.

Osinubi, K. J. (2001a). “Influence of Compaction Energy Levels and Delays on Cement Treated Soil.” *Nigerian Society of Engineers Technical Transactions*. Vol. 36, No 4.

Osinubi K.J (2001b), "Stabiization of lateritic soil with cationic bitumen emulsion." *Journal of Engineering Research*, Vol. JER-9, No 384, pp. 137-150.

Osinubi, K. J. (2000a). "Laboratory trial of soil stabilization of Nigerian black cotton soils" *Nigerian Society of Engineers Technical Transactions*, Vol. 35, No 4 pp 13 – 21.

Osinubi, K. J. (2000b) "Treatment of laterite with anionic bitumen emulsion and cement: A Comparative Study." *Ife Journal of Technology*, Obafemi Awolowo University, Ile-Ife, Vol. 9, No 1, pp. 139–145.

Osinubi, K.J (1999). "Evaluation of admixture stabilization of Nigerian black cotton soils." *NSE Technical Transaction*, Vol. 34, No. 3, pp 88-96.

Osinubi, K.J., (1998a). Influence of compactive efforts and compaction delays on lime treated soil. *Journal of Transportation Engineering*, *ASCE*, Vol.124, No.2, pp.149-155.

Osinubi, K. J. (1998b). "Stabilization of tropical black clay with cement and pulverised coal bottom ash admixture." In: *Advances in Unsaturated Geotechnics*. Edited by Charles, D., Shackelford, Sandra L. Houston and Nien-Yin Cheng. *ASCE Geotechnical Special Publication*, No 99, pp 289-302.

Osinubi K.J. (1995). "Lime modification of black cotton soils." *Spectrum Journal*, Vol. 2, Nos. 1 and 2, pp. 112-122.

Osinubi K J and Medubi A (1998). **"**Evaluation of Cement and Phosphatic Waste Admixture on Tropical Black Clay Road Foundation", *Proc of Engineering Analysis and Modeling (SEAM4)* Accra vol, pp297-30.

Osinubi, K. J. (1997). "Soil stabilization using phosphatic waste." *Proceedings of 4th Regional Conference on Geotechnical Engineering, GEOTROPIKA '97*. Johor Bahru, Malaysia, 11 – 12 Nov., pp 225 -244.

Osinubi, K.J. and Moses, G. (2013). "Influence of compactive efforts on cement-bagasse ash treatment of expansive black cotton soil", *World Academy of Science, Engineering and Technology 79 2013* pp. 1574-1581.

Osinubi, K J and Oyelakin, M A (2012). " Optimising soil-cement-ash stabilisation mix for maximum compressive strength: A case study of the tropical clay sub-base material stabilised with cement-locus bean waste ash" In: Laryea, S., Agyepong, S.A., Leiringer, R. and Hughes, W. (Eds) *Procs 4th West Africa Built Environment Research (WABER) Conference*, 24-26 July 2012, Abuja, Nigeria, 1207-1218.

Osinubi, K. J., Eberemu, A. O. and Oyelakin, M. A. (2011). "Improvement of Black Cotton Soil with Ordinary Portland Cement - Locust Bean Waste Ash Blend" *Electronic Journal of Geotechnical Engineering*, Bund. F. Vol. 16 pp 619 – 627.

Osinubi, K. J., Soni, E. J. and Ijimdiya, T. S. (2010) "Lime and slag admixture improvement of tropical black clay road foundation" Transportation Research Board (TRB) 89th Annual Meeting CD-ROM, January 10 - 14 Washington, D. C., U.S.A. Subject: *Recycled Materials in Transportation Infrastructure, Session AFP40 – Physico-chemical and Biological Processes in Soils Committee*, Paper # .10-0585, pp. 1 -18.

Osinubi, K. J., Akinmade, O. B. and Eberemu, A. O. (2009). "Stabilization potential of locust bean waste ash on black cotton soil." *Journal of Engineering Research*, University of Lagos, Nigeria, Vol. 14, No. 2, pp. 1-13.

Osinubi, K. J. and Eberemu, A. O., (2009) "Desiccation-induced shrinkage of compacted lateritic soil treated with bagasse ash". *The twenty fourth international conference of solid waste technology and management CD-ROM, 15th-18th March 2009*, Philadelphia, PA. USA. Session 5c, bioreactors and innovative landfills pp. 856-867

Osinubi, K. J. and Ijimdiya, T. S. (2009) "Laboratory investigation of desiccation characteristics of black cotton soil treated with bagasse ash." *Proceedings of Bi-monthly Meetings/Workshops* organized by Zaria Chapter of Materials Society of Nigeria, pp. 61 - 68.

Osinubi, K. J. and Eberemu, A. O. (2009a) " Compatibility and attenuative properties of laterite-blast furnace slag mixtures." *Journal of waste technology and management*, vol. 35. No. 1, pp. 7-16

Osinubi, K. J., Eberemu, A. O. (2009b) "Desiccation-induced Shrinkage of Compacted Lateritic Soil treated with bagasse ash." *The Twenty-Fourth International*

Conference on Solid Waste Technology and Management CD-ROM, 15-18 March, Philadelphia, PA, U.S.A. Session 5C: Bio-reactors and Innovative Landfills, pp.856-867.

Osinubi, K. J. and Mustapha, A. M. (2008). 'Effect of compactive efforts on cement – sugarcane bagasse ash – laterite mixture.' *Nigerian Society of Engineers Technical Transactions*. Vol. 43, No. 2, pp 33 – 46

Osinubi, K.J., Ijimdiya, T. S. and Nmadu, I. (2008a). 'Effect of compactive effort on lime treated black cotton soil using bagasse ash as admixture*.' Book of Abstracts of the 2nd International Conference on Engineering Research & Development: Innovations (ICER&D 2008)*, Benin City, Nigeria, 15-17 April. Technical Session 9B – Construction and Structures, Paper ICERD08056, p. 216 - 217.

Osinubi, K.J., Ijimdiya, T. S. and Nmadu, I. (2008b). 'Lime stabilization of black cotton soil using bagasse ash as admixture*.' Book of Abstracts of the 2nd International Conference on Engineering Research & Development: Innovations (ICER&D 2008)*, Benin City, Nigeria, 15-17 April. Technical Session 9B – Construction and Structures, Paper ICERD08058, p. 217

Osinubi, K. J., Bafyau, V. and Eberemu, A. O.(2008c). 'Bagasse ash stabilization of lateritic soil.' In:*Appropriate Technologies for Environmental Production in the developing World*. Edited by E. K. Yanful Springer, Netherlands.(To be published in 2008).

Osinubi, K. J., Eberemu, A.O. and Aliu, O.S. (2007a) "Stabilization of laterite with cement and bagasse ash admixture*." Proc. of the first Inter. Conf. on Environ. Res., echn. And Policy* "ERTEP 2007" under the auspices of International Society of Environmental Geotechnology, Accra, Ghana, 16 – 19 July, Category B: Mining and Environment, PP. 1.

Osinubi, K. J., Eberemu, A. O. and Simon, K. L. (2007c). "Influence of Bagasse ash content and curing period on the permeability of lateritic soil compacted at reduced Proctor effort." *Proc. of Bi-monthly Meetings/Workshops* organized by the Zaria Chapter of Materials Society of Nigeria, pp.17 -25

Osinubi, K. J. and Stephen, A. T. (2007). "Influence of compactive efforts on bagasse ash treated black cotton soil." *Nigerian Journal of Soil and Environmental Research*, Vol. 7, pp. 92 – 101.

Osinubi, K. J. and Eberemu, A. O. (2006). "Effect of bagasse ash on the strength of stabilized lateritic soil." *Book of Abstracts of the 5th Nigerian Materials Congress "NIMACON* 2006*"*, Abuja, Nigeria, 17-19 November. pp.202– 208.

Osinubi, K. J. and Stephen, T. A. (2006a). 'Effect of bagasse ash content on particle size distribution and plasticity characteristics of black cotton soil." *Proceedings of the 5th Nigerian Materials Congress "NIMACON* 2006*"*, Abuja, Nigeria, 17-19 November. pp. 214 - 220.

Osinubi, K. J. and Stephen, T .A. (2006b). 'Effect of curing period on bagasse ash stabilized black cotton soil.' *Proc. of Bi-monthly Meetings/Workshops* organized by the Zaria Chapter of Materials Society of Nigeria, pp. 1 - 9.

Osinubi K. J. and Eberemu, A. O. (2005). "The use of blast furnance slag treated latrite in attenuation of ground contaminants." *Proc. Of The Nigeria Marterial Congress 2005 (NIMACON)*. Nov. 17th – 19th 2005. Zaria, Nigeria. pp. 28-35.

Osinubi, K. J. and Stephen, T. A. (2005). "Economic utilization of an agro-industrail waste-bagasse ash." *Proc. of The Nigerian Material Congress* 2005 (NIMACON 2005). 17-19 Nov., Zaria, Nigeria, pp. 36-40.

Osinubi, K. J. and Mustapha.A. M. (2005). 'Potentials of bagasse ash as a pozzolana.' *Proceedings of the 4th Nigerian Materials Congress "NIMACON* 2005", Zaria, Nigeria, 17 – 19 November, pp. 41 -45.

Osinubi, K. J. and Medubi, A. B. (1997a). "Evaluation of cement and phosphatic waste admixture on tropical black clay road foundation." *Proceedings of 4th Intn'l. Conference on Structural Engineering Analysis and Modeling* (SEAM 4), Kumasi, Ghana, 9-11 July, Vol. 2, pp. 297-307.

Osinubi, K. J. and Medubi, A. B. (1997b) "Effect of lime and phosphatic waste admixture on tropical black clay." *Proceedings, 4th Regional Conference on Geochemical Engineering*, GEOTROPIKA '97, Johor Bahru, 11-12 Nov., Malaysia, pp. 257–272.

Osinubi, K. J., and Brajeh, I., (1994), *"*Bituminous stabilization of laterite*", Spectrum Journal*, Vol. 1, No. 2, pp. 104-112

Osinubi, K. J. and Katte, V. Y. (1991), *"*Effect of elapsed time after mixing on grain size and plasticity characteristics."*NSE technical transactions*, Vol. 34 No. 3, pp. 38-46

Osula, D. O. A. (1991) "Lime Modification of Problem Laterite". *Eng. g Geol.* 30, pp 141 – 149

Oyediran I.A. and Kalejaiye M. (2011), "Effect of increasing cement content on strength and compaction parameters of some lateritic soils from southeastern Nigeria", *Electronic Journal of Geotechnical Engineering*, vol. 16 pp. 1501-1514

Oyelakin , M.A. (2011). "*Cement Stabilization of Black Cotton Soil Using Locust Bean Waste Ash as Admixture".*Unpublished M.Sc. Thesis, Ahmadu Bello University, Zaria, Nigeria.

Plait, R. M. (1953). "Determination of swelling pressure of black cotton soil–A method." *Proceedings of the Third Intn'l. Conference on Soil Mechanics and Foundation Engineering.*, Zurich, Switzerland, 16th – 27th August, Vol. 1, pp. 170–172.

Portland Cement Association (1970). *Recommended Practice for construction of Residential Concrete Floors on Expansive soil.* Vo1. 2. Portland Cement Association, Los Angeles.

Reyes, A. and Pando, M. (2007), *"*Evaluation of CFBC fly ash for improvement of soft clays*", World of Coal Ash* (WOCA), Covington, Kentucky, USA, May 7-10

Robert, L. S. (1993) "Fly ash for use in the stabilization of industrial wastes." In: *Fly Ash for Soil Improvement*, K. D. Sharp (ed.) Geotechnical Engineering Division of the ASCE, Geotechnical Special Publication, No 36, K. D. Sharp(ed) Geotechnical Engineering Division of ASCE, pp. 30-35.

Sabat, A. K. (2012), "A study on some geotechnical properties of lime stabilized expansive soil-quarry dust mixes", *Int. Journal of emerging trends in Engineering and Development*, ISSn 2249-6149 issue2, vol. 1, pp. 42-49

Sani, J.E. (2012). "*Locust Bean Waste Ash Stabilization of Black Cotton Soil using Cement Kiln Dust as an Activator".*Unpublished M.Sc. Thesis, Ahmadu Bello University, Zaria, Nigeria.

Saravut, J., William, O. Y. and Pichai, T., (2012), “Microstructure and strength characteristics of lateritic soil-cement”, *EJGE* vol. 13, Bund. B , pp. 2393-2403

Sayah, A. I, (1993), “*Stabilization of a highly expansive clay using cement kiln dust’*, M.Sc Thesis, University of Oklahoma, Graduate College, Norman, Oklahoma, USA.

Senol, A., Edil, T.C., Hector, A. A., and Benson, C. H., (2006), “Soft subgrades stabilization by using various fly ashes”, *Resources, Conversation and recycling*, 46 (4); pp. 365-376

Stephen, A. T. (2006). *Stabilization Potential of Bagasse Ash on Black cotton Soil.* Unpublished M.Sc. Thesis, Department of Civil Engineering, Ahmadu Bello University, Zaria.

Singh, G. (1991*): Highway Engineering*, 3rd Edition, Standard Publishers Distributors. pp 599 – 619.

Smith, R.G (1992), "Alternatives to ordinary portland cement". *British Building Society Journal*, Vol.25, pp.1-17.

Toland, G. (1977), “Case history of failure and reconstruction of Mike Horse tailings dam near Lincoln, Montana*.” In Proc. 15th Am. Eng. Geol. And Soil Eng. Symp.* Idaho State University.

Tomlinson, M.J. (1999), *Foundation Design and Construction*. 6th edition, Longman, Harlow, Essex.

TRRL (1977). “A guide to the structural design of bitumen surfaced roads in tropical and sub-tropical countries.” *Transport and Road Research Laboratory, Road Note 31*, H. M. S. O., London.

Warren, K.W. And Kirby, T.M. (2004) *‘*Expansive Clay Soil A Wide Spread And Costly Geohazard”, *Geostra*, Geoinstitute Of The American Society Of Civil Engineers.

Winterkorn, H. F., and Pamukcu, S., (1990), *“*Soil stabilization and grouting*.”* *Foundation Engineering Handbook* edited by Hsai-Yang Fang, 2nd edn, Van Nostrand Reinhold, New York.

World Bank Group (1998), “*Pollution prevention and abatement Handbook*”.

Yamanouchi, T (1975). ”Problems in the development of soil stablilization.”, *State and Municipal Record*, Vo1.68, No. 7, pp. 365-374.

Yoder, F. J and Witczak N. W (1975). *Principles of Pavement Design*. Wiley-Intercience Publication, New York. 711pp

Yudhbir, L. and Honjo, Y. (1991),“*Application of geotechnical engineering to environmental control*,” 9 ARC, Vol. 2, Bangkok Thailand, pp. 431-469.

Zaman, M., Laguros, J. G., and Sayah, A. I., (1992), “Soil stabilization using cement kiln dust”, *Proceeding of the 7th International conference on expansive soils*, Dallas, Texas, USA

APPENDIX A

Comment [KJO10]: Correct text of titles as shown

Table A4.1: Results of specific gravity of iron ore tailing

Flask No	K23	L91	L10
Mass of Bottle M1	20.7	23	18.1
Mass of Bottle + Soil M2	25.3	27.8	23
Mass of Bottle + Soil + Water M3	49	51.3	46.8
Mass of Bottle + Water M4	45.6	47.8	43.2
M2 - M1	4.6	4.8	4.9
M4 - M1	24.9	24.8	25.1
M3 - M2	23.7	23.5	23.8
(M4 - M1) - (M3 - M2)	1.2	1.3	1.3
Gs = (M2-M1) / ((M4-M1)-(M3-M2))	3.8333	3.6923	3.7692
Average Gs	3.76		

Table A4.2: Results of specific gravity of black cotton soil - iron ore tailing mixtures

IOT content %	specific gravity
0	2.42
2	2.46
4	2.52
6	2.64
8	2.68
10	2.74
12	2.79
14	2.83
16	2.88

Table A4.3: Results of moiture content of natural black cotton Soil

Container No	X46	1Q	M15
Mass of Container M1	10.2	11.6	13.6
Mass of Container + Wet Soil M2	77	89.7	84.2
Mass of Container + Dry Soil M3	68.21	79.4	74.9
Mass of Dry Soil (M3-M1) = Ws	58.01	67.8	61.3
Mass of Wet Soil (M2- M1)	66.8	78.1	70.6
Ww = (M2-M10-(M3-M1)	8.79	10.3	9.3
Moisture Content = W = Ww/Ws	15.153	15.192	15.171
Average W	15.17		

Table A4.4a: Results of wet sieve analysis values of black cotton soil-iron ore tailing mixtures

Comment [KJO11]: Ditto for the remaining table titles

0% IOT		**2% IOT**		**4% IOT**		**6% IOT**		**8% IOT**		**10% IOT**	
B.S SIEVE SIZE	**% PASSING**	**B.S SIEVE SIZE**	**% PASSING**	**B.S SIEVE SIZE**	**% PASSING**	**B.S SIEVE SIZE**	**% PASSING**	**B.S SIEVE SIZE**	**% PASSING**	**B.S SIEVE SIZE**	**% PASSING**
2.4	90.3	2.4	89.3	2.4	91.2	2.4	90.3	2.4	89.7	2.4	92.55
1.4	89	1.4	88	1.4	89.8	1.4	89	1.4	88.35	1.4	91.55
0.6	84.95	0.6	84.25	0.6	85.9	0.6	84.95	0.6	84.85	0.6	87.55
0.425	80	0.425	79.6	0.425	81.05	0.425	80	0.425	79.4	0.425	81.4
0.3	78.85	0.3	78.5	0.3	80.05	0.3	78.85	0.3	77.95	0.3	79.75
0.212	77.65	0.212	77.3	0.212	79	0.212	77.65	0.212	76.35	0.212	77.75
0.15	76.35	0.15	74.75	0.15	77.65	0.15	76.35	0.15	74.35	0.15	75
0.075	74.7	0.075	72.9	0.075	75.95	0.075	74.7	0.075	72.2	0.075	72.4
0.067	47.33	0.067	48.55	0.067	49.57	0.067	47.33	0.067	45.2	0.067	44.7
0.049	44.11	0.049	45.19	0.049	47.08	0.049	44.11	0.049	42.02	0.049	40.79
0.037	43.3	0.037	43.51	0.037	46.26	0.037	43.3	0.037	39.63	0.037	39.21
0.027	40.89	0.027	40.15	0.027	42.94	0.027	40.89	0.027	37.25	0.027	35.06

0.019	31.23	0.019	27.58	0.019	32.99	0.019	31.23	0.019	27.69	0.019	25.83
0.014	23.99	0.014	20.84	0.014	26.36	0.014	23.99	0.014	20.53	0.014	18.74
0.01	21.38	0.01	18.31	0.01	24.7	0.01	21.38	0.01	18.1	0.01	16.38
0.009	20.77	0.009	14.95	0.009	20.56	0.009	20.77	0.009	15.75	0.009	14.05
0.006	14.33	0.006	11.59	0.006	16.41	0.006	14.33	0.006	11.78	0.006	10.05
0.004	12.87	0.004	11.89	0.004	12.29	0.004	9.01	0.004	8.79	0.004	8.58

Table A4.4a:Results of wet sieve analysis values of black cotton soil-iron ore tailing Mixture (continuation)

12% IOT		**14% IOT**		**16% IOT**	
B.S SIEVE SIZE	**% PASSING**	**B.S SIEVE SIZE**	**% PASSING**	**B.S SIEVE SIZE**	**% PASSING**
2.4	92.2	2.4	92.1	2.4	94.35
1.4	91	1.4	91	1.4	93.2
0.6	87.1	0.6	87.05	0.6	88.9
0.425	80.75	0.425	80.4	0.425	81.25
0.3	78.85	0.3	78.3	0.3	78.9
0.212	76.3	0.212	75.7	0.212	76.15
0.15	73.55	0.15	72.5	0.15	72.95
0.075	70.45	0.075	69.25	0.075	70
0.067	44.18	0.067	46.24	0.067	44.25
0.049	40.29	0.049	41.6	0.049	41.97
0.037	36.4	0.037	38.51	0.037	38.91
0.027	34.07	0.027	34.64	0.027	36.61
0.019	24.73	0.019	33.09	0.019	32.78
0.014	16.18	0.014	23.81	0.014	22.06
0.01	14.62	0.01	10.67	0.01	6.74
0.009	11.15	0.009	8.35	0.009	4.44
0.006	7.62	0.006	6.03	0.006	1.39
0.004	8.53	0.004	2.17	0.004	0

Table A4.4 (b): Results of dry sieve values of black cotton soil-iron ore tailing mixtures (BSL Compaction)

BS SIEVE	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10%IOT	12%IOT	14%IOT	16%IOT
SIZE	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING
3.175	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
2.4	53.7	52.85	40.45	43.8	57.8	42.25	52	50.7	57.5
1.4	46.8	45.1	32.9	36.55	50.1	35.75	43.3	42.45	50.45
0.6	28.8	25.3	18.2	20.5	29.2	22.3	24.55	23.7	35.45
0.425	8.8	6.85	5.8	6.25	8.45	9.5	9.15	8.25	14.7
0.3	6.55	3.95	3.95	4.05	5.9	7.35	6.55	6.05	11.45
0.212	4.95	2.45	2.9	2.75	4.3	5.35	4.65	4.05	8.95
0.15	3.6	1.5	2.15	1.7	3.2	3.9	2.9	2.75	6.8
0.075	2.7	0.7	1.65	0.85	2.3	2.95	1.7	1.45	5.05

Table A4.4 (c): Results of dry sieve values of black cotton soil-iron ore tailing mixtures (WAS Compaction)

BS SIEVE	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10%IOT	12%IOT	14%IOT	16%IOT
SIZE	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING
3.175	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
2.4	68.15	70	71.15	72.8	75.6	75.4	63.1	70.1	71.3
1.4	60.6	60.65	64.2	64.9	68.9	69.5	52.4	59.5	64.9
0.6	39.85	39.05	43.55	44.5	48.2	49.7	33.15	42.45	46.65
0.425	11.55	13.25	13.75	15.75	17.5	18.5	12	18.4	20.55
0.3	8.45	9.2	8.85	10.75	11.95	13.4	8.65	13.2	14.2
0.212	6.4	6.85	6.4	8	8.7	9.95	6.35	9.5	11.2
0.15	5.2	5.35	4.5	5.5	6.3	7.8	4.75	7.05	7.9
0.075	4.1	3.5	3.25	3.95	4.1	5.25	2.95	4.55	4.9

Table A4.4 (d): Results of dry sieve values of black cotton soil-iron ore tailing mixtures (BSH Compaction)

BS SIEVE	0% IOT	2% IOT	4% IOT	6% IOT	8% IOT	10%IOT	12%IOT	14%IOT	16%IOT
SIZE	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING	% PASSING
3.175	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
2.4	59.7	67.8	72.6	64.75	69.4	68.55	69.7	68.05	65.15
1.4	51.75	59.7	64.95	57.55	62.8	61.35	63.1	62.15	58.6
0.6	29.6	35.7	44.05	36.45	41.05	40	42.4	44.7	41.1
0.425	6.9	9.25	11.15	11.1	13.05	14.35	14.7	19.7	16.5
0.3	4.45	6.1	7.45	7.1	8.25	9.95	10.5	14.65	12.25
0.212	2.75	4.15	5.05	4.85	5.3	6.95	7.2	10.45	8.8
0.15	1.95	2.65	3.2	3.35	3.3	4.85	5.2	7.1	6.1
0.075	1.35	1.9	2.2	1.9	1.6	3	3	4.2	3.8

Table A4.5: Results of Atterberg limit of black cotton soil-iron ore tailing mixtures

IOT CONTENT %	**LL**	**PL**	**PI**	**LS**
0	64.5	25	39.5	27.14
2	71	30.41	40.59	25.71
4	69.4	32.94	36.46	23.57
6	68.3	34.05	34.25	21.43
8	67.6	34.9	32.7	20.71
10	65	32.86	32.14	20
12	64.6	30.14	34.46	19.29
14	61.5	29.48	32.02	18.57
16	59.9	27.46	32.44	18

Table: A4.6 Results of cation exchange capacity of black cotton soil-iron ore tailing mixtures

0%IOT	2%IOT	4%IOT	6%IOT	8%IOT	10%IOT	12%IOT	14%IOT	16%IOT
35.5	36.2	38.1	40.4	41	42.2	39	37.9	36.7

Table A4.7: Results of maximum dry density of black cotton soil-iron ore tailing mixtures

IOT CONTENT (%)	BSL	WAS	BSH
0	1.38	1.52	1.59
2	1.41	1.54	1.62
4	1.46	1.57	1.64
6	1.48	1.59	1.65
8	1.49	1.61	1.67
10	1.51	1.62	1.68P
12	1.52	1.62	1.69
14	1.53	1.63	1.71
16	1.53	1.66	1.72

Table A4.8: Results of optimum moisture content of black cotton soil-iron ore tailing mixtures

IOT CONTENT (%)	BSL	WAS	BSH
0	28.5	18.5	16.5
2	26	18	16
4	25.5	17.5	15.2
6	25	16.4	14
8	24	16	13.5
10	23	15	12.5
12	22.5	14.5	11.8
14	22.5	14	11.5
16	22	15	12

Table A4.9a: Results of unconfined compressive strength (7 days curing period) of black cotton soil-iron ore tailing mixture

IOT CONTENT (%)	BSL	WAS	BSH
0	172.59	328.36	448.83
2	197.36	392.18	599.21
4	204.96	430.29	663.19
6	213.84	445.03	705.94
8	242.08	471.45	739.41
10	270.75	487.57	793.32
12	296.73	479.44	821.57
14	318.48	447.74	797.53
16	337.77	429.99	754.96

Table A4.9b: Results of unconfined compressive strength (14 days curing period) of black cotton soil-iron ore tailing mixture

0	238.03	346.98	458.37
2	311.14	376.71	510.73
4	329.8	411.11	565.72
6	345.36	428.28	629.61
8	356.67	433.83	660.34
10	383.23	458.31	698.85
12	397.35	463.2	747.4
14	400.12	478.1	789.23
16	432.16	472.98	779.55

Table A4.9c: Results of unconfined compressive strength (28 days curing period) of black cotton soil-iron ore tailing mixture

IOT CONTENT (%)	BSL	WAS	BSH
0	273.24	514.45	627.81
2	364.26	628.46	691.14
4	389.96	638.23	727.42
6	405.3	666.13	772.42
8	427.23	698.73	824.91
10	445.03	762.17	899.91
12	458.88	859.85	942.89
14	494.36	907.41	1009.3
16	504.91	947.68	1021.2

Table A4.9d: Results of unconfined compressive strength (7 days curing, 7 days soaking period) of black cotton soil-iron ore tailing mixture

IOT CONTENT (%)	BSL	WAS	BSH
0	25.72	41.08	60.02
2	33.94	46.17	75.55
4	50.91	58.76	86.19
6	74.75	78.9	90.03
8	88.15	92.34	106.61
10	90.37	110.91	120.03
12	84.86	114.54	115.14
14	71.52	85.29	102.35
16	59.7	78.9	97.05

Table A4.10a: Results of California bearing ratio (unsoaked) of black cotton soil-iron tailing mixtures

IOT CONTENT (%)	BSL	WAS	BSH
0	7.93	9.82	15.03
2	8.69	11.33	18.04
4	9.44	12.84	21.15
6	10.2	13.6	22.66
8	12.31	15.11	25.68
10	14.35	16.09	27.19
12	16.62	18.13	29.06
14	16.24	19.64	21.15
16	15.86	18.88	20.54

Table A4.10b: Results of California bearing ratio (Soaked) of black cotton soil-iron tailing mixtures

IOT CONTENT (%)	BSL	WAS	BSH
0	3.02	3.78	5.29
2	3.32	4.15	6.42
4	3.78	5.29	7.52
6	4.53	5.66	9.02
8	5.29	6.42	9.44
10	5.66	7.55	10.57
12	5.66	8.69	11.33
14	3.78	8.31	10.57
16	3.02	6.8	9.06

Table A4.11: Results of resistance to loss in strength of black cotton soil-iron ore tailing mixtures

IOT CONTENT (%)	BSL	WAS	BSH

0	10.81	11.84	13.09
2	10.99	12.26	14.79
4	15.44	14.29	15.24
6	21.64	18.42	14.3
8	24.71	21.28	16.14
10	23.58	24.2	17.18
12	21.36	24.73	15.41
14	17.87	17.84	12.97
16	13.81	16.68	12.43

APPENDIX B

Table B4.1: Results of analysis of variance for cation exchange capacity of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
CEC	9	347	38.556	5.2278

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4201.4	1	4201.4	238.53	4.9281E-11	4.494
Within Groups	281.82	16	17.614			
Total	4483.2	17	_	_	_	_

Table B4.2a: Results of analysis of variance for liquid limit of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
LIQUID LIMIT	9	591.8	65.756	13.318

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	15011	1	15011	693.05	1.33367E-14	4.494
Within Groups	346.54	16	21.659			
Total	15357	17	_	_	_	_

Table B4.2b: Results of analysis of variance for plastic limit of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
PLASTI LIMIT	9	276.07	30.674	9.3693

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2313.6	1	2313.6	117.53	8.82764E-09	4.494
Within Groups	314.95	16	19.685			
Total	2628.5	17				

Table B4.2c: Results of analysis of variance for plasticity index of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
PLASTIC INDEX	9	315.73	35.081	9.9144

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3300.2	1	3300.2	165.37	7.50517E-10	4.494
Within Groups	319.32	16	19.957			
Total	3619.6	17				

Table B4.2d: Results of analysis of variance for linear shrinkage of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
LINEAR SHRINKAGE	9	194.42	21.602	10.2903

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	832.59	1	832.59	41.3296	8.33973E-06	4.494
Within Groups	322.32	16	20.145			
Total	1154.9	17				

Table B4.3a: Results of analysis of variance for maximum dry density (BSL Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
MDD	9	13.31	1.4789	0.0029

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	191.36	1	191.36	12.756	0.0025	4.494
Within Groups	240.02	16	15.001			
Total	431.38	17				

Table B4.3b: Results of analysis of variance for maximum dry density (WAS Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
MDD	9	14.36	1.5956	0.002

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	184.58	1	184.58	12.304	0.0029	4.494
Within Groups	240.02	16	15.001			
Total	424.59	17				

Table B4.3c: Results of analysis of variance for maximum dry density (BSH Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
MDD	9	14.97	1.6633	0.0018

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	180.69	1	180.69	12.045	0.0032	4.494
Within Groups	240.01	16	15.001			
Total	420.7	17				

Table B4.4a: Results of analysis of variance for optimum moisture content (BSL Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
OMC	9	219	24.333	4.5

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1200.5	1	1200.5	69.594	3.20657E-07	4.494
Within Groups	276	16	17.25			
Total	1476.5	17				

Table B4.4b: Results of analysis of variance for optimum moisture content (WAS Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
OMC	9	144.9	16.1	2.6025

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	295.25	1	295.25	18.112	0.0006	4.494
Within Groups	260.82	16	16.301			
Total	556.07	17				

Table B4.4c: Results of analysis of variance for optimum moisture content (BSH Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
OMC	9	123	13.667	3.535

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	144.5	1	144.5	8.6179	0.0097	4.494
Within Groups	268.28	16	16.768			
Total	412.78	17				

Table B4.5a: Results of analysis of variance for unconfined compressive strength (7 days curing period) , (BSL Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
UCS	9	2254.6	250.51	3395.9

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	264643	1	264643	154.5	1.23392E-09	4.494
Within Groups	27407	16	1712.9			
Total	292050	17				

Table B4.5b: Results of analysis of variance for unconfined compressive strength (7 days curing period), (WAS Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
UCS	9	3912.1	434.67	2447.7

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	819221	1	819221	661.26	1.9258E-14	4.494
Within Groups	19822	16	1238.9			
Total	839043	17				

Table B4.5c: Results of analysis of variance for unconfined compressive strength (7 days curing period), (BSH Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
UCS	9	6324	702.662	14018

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2171500	1	2171500	309.15	6.90388E-12	4.494
Within Groups	112385	16	7024.08			
Total	2283885	17				

Table B4.5d: Results of analysis of variance for unconfined compressive strength (14 days curing period), (BSL Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	Count	Sum	Average	Variance
IOT	9	72	8	30
UCS	9	3193.9	354.87	3364.5

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	541445	1	541445	319.01	5.4327E-12	4.494
Within Groups	27156	16	1697.3			
Total	568601	17				

Table B4.5e: Results of analysis of variance for unconfined compressive strength 14 days curing period), (WAS Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	Count	Sum	Average	Variance
IOT	9	72	8	30
UCS	9	3869.5	429.94	2021.4

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	801167	1	801167	781.09	5.22263E-15	4.494
Within Groups	16411	16	1025.7			
Total	817578	17				

Table B4.5f: Results of analysis of variance for unconfined compressive strength (14 days curing period), (BSH Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	Count	Sum	Average	Variance
IOT	9	72	8	30
UCS	9	5839.8	648.867	13972

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1848195	1	1848195	264	2.29179E-11	4.494
Within Groups	112014	16	7000.86			
Total	1960209	17				

Table B4.5g: Results of analysis of variance for unconfined compressive strength (28 days curing period) , (BSL Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	Count	Sum	Average	Variance
IOT	9	72	8	30
UCS	9	3763.2	418.13	5082.8

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	756930	1	756930	296.09	9.59175E-12	4.494
Within Groups	40902	16	2556.4			
Total	797832	17				

Table B4.5h: Results of analysis of variance for unconfined compressive strength (28 days curing period), (WAS Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	Count	Sum	Average	Variance
IOT	9	72	8	30
UCS	9	6623.1	735.901	20837

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2384280	1	2384280	228.53	6.79943E-11	4.494
Within Groups	166933	16	10433.3			
Total	2551213	17				

Table B4.5i: Results of analysis of variance for unconfined compressive strength (28 days curing period), (BSH Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	Count	Sum	Average	Variance
IOT	9	72	8	30
UCS	9	7517	835.226	20016

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3079360	1	3079360	307.23	7.2408E-12	4.494
Within Groups	160370	16	10023.1			
Total	3239729	17				

Table B4.5j: Results of analysis of variance for unconfined compressive strength (7 days curing and 7 days soaking period), (BSL Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	Count	Sum	Average	Variance
IOT	9	72	8	30
UCS	9	579.92	64.436	555.37

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	14332	1	14332	48.969	3.00764E-06	4.494
Within Groups	4682.9	16	292.68			

Total	19015	17				

Table B4.5k: Results of analysis of variance for unconfined compressive strength (7 days curing, 7 days soaking) test results (WAS Compaction)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
UCS	9	706.89	78.543	677.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	22394	1	22394	63.277	5.96925E-07	4.494
Within Groups	5662.4	16	353.9			
Total	28056	17				

Table B4.5l: Results of analysis of variance for unconfined compressive strength (7 days curing, 7 days soaking period), (BSH Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
UCS	9	852.97	94.774	366.11

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	33884	1	33884	171.08	5.84737E-10	4.494
Within Groups	3168.9	16	198.06			
Total	37053	17				

Table B4.6a: Results of analysis of variance for California bearing ratio (Unsoaked), (BSL Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
CBR	9	111.64	12.404	11.96

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	87.296	1	87.296	4.1609	0.0582	4.494
Within Groups	335.68	16	20.98			
Total	422.98	17				

Table B4.6b: Results of analysis of variance for California bearing ratio (Unsoaked), (WAS Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
CBR	9	135.44	15.049	11.811

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	223.59	1	223.59	10.695	0.0048	4.494
Within Groups	334.49	16	20.905			
Total	558.08	17				

Table B4.6c: Results of analysis of variance for California bearing ratio

(Unsoaked), (BSH Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
CBR	9	200.5	22.278	19.738

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	917.35	1	917.35	36.887	1.61259E-05	4.494
Within Groups	397.9	16	24.869			
Total	1315.2	17				

Table B4.6d: Results of analysis of variance for California bearing ratio (Soaked), (BSL Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
CBR	9	38.06	4.2289	1.1831

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	63.996	1	63.996	4.1045	0.0598	4.494
Within Groups	249.46	16	15.592			
Total	313.46	17				

Table B4.6e: Results of analysis of variance for California bearing ratio (Soaked), (WAS Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	Count	Sum	Average	Variance
IOT	9	72	8	30
CBR	9	56.65	6.2944	2.9977

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	13.09	1	13.09	0.7934	0.3863	4.494
Within Groups	263.98	16	16.499			
Total	277.07	17				

Table B4.6f: Results of analysis of variance for California bearing ratio (Soaked), (BSH Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	Count	Sum	Average	Variance
IOT	9	72	8	30
CBR	9	79.22	8.8022	4.1019

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.896	1	2.896	0.1698	0.6857	4.494
Within Groups	272.82	16	17.051			
Total	275.71	17				

Table B4.7a: Results of analysis of variance for resistance to loss in strength (BSL Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	Count	Sum	Average	Variance
IOT	9	72	8	30

DURABILITY	9	160.21	17.801	28.163

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	432.28	1	432.28	14.864	0.0014	4.494
Within Groups	465.31	16	29.082			
Total	897.58	17				

Table B4.7b: Results of analysis of variance for resistance to loss in strength (WAS Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
DURABILITY	9	161.54	17.949	22.634

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	445.41	1	445.41	16.925	0.0008	4.494
Within Groups	421.07	16	26.317			
Total	866.48	17				

Table B4.7c: Results of analysis of variance for resistance to loss in strength (BSH Compaction) of black cotton soil-iron ore tailing mixtures

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
IOT	9	72	8	30
DURABLITY	9	131.55	14.617	2.4829

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	197.01	1	197.01	12.13	0.0031	4.494
Within Groups	259.86	16	16.241			
Total	456.87	17				

Table B4.8: Results of two way analysis of variance for maximum dry density of iron tailing-compactive effort

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
0 % IOT	3	4.49	1.49667	0.01143
2 % IOT	3	4.57	1.52333	0.01123
4 % IOT	3	4.67	1.55667	0.00823
6 % IOT	3	4.72	1.57333	0.00743
8 % IOT	3	4.77	1.59	0.0084
10 % IOT	3	4.81	1.60333	0.00743
12 % IOT	3	4.83	1.61	0.0073
14 % IOT	3	4.87	1.62333	0.00813
16 % IOT	3	4.91	1.63667	0.00943
BSL	9	13.31	1.47889	0.00286
WAS	9	14.36	1.59556	0.00203
BSH	9	14.97	1.66333	0.0018

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
IOT	0.05211852	8	0.00651	74.8511	3.23624E-11	2.5911
COMPACTIVE EFFORT	0.15667407	2	0.07834	900.043	3.63E-17	3.63372
Error	0.00139259	16	8.7E-05			
Total	0.21018519	26				

Table B4.9: Results of two way analysis of variance for optimum moisture content of iron tailing-compactive effort

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
0 % IOT	3	63.5	21.1667	41.3333
2 % IOT	3	60	20	28
4 % IOT	3	58.2	19.4	29.23
6 % IOT	3	55.4	18.4667	33.4533
8 % IOT	3	53.5	17.8333	30.0833
10 % IOT	3	50.5	16.8333	30.0833
12 % IOT	3	48.8	16.2667	30.9633
14 % IOT	3	48	16	33.25
16 % IOT	3	49	16.3333	26.3333
BSL	9	219	24.3333	4.5
WAS	9	144.9	16.1	2.6025
BSH	9	123	13.6667	3.535

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
IOT	82.1	8	10.2625	54.7333	3.58E-10	2.5911
COMPACTIVE EFFORT	562.46	2	281.23	1499.89	6.27704E-19	3.63372
Error	3	16	0.1875			
Total	647.56	26				

Table B4.10a: Results of two way analysis of variance for unconfined compressive strength (7 days curing period) of iron tailing-compactive effort

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
0 % IOT	3	949.78	316.593	19181
2 % IOT	3	1188.75	396.25	40383.3

4 % IOT	3	1298.44	432.813	52498.5
6 % IOT	3	1364.81	454.937	60614.2
8 % IOT	3	1452.94	484.313	61958.4
10 % IOT	3	1551.64	517.213	68928.9
12 % IOT	3	1597.74	532.58	70982.2
14 % IOT	3	1563.75	521.25	61425
16 % IOT	3	1522.72	507.573	48026.3
BSL	9	2254.56	250.507	3395.9
WAS	9	3912.05	434.672	2447.75
BSH	9	6323.96	702.662	14018.2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
IOT	121440	8	15180	6.48466	0.00078	2.5911
COMPACTIVE EFFORT	930541	2	465270	198.756	5E-12	3.63372
Error	37454.5	16	2340.91			
Total	1089435	26				

Table B4.10b: Results of two way analysis of variance for unconfined compressive strength (14 days curing period) of iron tailing-compactive effort

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
0 % IOT	3	1043.38	347.793	12137.9
2 % IOT	3	1198.58	399.527	10349.5
4 % IOT	3	1306.63	435.543	14362.3
6 % IOT	3	1403.25	467.75	21367.9
8 % IOT	3	1450.84	483.613	24912.7
10 % IOT	3	1540.39	513.463	27185.4
12 % IOT	3	1607.95	535.983	34606.8
14 % IOT	3	1667.45	555.817	42381.6
16 % IOT	3	1684.69	561.563	36055.2
BSL	9	3193.86	354.873	3364.53
WAS	9	3869.5	429.944	2021.4
BSH	9	5839.8	648.867	13971.7

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
IOT	128127	8	16015.8	9.58511	7.90706E-05	2.5911
COMPACTIVE EFFORT	419984	2	209992	125.676	1.64553E-10	3.63372
Error	26734.5	16	1670.91			
Total	574845	26				

Table B4.10c: Results of two way analysis of variance for unconfined compressive strength (28 days curing period) of iron tailing-compactive effort

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
0 % IOT	3	1415.5	471.833	32792.1
2 % IOT	3	1683.86	561.287	30096.8
4 % IOT	3	1755.61	585.203	30578.7
6 % IOT	3	1843.85	614.617	35684.5
8 % IOT	3	1950.87	650.29	41297.2
10 % IOT	3	2107.11	702.37	54411
12 % IOT	3	2261.62	753.873	66989.7
14 % IOT	3	2411.07	803.69	74359.2
16 % IOT	3	2473.79	824.597	78001
BSL	9	3763.17	418.13	5082.75
WAS	9	6623.11	735.901	20836.6
BSH	9	7517	835.222	20014.9

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
IOT	333480	8	41685.1	19.6205	6.84115E-07	2.5911
COMPACTIVE EFFORT	854427	2	427214	201.083	4.59375E-12	3.63372
Error	33993	16	2124.56			
Total	1221901	26				

Table B4.10d: Results of two way analysis of variance for unconfined compressive strength (7 days curing + 7 days soaking periods) of iron tailing-compactive effort

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
0 % IOT	3	126.82	42.2733	295.191
2 % IOT	3	155.66	51.8867	457.358
4 % IOT	3	195.86	65.2867	343.118
6 % IOT	3	243.68	81.2267	62.4296
8 % IOT	3	287.1	95.7	93.6601
10 % IOT	3	321.31	107.103	230.797
12 % IOT	3	314.54	104.847	299.69
14 % IOT	3	259.16	86.3867	238.524
16 % IOT	3	235.65	78.55	348.847
BSL	9	579.92	64.4356	555.368
WAS	9	706.89	78.5433	677.799
BSH	9	852.97	94.7744	366.112

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
IOT	12203.8	8	1525.47	41.3372	2.99427E-09	2.5911
COMPACTIVE EFFORT	4148.78	2	2074.39	56.2117	5.80503E-08	3.63372
Error	590.45	16	36.9031			
Total	16943	26				

Table B4.11: Results of two way analysis of variance for California bearing ratio (unsoaked) of iron tailing-compactive effort

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
0 % IOT	3	32.78	10.9267	13.521
2 % IOT	3	38.06	12.6867	23.236
4 % IOT	3	43.43	14.4767	36.29
6 % IOT	3	46.46	15.4867	41.4825
8 % IOT	3	53.1	17.7	49.7203
10 % IOT	3	57.63	19.21	48.5172
12 % IOT	3	63.81	21.27	46.0831
14 % IOT	3	57.03	19.01	6.3247
16 % IOT	3	55.28	18.4267	5.62973
BSL	9	111.64	12.4044	11.9603
WAS	9	135.44	15.0489	11.8108
BSH	9	200.5	22.2778	19.7378

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
IOT	276.66	8	34.5825	7.74834	0.00028	2.5911
COMPACTIVE EFFORT	470.198	2	235.099	52.6748	9.1E-08	3.63372
Error	71.4114	16	4.46321			
Total	818.269	26				

Table B4.12: Results of two way analysis of variance for California bearing ratio (soaked) of iron tailing-compactive effort

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
0 % IOT	3	12.09	4.03	1.3351
2 % IOT	3	13.89	4.63	2.5753
4 % IOT	3	16.59	5.53	3.5401
6 % IOT	3	19.21	6.40333	5.45443
8 % IOT	3	21.15	7.05	4.6033
10 % IOT	3	23.78	7.92667	6.13343
12 % IOT	3	25.68	8.56	8.0499
14 % IOT	3	22.66	7.55333	11.9554
16 % IOT	3	18.88	6.29333	9.31293
BSL	9	38.06	4.22889	1.18309
WAS	9	56.65	6.29444	2.99768
BSH	9	79.22	8.80222	4.10189

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
IOT	54.7539	8	6.84424	9.51636	8.26591E-05	2.5911
COMPACTIVE EFFORT	94.4125	2	47.2063	65.6365	1.94078E-08	3.63372
Error	11.5073	16	0.71921			
Total	160.674	26				

Table B4.13: Results of two way analysis of variance for resistance to loss in strength of iron tailing-compactive effort

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
0 % IOT	3	35.74	11.9133	1.30363
2 % IOT	3	38.04	12.68	3.7423
4 % IOT	3	44.97	14.99	0.3775
6 % IOT	3	54.36	18.12	13.5364
8 % IOT	3	62.13	20.71	18.6049
10 % IOT	3	64.96	21.6533	15.1041
12 % IOT	3	61.5	20.5	22.2703
14 % IOT	3	48.68	16.2267	7.95463
16 % IOT	3	42.92	14.3067	4.70063
BSL	9	160.21	17.8011	28.1633
WAS	9	161.54	17.9489	22.6337
BSH	9	131.55	14.6167	2.4829

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
IOT	314.849	8	39.3561	5.65308	0.00163	2.5911
COMPACTIVE EFFORT	63.7987	2	31.8993	4.582	0.02671	3.63372
Error	111.39	16	6.96189			
Total	490.038	26				

Formatted: Left

Table

Page

Table **Page**

Table

Page

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
BS	British Standard
BSH	British Standard heavy
BSL	British Standard light
CEC	Cation Exchange Capacity
F_{CRIT}	F- Critical value
F_{STAT}	F- Statistic
IOT	Iron Ore Tailing
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content

PL	Plastic Limit
PI	Plasticity Index
USCS	Unified Soil Classification System
WAS	West African Standard