THE EFFECT OF ELAPSED TIME AFTER MIXING ON BAGASSE ASH MODIFIED BLACK COTTON SOIL

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BY

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JUNE, 2016

DECLARATION

I declare that the work in this dissertationentitled “The Effect of Elapsed Time after Mixing on Bagasse Ash Modified Black Cotton Soil” has been carried out by me in the Department of Civil Engineering. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree at this or any other institution.

SANI, REUBEN ORUMAH

Student	**Signature**	**Date**

CERTIFICATION

This dissertationtitled “THE EFFECT OF ELAPSED TIME AFTER MIXING ON BAGASSE ASH MODIFIED BLACK COTTON” by Reuben Orumah SANI meets the regulation governing the award of the degree of Master of Science in Civil Engineering of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This research work is dedicated to the Almighty God who made it possible for me toundertake this masters program, my late parents whose desire was to see their children progress academically, my wife; Gushiji Patience Sani and to my brother and sisters.

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ABSTRACT

Engineers are often faced with the problem of constructing on black cotton soils, because of their unsuitable behaviour for construction.The preliminary investigation conducted on the natural black cotton soil collected fromDeba, Deba Local Government Area of Gombe State shows that it falls under A-7-6(16) AASHTO classification and CL according to Unified Soil Classification System (USCS). The soil was treated with bagasse ash (BA) in stepped concentrations of 0, 2, 4, 6 and 8 % by dry weight of soil. The effect of elapsed time after mixing on modified soil was studied with respect to specific gravity, particle size distribution, Atterberg limits, cation exchange capacity, compaction characteristics and shear strength parameters using three (3) compactive efforts namely, British Standard light (BSL), West African Standard (WAS) and British Standard heavy (BSH). Test results of the black cotton soil - bagasse ash mixtures considered showed a decrease in the specific gravity and percentage of fines of the natural soil with increase in bagasse ash treatment it also showed adecrease in the cation exchange capacity (CEC) and plastic limit values with increase in bagasse ash treatment till an optimum mix of4 % BAand consequently increased with further increase in BA treatment.The liquid limit values increased with increase in bagasse ash treatment till an optimum mix of 4 % BAand consequently decreasedwith further increase in BA treatment.The plasticity indices of all the test samples were within the 30 % value prescribed for sub grade by the Nigeria General Specifications. Test results showed that values of maximum dry density (MDD)and cohesion decreased while optimum moisture content (OMC) and angle of internal friction increased with an increase in elapsed time after mixing for BSL, WAS and BSH compactions. Statistical analysis was carried out on results obtained using analysis of variance (ANOVA) with the Microsoft Excel Analysis Tool Pak Software Package. An optimal 4 % BA treatment of black

cotton soil when compacted with British Standard heavy energy is recommended for use as a sub-grade material of lightly trafficked roads and a maximum elapsed time of 2 hours after mixing should not be exceeded.

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ABBREVIATIONS

AASHTO	-	American Association of State Highway and Transportation Officials
ANOVA	-	Analysis of Variance
ASTM	-	American Society for Testing and Materials
BA	-	Bagasse Ash
BS	-	British Standard
BSH	-	British Standard heavy
BSL	-	British Standard light
c	-	Cohesion
CEC	-	Cation Exchange Capacity
F_{cal}	-	F -calculated
F_{crit}	-	F -critical
LL	-	Liquid Limit
MDD	-	Maximum Dry Density
OMC	-	Optimum Moisture Content
PI	-	Plasticity Index

CHAPTER ONE

INTRODUCTION

1.1 Preamble

Soilsare used as load bearing materials for construction. When used for this purpose, soilshould possesengineering properties to meet requirements such as highstrength and low settlement (Vincy and Muttharam, 2009). In many situations, the soil present in the field may be a problematic one such asexpansive soils. Black cotton soil is an example of an expansive soil. Black cotton soils are known as vertisols, Chernozens, Gilgais; self mulching soils; self swallowing soils; black cracking clays; Vleis; Wadi soils (Greenfield. 2004). Warren and Kirby (2004) referred to expansive soils as "swelling soils", "heaving soils" and "volume change" soils. Black cotton soils occur principally in hot environments, in the semi arid tropics with marked alternating wet and dry seasons, they are generally found on sedimentary plains as the result of thousands of years of erosion of the clay content out of the surrounding hills. They can also be found on level land and in depressions. Black cotton soil swells and shrinks with changes in moisture content. The reason for this behavior is the presence of certain type of mineral known as monmorillonitewhich has an expanding lattice (Hussein, 2001).

Black cotton soils cover an estimated 340million hectare, or about 3% of the world's cultivatable soils (Greenfield. 2004). They are found in India, Australia, South Western U.S.A (Tomlinson. 1999), South Africa and Israel (Ola, 1978). They are also found in the northeastern parts of Nigeria, Cameroon, Lake Chad basin, Sudan, Ethiopia, Kenya, South Zimbabwe and other Eastern African countries. Black cotton soils in Nigeria occupy an estimated area of 104,000km^2 in the north eastern part of the country (Osinubi et al., 2011).

Engineers are often faced with the problem of constructing on black cotton soils, because of their unsuitable behaviour for construction.The characteristic swelling and shrinkage of black cotton soils causes damage to many loaded structures. Therefore, at times it is necessary to modify or stabilize these soils to provide a stable sub grade or a working platform for the construction of buildings and pavements (Design Procedures, 2013).Sugar cane is a major commercially grown agricultural crop in the vast majority of countries in Africa. Sugar cane is a major raw material for sugar production; it is grown on 25-30,000 hectare; with a production rate of 80 tons/hectare in Nigeria (Misari et al. 1998).Bagase is the cellulose fiber remaining after extraction of sugar – bearing juice from sugar cane.Bagasse has come to be regarded as a fuel rather than refuse in the sugar mills (Paya, et al., 2007). Biomass is an important source of energy in tropical countries like Thailand (Ojha et al., 2004).Burning bagasse as an energy source yields its ash, considered as a waste causing disposal problems (Kuprianovaetal.,2006).Bagasse ash possesses pozzolanic substances in the form of oxides of silica, alumina and iron therefore they can be used to modify black cotton soils.

Modification is a process of altering the engineering properties of soils such as hydraulic conductivity, workability, swelling potential and volume change tendencies.The term modification is used only when the sole aim of the process is to make the soil workable and the long term effects are not taken into account (Daita et al., 2005).The benefits of soil modification include reduction in, plasticity moisture-holding capacity (drying), and swell, improved stability, and the ability to construct a solid working platform. These benefits expedite construction and save time and money (Design Procedures, 2013).

Construction specification commonly requires that compaction and final shaping should be carried out as soon as possible after mixing/placing is completed, but usually this is not the

case. Sometimes, there is a delay between mixing/placing and compaction because of some unforeseen circumstances like machine breakdown, injury to workers in the field, among others, (Okonkwo, 2009). Elapsed time or delay time is the interval between mixing and compaction of the soil with the modifier so as to produce desired and workable properties of the problem soil (Trindade, 2005).

1.1 Statement of the Problem

Nowadays, it is commonplace to reutilize sugar cane bagasseas a biomass fuel in boilers for vapor and power generation insugar factories. (Kulkarmi et al 2013). The major problem in every sugar industry is how to dispose effectively the bagasse ash generated. Bagasse ash possesses pozzolanic properties therefore it can be used as a replacement of the conventional lime and cement used during modification processes of problematic soils and to help dispose wastes in sugarcane industries.

An improvement in the frictional characteristics, durability properties and a reduction in plasticity characteristics of expansive soils can be achieved by modification. During modification, construction specification commonly requires thatcompaction and final shaping should be carried out as soon as possible after mixing/placing is completed but usually this is not the case as a result ofdelay between mixing/placing and compaction because of some unforeseen circumstances such as;machine breakdown, injury of workers on the field, Sudden raining, insufficient workers, etc.Effects of elapsed time have been investigated for conventional stabilizers such as cement and lime. Research on bagasse ash black cotton soil mixtures focused on strength development and no attention was given to elapsed time which may occur due to unforeseen circumstances highlighted above. The compaction delays on mixing of black cotton

soil with modifiers have effect on the strength properties and density of the soil that is to be developed after compaction. Therefore there is need to investigate these properties experimentallyfor up to 1–3hours elapsed time after mixing to define the minimum values that can be achieved in the field.

1.2 Justification for the Study

The presence of swelling clay minerals mainly montmorillonite in black cotton soils, makes it to expand and contract as a result of wetting and drying. This contraction leads to the formation of wide and deep cracks. Though special designs may be implemented at higher cost on structures and pavements which are directly constructed on this soil, without proper modification and stabilization processes, they eventually get damaged.

Numerous methods are known and used in the modification/stabilization of black cotton soil but each method is based on how economical and if it would help achieve the desired soil properties. Chemical modifiers and stabilizers are commonly used to improve the performance of high plasticity soils, soils with high volumetric changes, poor workability, and low strength. Lime, cement and fly ash or their combinations are typically used for this purpose.

Sometimes, delay time after mixing is unavoidable one due to the followings reasons; sudden raining, delaying of compaction equipments after mixing, insufficient workers, poor transportations etc. these makes the modification process a delayed one. This delayed time might affect the workability of modified soils. In addition it could lead to hydration reaction of the modifier with soil, evaporation of mixed water. Therefore, while planning for the modification of soils with bagasse ash, the aspect of loss of workability in the likely transit time involved must be taken into account.

1.3 Aim and Objectives

This study is aimed at the evaluation of the effect of elapsed time after mixing on the properties of bagasse ash modified black cotton soil.

The following were the objectivesthat were to be achieved:

1. Determination of the index properties of the natural and modified black cotton soils.
2. Evaluation of cation exchange capacity of black cotton soil – bagasse ash mixtures.
3. Determination of the moisture-density relationships of up to 3 hours compaction delay for different compactive efforts (British Standard light, BSL, West African Standard, WASand British Standard heavy, BSH)
4. Determination of shear strength parameters of natural and treated soil with compaction delays.
5. Microanalysis of the optimal blackcotton soil-bagasse ash mixture using scanning electron microscope.
6. Determination of the permissible elapsed time after mixing for thebagasse ash modifiedblack cotton soil.

1.4 Scope of the Study

The study involves the determination of the properties of black cotton soil modified with up to 8 % bagasse ash content for1, 2, and 3 hours delays after mixing using three compaction energies (British Standard light, BSL, West African Standard, WAS and British Standardheavy, BSH).

1.5 Significance of the Study

Delay after mixing is unavoidable due to foreseen and unforeseen circumstances therefore this research work would determinethe allowable maximum elapsed time after mixing bagasse ash with black cotton soil beyond which undesirable results/properties would be obtained.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

To geotechnical and highway engineers, a problem soil is one that poses problem to construction. Such problem may be as a result of instability of the soil which makes it unsuitable as a construction material in foundations, buildings, highways, water retaining structures, dams, etc., (Ola. 1987).Problematic soils such as expansive soils are normally encountered in foundation engineering designs for embankments, retaining walls, backfills etc. Expansive soils are normallyfound in semi – arid regions of tropical and temperate climate zones and are abundant, where theannual evaporation exceeds the precipitation and can be found anywhere in the world (Chen,1975; Warren and Kirby; 2004).Swelling/expansive/black cotton soils are one of Nigeria's prevalent causes of damage to buildings and other construction works. Possible damages that can be caused by expansive soils includes; foundation cracks, severe structural damage, heaving and cracking of sidewalks, roads and basement floors, ruptured pipelines, jammed doors and windows. The destructive force may be upward, horizontal or both, (www.geosurvey.state.co.us. 2007Accessed 8th September 2014.).

A majorconcern in geotechnical engineering is identification of expansive soils and estimation oftheirswelling magnitudes when subjected to changes in environment (SubbaRao andSatyadas, 1987; Day, 1994; Al-Homoud*et al.*, 1995).In order to make expansive soils useful and meet geotechnical engineering designrequirements researchers (Osinubi, 1997; 2000a,b; Moses, 2008; Alhassan and Mustapha, 2007;Osinubi and Medubi, 1998; Medjo and Riskowiski, 2004; Osinubi and Eberemu, 2006; Osinubiand Stephen, 2006) have focused more on the use of

potentially cost effective materials that arelocally available from industrial and agricultural waste in order to improve the properties ofdeficient soils.

2.2 Black Cotton Soil

Black cotton soils are formed under conditions of poor drainage from basic rocks or limestone under alternating wet or dry climatic conditions.Black cotton soils are problematic for Civil Engineers, because of their unconventional behaviour. About 40- 60 % or more of the particle size of black cotton soil (BCS) is less than 0.001 mm. At the liquid limit of black cotton soil, the volumechange is between 200 and 300 %, resulting in swelling pressure as highas 7.85 kN/m^2 to 9.81 kN/m^2. The soil therefore, has very low bearingcapacity and high swelling and shrinkage characteristics.These soilsshow large volume changes with respect to variation of seasonal moisture content. These soils when subjectedto vehicular traffic, road pavement gets heaved andcracked due to swelling and shrinkage. (Srideviet al., 2005). Black cotton soils owe their specific properties to the swelling clay minerals mainly montmorillonite. As a result of the wetting and drying, massive expansion and contraction of the clay minerals takes place.

2.2.1 Origin of black cotton soil

Black cotton soils are black clays that are produced from thebreakdown of basic igneous rocks, where seasonal variation of weather is extreme.Nigerian black cotton soils are formed from the weathering of shaly and clayeysediments and basaltic rocks. The Nigerian black cotton soil contains more ofmontmorillonite with subsequent manifestation of swell properties and expansivetendencies (Ola, 1983).The parent igneous rocks are made up of calcium-rich feldspar and darkminerals which are high in the weathering order and all the constituents areweathered to form amorphous hydrous oxide and under suitable conditions clayminerals develop. The absence

of quartz leads to the formation of fine grainedplastic soil highly impermeable and easily waterlogged. Other conditionsfavouring the formation of black cotton soil are evaporation exceeding precipitation, poorleaching, alkaline conditions and retention of magnesium and calcium in the soil(Ola, 1983).

2.2.2 Problems associated with black cotton soil

Black cotton soils are themajor problem soils in Nigeria where they occupy an estimated area of 104,000km^2 in the north easternpart (Osinubi et al., 2011). Contraction of black cotton soils as a result of repeated wetting and drying of the soil leads to the formation of wide and deep cracks (see Fig 2.1). Surface materials accumulate in these cracks during the dry season and are "swallowed" by the soil in the wet season, creating the self mixing or self mulching action of the black cotton soils. The cracks close after rain when the clay minerals swell. Black cotton soils are difficult to work, they are of very hard consistence when dry and very plastic and sticky when wet. Therefore the workability of the soil is often limited to very short periods of (optimal) water status.



Fig. 2.1 Dry season deep cracks in roughly polygonal patterns of black cotton soil (Gandhi, 2012)

In road construction, expansive clay sub grades have low strength in wetconditions and lead to sub grade intrusion into overlyinglayer and penetration of sub base material into it(Holz.1959; Stevens and Matlock, 1986; Steinberg, 1985).Pavements constructed over expansive soil sub grades exhibit cracksresulting from alternate heave and settlement that leadto ultimate failure of pavements.

2.2.3 Mineralogy and chemical composition of black cotton soil

Black cotton soils owe their specific properties to the swelling clay minerals mainly montmorillonite. Clay minerals are complex silicates of aluminum, magnesium, and iron.Twobasic crystalline units form the clay minerals: (1) a silicon–oxygen tetrahedron,and (2) an aluminum or magnesium octahedron. A silicon-oxygen tetrahedron unit shown in Fig. 2.2a consists of four oxygen atoms surrounding a silicon atom. The tetrahedron units combine to form a *silicasheet*, an octahedral unit consisting of six hydroxylunits surrounding an aluminum (or a magnesium) atom. The combinationof the aluminium octahedral units forms a *gibbsite sheet* (see Fig. 2.2*b*). Ifthe main metallic atoms in the octahedral units are magnesium, these sheetsare referred to as *brucite sheets*.

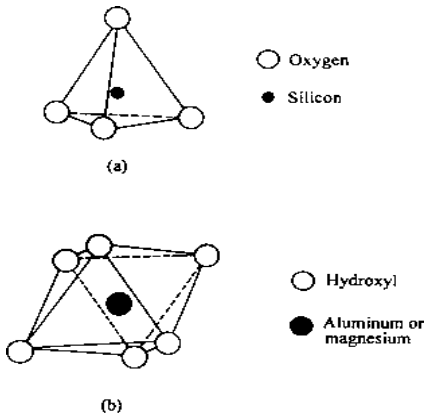


Fig. 2.2 (a) Silicon-oxygen tetrahedron unit and (b) Aluminium or magnesium octahedral unit (Braja. 2008)

The montmorillonite mineral consists of repeated layers of a three-layer sheet of an octahedral sheet in the middle with one silica sheet at the top and one at the bottom with a large amount of water attracted into the space between the three-sheet layers (see fig 2.3).

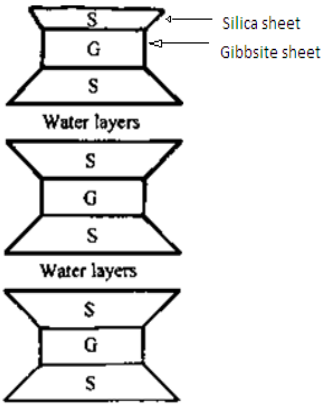


Fig. 2.3 Symbolic structure of montmorllonite (Braja. 2008)

The specific surface (in m^2/g) of montmorillonite is 800 m^2/g and its cation exchange capacity is 100 me/100g. To balance the negative charge, the clay particles attract positively charged ions from salts in their pore water. These are referred to as exchangeable ions. Some are more strongly attracted than others. The cation exchange capacity (CEC) of clay is the amount of exchangeable ions, expressed in milliequivalents, per 100g of dry clay.

2.3 Sugarcane Bagasse Ash

The sugarcane plant is an agricultural crop that is known to have bioconversion efficiency of capture of sunlight as a result of which a high amount of atmospheric carbon is fixed into biomass. Bagasse is a cellulose fiber remaining after the extraction of the sugar bearing juice from sugarcane. After burning, the ash that remains is known as bagasse ash. Bagasse ash is one of the biomass sources and valuable byproducts in sugar milling that often uses bagasse as a primary fuel source to supply all the needs of energy to move the plants. Burning bagasse as an

energy source yields its ash considered as a waste causing disposal problems. (kuprianova et al., 2006). Several studies have investigated bagasse ash potentialapplications such as producing silica gel as adsorbent rawmaterial for ceramic, cements and concrete additives, catalyst,cosmetics, paint and coating, etc (Fotovat et al., 2007; Vital et al., 2008; Kuprianova et al 2006,) based on itscharacteristic. The silica contents of bagasse and its ash arevaried depending on the type of soil and harvesting (Fotovat et al., 2007). The sugarcane bagasse cogeneration is environment friendly and the exploitation of sugarcane bagasse as an annually renewable energy resource carries a high priority in the context of global warming (Deepchand, et al., 2005).

Many plants absorb silica from the ground during growth. When theyare burnt up, ash that is left as residue consists of mainly silica which canreact with lime to form insoluble cementitious compounds. This explains thepozzolanic properties or characteristics of plants such as rice, sugarcane (bagasse) and locust bean when burnt to ashes. Pozzolan is defined as "asiliceous or alumino-siliceous material that possesses little or nocementitious value but in finely divided form and in the presence ofmoisture will chemically react with alkali and alkaline earth hydroxide atordinary temperatures to form or assist in forming compounds possessingcementitious properties" (ASTM C618, 1978). In a work done on the development of bagasse ash as a pozzolanic material in concrete, the original bagasse ashes were not suitable to be used as pozzolanic materials. However, the ground bagasse ashes with particles passing sieve No. 325 (0.044mm aperture size) and used at 20% cement replacement gave compressive strengths of 80-100% of cement mortar at 28days. When the ground bagasse ashes was made finerand used at the same percentage of replacement, the compressive strengths were 98-103% of cement mortar at 28days. It was then concluded that the fineness and percentage replacement of

bagasse ash is more pronounced on the compressive strengths of bagasse ash mortars, rather than the chemical composition (Chusilpet al., 2009).ASTM specifications for pozzolanas are as summarized in Table 2.1

Table 2.1: Properties of Pozzolanas

Property	Class N	Class F	Class C
SiO_2+Al_2O_3 + Fe_2O_3 (%)	70	70	70
SO_3 (Max%)	4	5	5
MgO (max %)	5	5	5
Loss on Ignition	10	2	6
Physical Properties			
Moisture Content (%)	3	3	3
Fineness (%) on Sieve Number 200	85	85	85
Pozzolanic Activity			
Index with OPC at 28days (%)	75	75	75
Pozzolanic Activity Index with lime at 7days	5.5	5.5	5.5

Source: (ASTM C618, 1992)

2.4 Modification

Engineers are often faced with theproblem of carrying out construction works on or with soils, which do not possess sufficient strength tosupport loadings; either wheel loads in pavements or imposed loads from buildings that are imposed upon them either in construction or during the service life of the infrastructure. It is, at times, necessary to treat these soils to provide a stable sub grade or a workingplatform for the construction. The result of these treatments are that less timeand energy is required in the production, handling, and placement of buildings, road and bridge fills andsub grades and therefore, less time to complete the construction process thus reducing thedisruption and delays during construction.

The term modification is used only when the sole aim of the process is to make the soil workable and the long term effects are not taken into account (Daita et al., 2005).The benefits of soil modification include reduction in plasticity, moisture-holding capacity (drying), and swell, improved stability, and the ability to construct a solid working platform. These benefits expedite construction and save time and money (Design Procedures, 2013). The methods of sub grade modification include physical processes such as soil densification, blends with granular material, use of reinforcements (geogrids), undercutting and replacement, and chemical processes such as mixing with cement, fly ash, lime, bagasse ash, rice husk ash and blends of any one of these materials.

2.4.1 Types of modification

2.4.1.1 *Mechanical modification*

This is the process of altering soil properties by changing the gradation through mixing withother soils, densifying the soils using compaction efforts, or undercutting the existing soils andreplacing them with granular material.A common remedial procedure for wet and soft sub grade is to cover it with granular material orto partially remove and replace the wet sub grade with a granular material to a pre-determineddepth below the grade lines. The compacted granular layer distributes the concentrated loads, point loads or wheel loads over awider area and serves as a working platform.

To provide a firm-working platform with granular material, the following conditions shall bemet(Thomson, 1977).

1. The thickness of the granular material must be sufficient to develop acceptable pressuredistribution over the wet soils.

2. The backfill material must be able to withstand wheel load without rutting.

3. The compaction of the backfill material should be in accordance with the StandardSpecifications.

2.4.1.2 *Chemical modification*

The transformation of soil index properties by adding chemicals such as cement, fly ash, lime, bagasse ash, rice husk ash ora combination of these, often alters the physical and chemical properties of the soil including thecementation of the soil particles. There are two primary mechanisms by which chemicalsalter the soil into a stable sub grade (Design Procedures for Soil Modification or Stabilization, 2013):

1. Increase in particle size by cementation, internal friction among the agglomerates, greater shear strength, reduction in the plasticity index, and reduced shrink/swell potential.
2. Absorption and chemical binding of moisture that will facilitate compaction.

2.5 Compaction Delay

Construction specification requires that compaction and final shaping should be carried out as soon as possible after mixing/placing is completed, but usually this is not the case. Sometimes, there is a delay between mixing/placing and compaction because of some unforeseen circumstances like machine breakdown, injury to workers in the field, among others (Okonkwo, 2009). Elapsed time or delay is the interval between mixing and compaction of the soil with the modifier so as to produce desired and workable properties of the problem soil (Trindade, 2005).

Some researchers (Osinubi, 1998, Osinubi and Katte, 1997; Obeahon, 1993) worked on lateritic soil with respect to elapse time after mixing. From work done on the effects of elapsed time on the properties of cement –bagasse ash modified black cotton soil, it was observed that both cohesion and angle of internal friction decreased with increase in elapsed time between

mixing and compaction. For the modification of black cotton soil, it was recommended that an optimal blend of 4% ordinary Portland cement/4%bagasse ash be used. Based on shear strength parameters consideration, the elapsed time between mixing and compaction was recommended not to exceed 2 hours. (Isah, 2009).

Ochepo(2008) carried out a study of the effect of elapsed time on the geotechnical properties of lime – bagasse ash stabilized black cotton soil. An optimal 6% lime/8% bagasse ashtreatment of black cotton soil when compacted with British Standard heavy energy was recommended. Furthermore, the delay between mixing and compaction should not exceed one and half hours.

2.6 Studies carried outusing Bagasse Ash

Thomas (2006) carried out a study on the stabilization potential of bagasse ash on black cotton soil. The study showed that the addition of bagasse ash improved the engineering properties of black cotton soil. But the results obtained from the laboratory testing placed the soil below the Nigeria General Specification (1997) requirement of liquid limit, plasticity index, and percentage passing BS sieve No 200 less than 40, 18 and 50%, respectively, it was concluded that since the 10% optimal strength value of treated soil does not meet the minimum specified in the Nigerian General Specifications (1997), the treated soil can be stabilized with a more potent stabilizer like cement.

Osinubi and Stephen (2007) carried out a study on the influence of compactive efforts on bagasse ash treated black cotton soil. The West African Standard (WAS) compaction energy which is conventionally used in theregion yielded California bearing ratio (CBR) value of 11 %. A 2% bagasse ash treatment of soil was recommended for use as sub grade of lightly trafficked roads in view of expected increase in strength due to time-dependent pozzolanic reactions.

On the use of bagasse ash in concrete and its impact on the strength and chloride resistivity, Noor-ul (2011) reported that bagasse ash is an effective mineral admixture and pozzolan with the optimal replacement ratio of 20% cement. He also reported that chloride diffusion was reduced by more than 50% without any adverse effects on the other properties of the hardened concrete.

Microanalysis of Specimens

The microscopic structure of fine-grained soils can be used as an index in identifying the type ofenvironmental processes and in estimating their resistance (Bennett et al., 1991).Transverse electron microscopy (TEM), scanning electron microscopy (SEM), and atomic force microscopy(AFM) are direct methods for particulate imaging at the nanoscale level that provide information such as thedimension, shape, and morphology of particles (Kollensperger et.al., 1999).

Scanning electron microscope(SEM) is an important tool for investigators who work inthe field of membranes (Mulder, 1997). When the morphology of a membranehas to be studied, SEM is often used so that photographs on a micron scale, or even smaller, can be obtained,and the distribution and size of the pores can be observed (Torras and Garcia-valls, 2004).A scanning electron microscope (SEM) is a powerful magnification tool that utilizes focused beams of electrons to obtain information. Advantages of a scanning electron microscope include its wide – array of applications, the detailed three dimensional and topographical imaging and the versatile information garnered from different detectors. SEMs are also easy to operate with the proper training and advance in computer technology and associated software make operation, user friendly. The microscope works fast, often completing analysis in less than

five minutes in addition, the technological advances in modern SEMs allow for the generation of data in digital form. Most SEM samples require minimal preparation actions.

The disadvantages of a scanning electron microscope start with the size and cost. SEMs are expensive, large and must be housed in an area free of any possible electric, magnetic or vibration interference. Maintenance involves keeping a steady voltage, currents to electromagnetic coils (www.Microscopemaster.comAccessed 8th September 2014).

Transverse electron microscope(TEM) uses electron emission toward the specimen, similarto SEM; however, in TEM, the emitted electrons pass through the specimen and reach a phosphorous detector toprovide a pattern of the specimen's structure (Wiliams and Carter, 2009). This device has also been employed for imagingsoil nanostructure (Citeau et al 2006). The major disadvantage of the transmission electron microscope is the extremely thin sections of specimens typically about 100 nanometers unlike the SEM which is able to image bulk samples up to many centimeters in size (Wikipedia) which is the main reason why SEM was adopted for the microanalysis of samples in this research work. In geotechnics, atomic force microscope(AFM) images arefrequently used to study the surface morphology of soil nanoparticles, measure the adhesive force between soilparticles, and to measure the friction angle between particulate soil particles (Michael, 2002).

Scanning electron microscopy (SEM) provides data on surface morphology and, together withenergy dispersive spectrometry (EDS); it can be used to determine the chemical composition ofany mineral particles attached. The transmission electron microscopy (TEM) and atomic forcemicroscopy(AFM) are able to visualize the structure of soilaggregates and provides a means to analyze the mineral phases present at a nano-scale which isanother reason why SEM was adopted for the microanalysis of samples in this research work.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Black Cotton Soil

Black cotton soil was obtained along DadinKowa(Latitude $10^0$13'N and Longitude $11^0$23'E) 30 km from Gombe town in Deba Local Government Area of Gombe State.Disturbed samples were obtained from a depth of 0.5m in order to avoid organic matter. The samples were packaged in sealed plastic bags and transported to the laboratory. The essence of keeping the samples sealed was to maintainthe moisture content of the soil at the time of collection. The collected soilsample was air-dried and pulverized into particles passing BS No. 4 sieve (4.76 mm aperture) before laboratory tests were conducted.

3.1.2 Sugarcane Bagasse Ash

The bagasse ash used in this study wasprepared by collecting sugar cane residue from an openwaste dumpsite in Tudun Wada, Zaria, Kaduna state. The bagasse was placed on a galvanized sheet and openly burnt at a temperature in the range 500 – 750^{o}C determined using a thermocouple.The burnt bagasse ash was left for 12 – 24 hours to ash. Theresulting ash was then passed through British Standard (BS)No. 200 sieve with 75 μm aperture. The sieved ash was storedin air tight containers to avoid pre-hydration until usage.

3.2Preparation of Specimens

Batches of black cotton soil modified with bagasse ash were prepared in stepped concentrations of 0, 2, 4, 6 and 8 % bagasse ash dry weight of soil. The tests described in the subsequent sections were conducted on each of the batches.

3.3 Methods

3.3.1 Natural moisture content

The natural moisture content of the soil as obtained from the site wasdetermined in accordance with BS 1377 (1990) Part 2. Three weighing containerswere cleaned and weighed to the nearest 0.01g (m_1).Freshlycollected soil sample was crumbled and placed loosely in the containers and the containerswith the samples were weighed together to the nearest 0.01g asm_2. The containerswere then placed in the oven and dried to a constant weight at 105 -110^{o}C for 24 hours. Thecontainers and the samples were then removed and weighed dry to the nearest0.01g asm_3. The natural moisture content (as collected from the site) is calculatedas the average as given by eq. (3.1).

$$w = \frac{m_2 - m_3}{m_3 - m_1} \times 100\% \qquad (3.1)$$

Where,

w = moisture content in percentage.

m_1 = wt of container

m_2 = wt of container and sample,

m_3 = wt of container and oven dried sample.

3.3.2 Oxide composition of materials

The oxide composition ofbagasse ash was determined in the Department of Chemistry, Faculty of Science, AhmaduBelloUniversity, Zaria, Kaduna State, using X-Ray Fluorescence (Nuclear Energy Test).

3.3.3 Specific gravity

The determination of specific gravity was carried out according to BS 1377(1990) test (6B). The empty density bottle and the stopper wereweighed to the nearest 0.001g (m_1).The air dried soil was transferred into thedensity bottle, and the bottle, content and the cover were weighed as m_2.Waterwas then added just enough to cover the soil, the solution is gently stirred toremove any air bubble. The bottle was then completely filled up and covered. Thecovered bottle was then wiped dry and the whole weighed to the nearest 0.001g(as m_3). The bottle was subsequently emptied and filled completely with water,wiped dry and weighed to the nearest 0.001g (m_4). The specific gravity iscalculated using eqn. (3.2).

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

The same procedure was repeated for all the percentages of bagasse ash.The procedure was repeated to obtain three values for each percentage from which theaverage specific gravity of each was determined.

3.3.4 Sieve analysis

3.3.4.1 Wet sieving

Particle size analysis was carried out in accordance with BS 1377;1990 Part 2. Wet sieving was conducted by measuring 200 g of the soilsample and soaking it for 24 hours. The sample was then washed throughBS No 200 sieve. The particles retained were then dried in an oven for 24hours and dry sieving was carried out on the dried sample to obtain theparticle size

distribution.The mixture that passed through sieve No 200was poured into a 1000 ml measuring cylinder then 25 ml of sodiumhexametaphosphate (commercial grade) was added and stirredthoroughly, then hydrometer was immersed gently and readings weretaken at intervals stipulated by BS 1377; 1990 part 2.

3.3.4.2 ***Dry sieving***

The particle size analysis test was carried out in accordance with BS 1377; 1990 Part 2. Dry sieving was conducted by measuring 200g of the dry soil sample passing sieve No 4 (4.76 mm).The dry sample was then mixed properly with the optimum moisture content of the mix obtained from compaction test and air drying it under shade for 48 hours. Dry sievingwas carried out on the dried sample to obtain the particle size distribution.

3.3.5Atterberglimits

The Atterberglimits tests included the determination of liquid andplastic limits, and plasticity indices of the natural and modified soilsamples. They were also conducted in accordance with Test 1(A) B S1377 (1990) Part 2 for the natural soil and BS 1924 (1990) for thestabilized soils.

3.3.5.1 ***Liquid limit:***

Liquid limit is the minimum moisture content at whichthe soil will flow under its own weight. In this test, 200 g of the sample passing sieve 425 μm was placed on a clean glass plate. Water wasadded little by little as it was mixed, using palette knife or spatula to formhomogeneous paste. A proportion of the paste was placed in Casagrandeapparatus and leveled parallel to the base of the chip and divided bydrawing the grooving tool through the paste along diameter passing thecentre of the hinge. The crank was turned to lift-drop the cup at the

rate of2 revs per second, noting the number of blows (falls) that would make thebottom two parts of the groove come together. A sample of it was takenand its moisture content determined. This test was repeated for well-spacedmoisture content starting from the drier to wetter state. Thedetermined moisture contents were plotted against corresponding numberof blows on a semi-logarithmic paper and liquid limit was determined at themoisture content corresponding to 25 blows.

3.3.5.2 ***Plastic limit:***

Plastic limit is the minimum water content at which asoil will just begin to crumble when rolled into a thread approximately3mm in diameter. Some 20 g of the air-dried natural soil passing sieve with 425μmaperture sieve was put on a flat glass plate and mixed thoroughlyenough to be shaped into a small ball. Liquid content for this test wasslightly less than the one for liquid limit test. The ball was thenmoulded between fingers and then rolled on the glass plate with palmof hand into thread of about 3mm diameter when the thread crumblesby shearing. The crumbled threads were immediately put in weighingpan for moisture content determination. The same test was performedfor each of the modified soils.

3.3.5.3 ***Plasticity index:***

Plasticity Indices of the natural and modified soilsamples were derived from the already determined values of liquidlimits and plastic limits using eq. (3.3)

$$PI = LL - PL \qquad (3.3)$$

Where,

PI = Plastic Index

LL= Liquid Limit

PL = plastic Limit

3.3.6 Linear shrinkage

The test was conducted in accordance with Test 5 BS 1377 (1990). Itinvolves the mixing of about 125g of soil, passing the BS No. 40 sieve (425μm),with water inorder to obtain a homogenous paste. Water mixed with the soil sample was in thesame amount as the moisture content corresponding to the liquid limit. (The water added to the natural soilcorresponded to the moisture content at liquid limit). The paste was then placed inthe shrinkage mould and vibrated gently in order to expel air pockets from themixture. The soil was then leveled by spatula and air dried at 60^{o}C. Initially, thesoil shrank clear of the mould. Subsequent drying to a constant weight was made at 105–110^{o}C in anoven in order to complete the shrinkage. On cooling, the length of the sample wasmeasured with a ruler and the linear shrinkage was calculated using eq.. (3.4).

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

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

3.3.7 Free swell

The test was conducted in accordance with the United States Bureau ofReclamation (USBR) method (Holtz and Gibbs, 1956). About 10 g of soil passingBS No 40 sieve (425μm aperture) was oven dried and allowed to cool in adesiccator. The sample was slowly poured into a 100cm^{3} measuring cylinder towhich water was added in order to fill the cylinder. The cylinder was then agitated in order to obtain a homogenous mixture of soil and water after which it was allowedto settle for 2 hours or more before the swell volume was recorded.Free swell wasdetermined from the equation:

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

3.3.8 Cationexchange capacity

The test was carried out in accordance with the procedures givenby ISRIC (1998). Some quantity of the natural soil was sieved through the 2mm screen and 10 g of the sieved sample was put into a 100ml plastic beaker. About 40 ml of ammonium acetate (1N at pH7.0) was added andstirred 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 until no test for calcium couldbe obtained in the effluent solution. To test for calcium, diluted Sodiumhydroxide (NaOH), few drops of each of 1N NaCl and 10 % ammoniumoxalate were added to 10ml of the leachate in a test tube and heated tonear boiling point. The presence of calcium was indicated by a whiteprecipitate or turbidity. As long as calcium was detected, the process wasrepeated until there was no trace of it. The calcium-free soil was thenleached with neutral 1N ammonium chloride NaCl four times and once with 0.25N of the acid. The electrolyte was then washed out using 150 – 200ml of isopropyl alcohol.Chloride in the leachate was tested for using silver nitrate ($0.1NAgN0_3$) till its trace was chloride free, and the soil was left to drain thoroughly. A 10 % percent acidified NaCl was added little by little to the ammoniumsaturated soil until 250ml had passed through the sample, allowing eachportion to pass through the sample before adding the next portion. Theleachate was transferred in quantities to flask for titration. To it, 25 ml of 1NNaOH was added, and 60 ml of the solution distilled into 50 ml of2%HBO. Ten drops of bromocresol green-mythel was added. The colourchanged from bluish green to pink at the end of the titration. Blank titrationwas run on the reagents to correct titration figure for the reagents and themilliequivalentsof ammonium in 100 g of soil was calculated. The NH-borate was titrated with a standard acid 0.1N HCl in the blank titration. Thecation exchange capacity was calculated using the formula:

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

where

B = Blank

NA = Normality of acid

This same procedure was repeated for each of the modified samples.

3.3.9 Compaction characteristics

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), West African Standard (WAS) as approved by Nigerian General Specification (1997) and British Standard heavy (BSH) energies.

3.3.9.1 *Maximum dry density*

The compaction tests were carried out for the natural soil and the modified soils (in different percentages of admixtures); all according to BS 1377 (1990) Part 4, using the British Standard light(BSL),West African Standard(WAS) and the British Standard heavy(BSH), in accordance with the Nigerian General Specification (1997).3000g of dry soil sample was weighed. The soil weighed was crushed to a powdered form on a metallic tray. Using varying percentages of water content at an increment of 4% added for every compaction. Compaction was carried out in three different compaction energies.

In the British Standard light (BSL), soil samples were compacted in three(3) layers, each layer rammed 27 blows using a 2.5 kg rammer dropping from a height of 304.8mm above the soil. The blows were distributed uniformly over the surface of each layer.the collar was then remove and the soils were leveled to the brim of the mould using edge. The mould and the

compacted soil were weighed. The compacted soil specimen was removed from the mould for moisture content determination. The whole soil sample is removed from the mould and place on a large tray another 4 % water was added to the sample and mixed properly. The compaction was repeated using the same no of blows and layers as described above. Successive increments of 4% water were added until when the weight of the mould and the soil sample have started falling.At least two further compactions were made after the peak weight of the mould and the compacted soil sample was obtained.

In the West African Standard (WAS), test the procedure was the same but a 4.5 kg rammer and the number of layers were increased to 5. With 10 blows per layer at hammer height of fall of 450.20mm was used. The British Standard heavy(BSH) compaction procedure involved 5 layers with 27 blows per layer. After determining the moisture content for every water increment, the results were plotted. A smooth curve was drawn through the resulting points and the positions of optimum moisture content and the maximum dry density were determined on the graphs. The bulk density is given by

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

where,

ρ = bulk density in (Mg/m^3)

m_1= mass of mould and base (g)

m_2= mass of mould, base and soil (g).

Dry densities of the samples were calculated from the equation:

$$\rho_d = {}^{100\rho}\Big/_{(100+W)} \qquad (3.8)$$

Where, w = water content.

3.3.9.2 *Optimum moisture content*

The corresponding values of moisturecontents at maximum dry densities (MDD), deduced from the graph of dry densityagainst moisture contents gives the optimum moisture content (OMC).

3.3.10 Shear Strength

The shear strength tests were performed using the undrainedtriaxial test procedure in accordance with BS 1377(1990) for specimens compacted with BSL, WAS and BSH energies. The natural black cotton soil and treated soilsamples were compacted in 1000 cm^3moulds at their respective OMC. The samples were extruded from the moulds and trimmed into cylindrical specimens of 38.1mm diameter and 76.2mm length. The three cylindrical specimens from the mould were then weighed before carrying out the test. Record was taken simultaneously of theaxial deformation and the axial force at regular intervals until failure of the sample occurred.The major principal stress (σ) was derived from the applied verticalload while the other two principal stresses σ_1 and σ_2 ($\sigma_1=\sigma_2$) wereapplied in horizontal direction by the water pressure round the specimen inthe triaxial cell until the cylindrical specimen sheared or deformed.Cell pressures were maintained and maintained at 103.4, 206.9 and 310$kN/m^2$for the three specimens, respectively. Mohrcircles of diameter $\sigma_2 - \sigma_1$for each test were plotted on a shear –stressgraph from which cohesion (c) and angle of internal friction (σ) weredetermined.

Compressive Shear Strength is given by the expression:

$$\delta = \frac{R.C(100-\sigma)1000KN/m^3}{100A} \qquad (3.9)$$

where,

σ = % percentage strain.

R= Load ring reading at strain.

C= Mean Callibration of load ring.

A= Initial cross-sectional area of specimen.

δ = Compressive Stress at Strain.

3.4 Microanalysis

Some quantity of sample was placed on a double adhesive sticker mounted in a sputter machine for a minute and a half; thus giving the sample a conductive property. The scanning electron microscope (SEM) (see Fig. 3.1) was allowed to stabilize for a few seconds, then parameters to be used was set, the sample was then put into the sample holder (see Fig 3.2) and slotted into the machine. 15kv was used in imaging the sample set at 1000x magnification and was focused using a rotary knob until a clear and proper image was produced. This was in an electron imaging mode, the image was then transferred to Phenom suite software where the elemental, fiber metric/pore measurements were carried out; after contrasting/ brighteningwas done.Elemental analysis was done by the software. The element visible in the sample was picked by virtue of confidence of the machine, after the sports where all analyzed then a report was generated by the machine and was saved in a folder using the name of the sample used. Some of the remaining sample was used to determine the pore measurement and fiber present in the sample.

Morphology/topology was saved in the PhenomProX machine itself whereas the pore fiber and element analysis were save in another PC and were all copied into a new folder using

the sample name for identification the test was repeated for elapsed times of 1hr, 2hr and 3hrs. The test was carried out in Chemical Engineering Department, A.B.U. Zaria.



Fig 3.1 PHENOM ProX Scanning Electron Microscope



Fig 3.2 Sample holder

3.5Statistical Analysis

Analysis of results was based on the following methods:

1. Graphical, using Microsoft Excel

2. One – way analysis of variance (ANOVA) without replicate.

3.5.1 One – way analysis of variance

The problem of analyzing quality of estimated regression line can be handled by analysis of variance (ANOVA). This is a procedure whereby thetotal variations in independent variables are subdivided into meaningfulcomponents that are observed and treated in a systematic manner. If thereare experimental data in the form *(xi - yi)* in n-numbers of experiments, then,the regression line is estimated by the equation:

$$S_{yy} = bS_{xy} + SSE \qquad (3.10)$$

where,

b = slope of underlying straight line of relationship.

An alternative and perhaps more informative formulation is,

$$\sum_{i=1}^{n}(y_i - \bar{y})^2 = \sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2 + \sum_{i=1}^{n}(y_i - fc)^a \qquad (3.11)$$

By this, the total experimental data are partitioned into two componentswith corrected sum of squares of y that makes the best fit line of regressionto establish whether results of experiments fall within acceptable limits orconfidence level.

The partitioning is represented symbolically as;

$$SST = SSR + SSE \qquad (3.12$$

where,

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

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

Suppose a test hypothesis

HQ: β = 0,

HI: β ≠ 0,

Where the null hypothesis with the model *μy/x = a.* then *Y* results from chance orrandom fluctuations which are independent of values of *x*. Under the nullhypothesis it can be shown that

SSR/o^{2}and *SSE/*$\sigma^2$are values of chi-squaredvariables with 1 and (n-2) degrees of freedom and that *SST/a*^{2}isalso a value of a chi-squared variable with *n*-1 degrees of freedom (thenumber of cells in a table – number of linear constraints on the expectedfrequencies). To test the hypothesis above, we compute

$$f = \frac{SSR/1}{SSE/(n-2)} - \frac{SSR}{S^2} \qquad (3.13)$$

However, HQ is rejected as the level of significance, "when the nullhypothesis is rejected. That is, when the F-statistic exceed the criticalvalue, *fQ(l,n — 2), "we conclude that there is a significant amount of variationin the response accounted for by the postulated straight line function. If theF-statistic is smaller we reject, we conclude that the data did not reflectsufficient evidence to support the model postulated".* It is customary torefer to the various sums of squares divided by their respective degrees offreedom as the mean squares.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND DISCUSSION

4.1 Properties of Materials Used In the Study

4.1.1 Natural Soil

Results of preliminary classification tests conducted in accordance with BS 1377 (1990) on the natural black cotton soil are summarized in Table 4.1. The particle size distribution curve is shown in Fig 4.1. The percentage passing sieve with 0.075 mm aperture is 69.4 and the soil can be classified as CL according to the Unified Soil Classification System (USCS) (ASTM, 1992) or A-7-6 (16) sub-group by the AASHTO classification (AASHTO, 1986). The natural soil is greyish - black in colour (from wet to dry states) with a liquid limit of 45.4 %, plastic limit of 21 % and plasticity index of 24.4 %.The soil is highly plastic and its plasticity index falls below the 30 % maximum standard recommendation for most geotechnical construction works, especially highway construction (Butches and Sailie, 1984; Osinubi and Medubi, 1997b). Detailed test results for the natural soil are given in Table4.1.

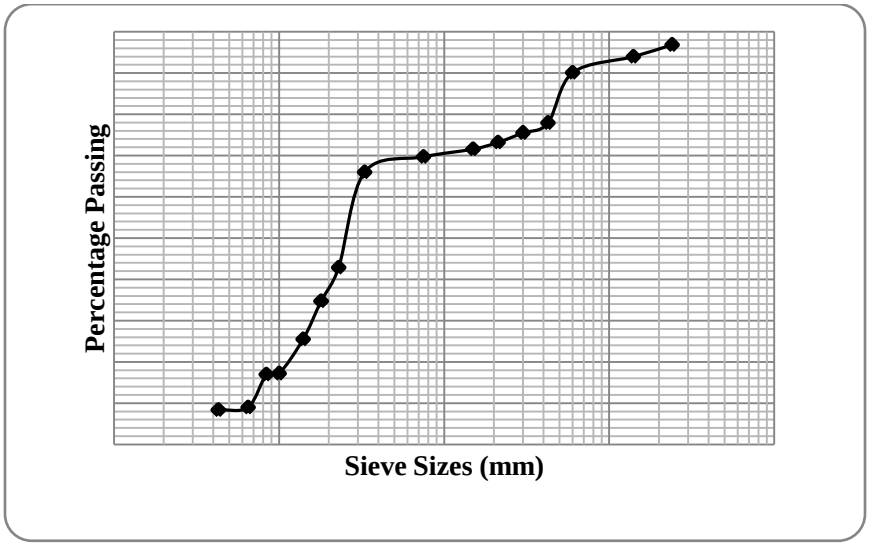


Figure 4.1Particle size distribution curve for the natural black cotton soil.

Table 4.1 Properties of the natural black cotton soil

Property	Quantity

Percentage passing BS No 200 sieve, %	69.4
Natural Moisture Content, %	21.0
Liquid Limit, %	45.4
Plastic Limit, %	21.0
Plasticity Index, %	24.4
Linear Shrinkage, %	14.8
Free Swell, %	55
Specific Gravity	2.35
AASHTO Classification	A-7-6 (16)
USCS	CL
Maximum Dry Density, Mg/m^3	
British Standard light	1.66
West African Standard	1.72
British Standard heavy	1.85
Optimum Moisture Content, %	
British Standard light	18.15
West African Standard	16.3
British Standard heavy	14.8
Cohesion, kN/m^2	
British Standard light	68
West African Standard	88
British Standard heavy	140
Angle of Internal Friction (degree)	
British Standard light	1
West African Standard	3
British Standard heavy	10
Cation Exchange Capacity, Cmol/Kg	40
Dominant Clay minerals	Montmorillonite
Colour	Greyish-black

4.1.2 Oxide compositions of bagasse ash and black cotton soil

The oxide compositions of bagasse ash and black cotton soil are given in Table 4.2. The sum of SiO_2, Al_2O_3 and Fe_2O_3 in bagasse ash is 76.8 % which is greater than 70 % and the loss on ignition is 12.8 %. Based on ASTM C618 specification for pozzolanas the bagasse ash used for this research is class N pozzolan.

Table 4.2:Oxide compositions of bagasse ash and black cotton soil

Oxide	Composition %	
	Bagasse ash	***Black cotton soil**
CaO	3.157	3.58
SiO_2	65.530	49.00
Al_2O_3	8.446	15.1
Fe_2O_3	2.823	14.23
Mn_2O_3	0.175	0.23
Na_2O	0.994	-------
K_2O	7.117	2.23
AgO	-------	2.17
P_2O_5	3.409	-------
MgO	3.155	-------
SO_3	2.115	-------
Cl	1.670	-------
Cr_2O_3	0.003	0.022
TiO_2	1.344	2.09
ZnO	0.037	0.10
SrO	0.025	0.16
LOI	12.8	11.1

*Azige (2012)

4.2 Effect of Modification on Black Cotton Soil at No Delay after Mixing

4.2.1 Specific gravity

The variation of specific gravity of black cotton soil with bagasse ash content is shown in Fig 4.2: The specific gravity (SG) of the black cotton soil decreased from 2.35 to 2.22 at 8 % bagasse ash content (i.e., a 6.3 % decrease). The observed trend is due to the lower specific gravity of the bagasse ash used (2.20) when compared with the value of 2.35 recorded for black cotton soil. Detailed test results are given in TableA4.2 in the Appendix

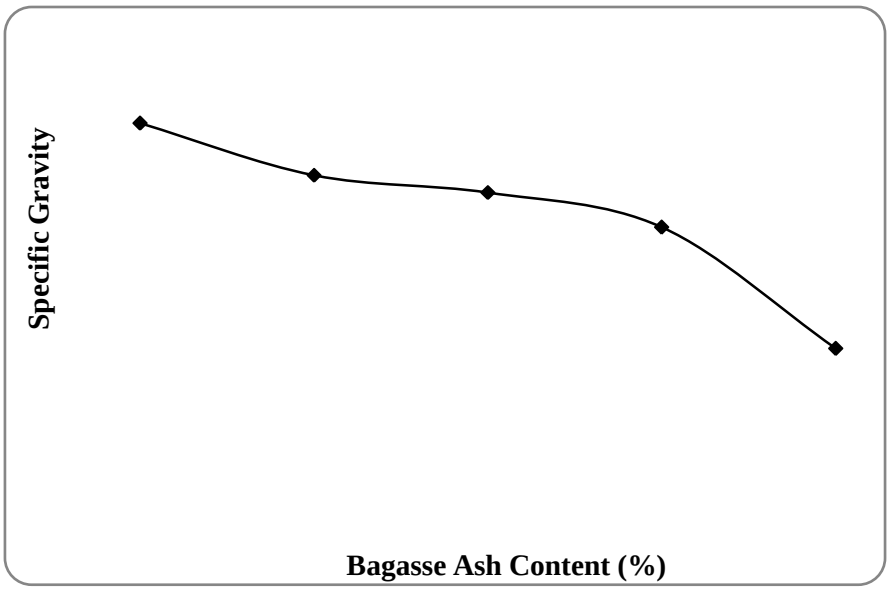


Fig. 4.2; **Variation of specific gravity of black cotton soil with bagasse ash content**

The analysis of variance (ANOVA) test on the specific gravity values (see Table 4.3) shows that bagasse ashtreatment has no significant effect statistically on the specific gravity of black cotton soil ($F_{CAL} = 1.45 < F_{CRIT} = 5.31$).

Table 4.3: Single factor analysis of variance for specific gravity of black cotton soil- bagasse ash mixtures

Property	Source of Variation	Degree of Freedom	F_{CAL}	P-value	F_{CRIT}	Remark
Specific gravity	Bagasse ash	9	1.44806	0.26324	5.31766	$F_{CAL}<F_{CRIT}$, No Significant effect

4.2.2 Cation exchange capacity

Cation exchange capacity (CEC) of clay is defined as the amount of exchangeable ions, expressed in milliequivalents, per 100 g of dry clay. Clay particles carry a net negative charge. In

an ideal crystal, the positive and negative charges would be balanced. However, isomorphous substitution and broken continuity of structures result in a net negative charge at the faces of clay particles. To balance the negative charge, the clay particles attract positively charged ions.

The variation of cation exchange capacity of black cotton soil with bagasse ash content is shown in Fig 4.3. The CEC value of the natural soil decreased from 40 Cmol/kg to a minimum value of 32.7 Cmol/kg at 4 % bagasse ash content, later increased up to 6 % bagasse ash content and thereafter slightly reduced with higher bagasse ash content. The initial decrease could be attributed to low CEC of bagasse ash (31.5 Cmol/kg), while the observed increase indicates that the CEC of black cotton soil can be improved by mixing it with bagasse ash. The observed slight decrease between 6 and 8 % bagasse ash treatment could have been associated to the excess percentage of bagasse ash content of low cation exchange capacity.Detailed results are given in Tables A4.3In the Appendix.

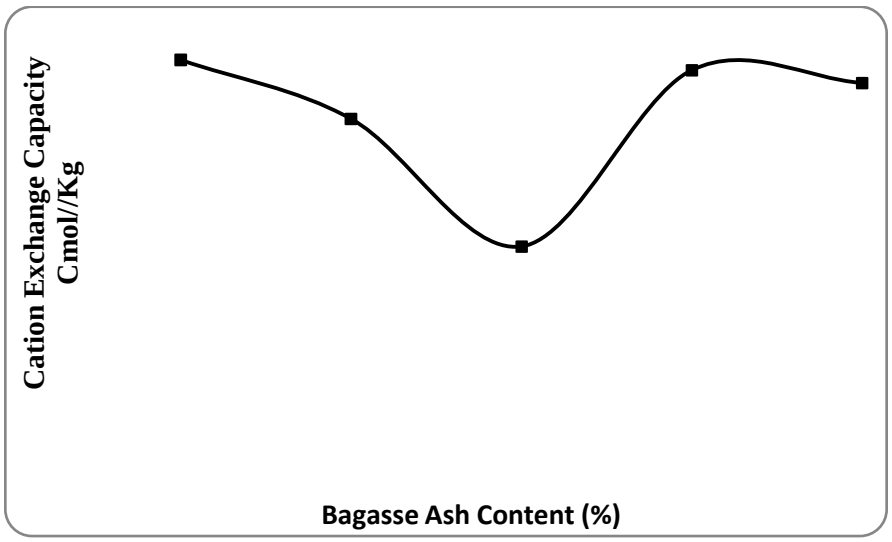


Fig. 4.3: Variation of cation exchange capacity of black cotton soil with bagasse ash content

The analysis of variance (ANOVA) test on the cation exchange capacity (CEC)of the natural soil (see Table 4.44.4) shows that bagasse ashtreatment has a statisticallysignificant effect on the cation exchange capacity(CEC) of black cotton soil (F_{CAL} =301.84 > F_{CRIT} = 5.32)at α =0.05.

Table 4.4: Single factor analysis of variance for cation exchange capacity of black cotton soil-
bagasse ash mixtures

Property	Source of Variation	Degree of Freedom	F_{CAL}	P-value	F_{CRIT}	Remark
Cation exchange capacity	Bagasse ash	9	301.84	1.23E-07	5.31766	$F_{CAL}>F_{CRIT}$, Significant Effect

4.2.3 Free Swell Index

The variation of free swell of black cotton soil with bagasse ash content is shown in Fig. 4.4. Free swell reducedfrom 55 % for the natural soil to 50 % at8 % bagasse ash content. This was primarily due to the supply of more silica, alumina and calcium ion with increased bagasse ash content. It could also be said that the reduction in free swell occurred because of the flocculation and agglomeration of the black cotton soil- bagasse ash mixtures. This reaction resulted in strong bond between the soil particles that prevented the swelling of soil (Akshaya, 2012). Detailed results are given in Tables A4.10In the Appendix.

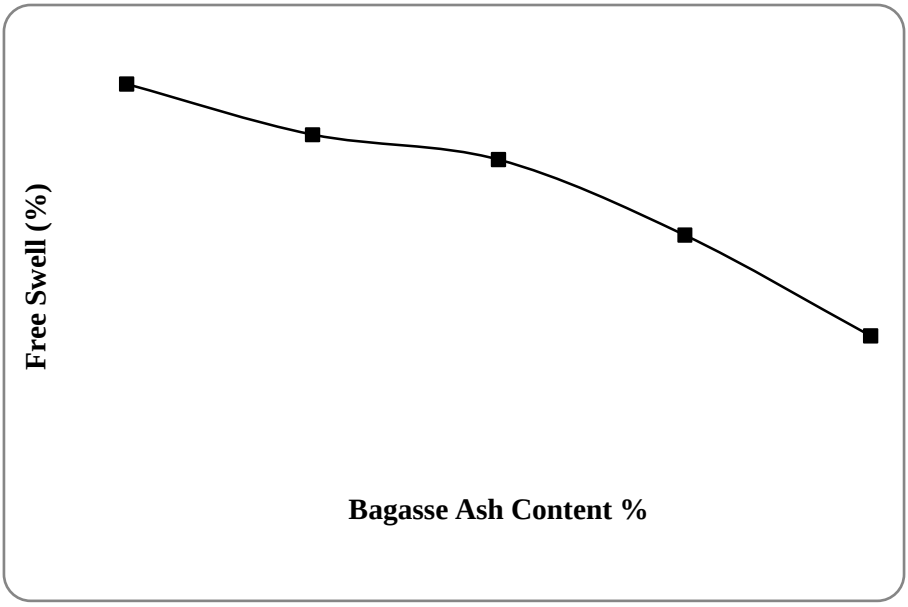


Fig 4.4: **Variation of free swell of black cotton soil with bagasse ash content**

The analysis of variance (ANOVA) test on the free swell results (see Table 4.5)shows that the effect of bagasse ashtreatment is statistically significanton the free swell of black cotton soil (F_{CAL} = 866.38> F_{CRIT} = 4.96).

Table 4.5: Single factor analysis of variance for free swell of black cotton soil- bagasse ash mixtures

Property	Source of Variation	Degree of Freedom	F_{CAL}	P-value	F_{CRIT}	Remark
Free swell	Bagasse ash	9	866.38	1.92E-09	5.32	$F_{CAL}>F_{CRIT}$, Significant effect

4.2.4 Particle Size Distribution

4.2.4.1 *Wet sieving*

The particle size distribution curves for black cotton – bagasse ash mixtures are shown in Fig 4.5. A reduction in the percentage of fines and an increase in coarser sizes were observed

with increased in bagasse ash content.The reduction in fines fraction with increase in bagasse ash content could be attributed to flocculation and agglomeration of the black cotton soil- bagasse ash mixtures and thus enabled the clay fraction to form larger soil sizes (Akinmade, 2008; Oyelakin, 2010,Amadi 2010a; Al karagooly, 2012 and Portelinha et al., 2012). The aggregation or clusters of clay-minerals and clay-size mineral fragments due to ion exchange at the surface of the soil particles resulted in more stable silt-sand like structures. With increasing percentage of bagasse ash, black cotton soil became more granular in nature. This is in agreement with the findings of Amadi (2010a). Also, reduction in fines fraction with increase in bagasse ash content could also be due to the formation of products of pozzolanic reaction, taking place between the $Ca(OH)_2$ from lime and silicate from both clay and the bagasse ash (Akinmade, 2008 and Oyelakin, 2010).



Fig 4.5: Particle size distribution curves for soil – bagasse ash mixtures

4.2.4.2 ***Dry sieving***

The particle size distribution curves of black cotton soil treated with 2, 4, 6 and 8% bagasse ash prepared using the optimum moisture content of BSL, WAS and BSH compactions at no delays after mixing are shown in Fig. 4.6a – 4.6c. In figure 4.6a, there is an observed decrease in the percentage passing the various sieve sizes with increase in bagasse ash content this means that there is an agglomeration and flocculation of particles to form larger particle sizes. Similar results are observed in fig 4.6b and fig 4.6c. The results obtained shows that higher bagasse ash treatment of black cotton soil caused the mixtures to flocculate and agglomerate with the mixture getting increasingly coarser and thus enabling the clay particle to form pseudo silt sizesand this is in agreement with findings of Amadi, 2010a;Sarkaretal., 2012; Al karagooly, 2012 andPortelinha et al, 2012. The decrease in the percentage passing the various sieves as shown on the graphs was due to the reduction in the proportion of silt sizes to form pseudo – sand sizes and the sand sizes form larger sand sizes (Mu'azu, 2007).

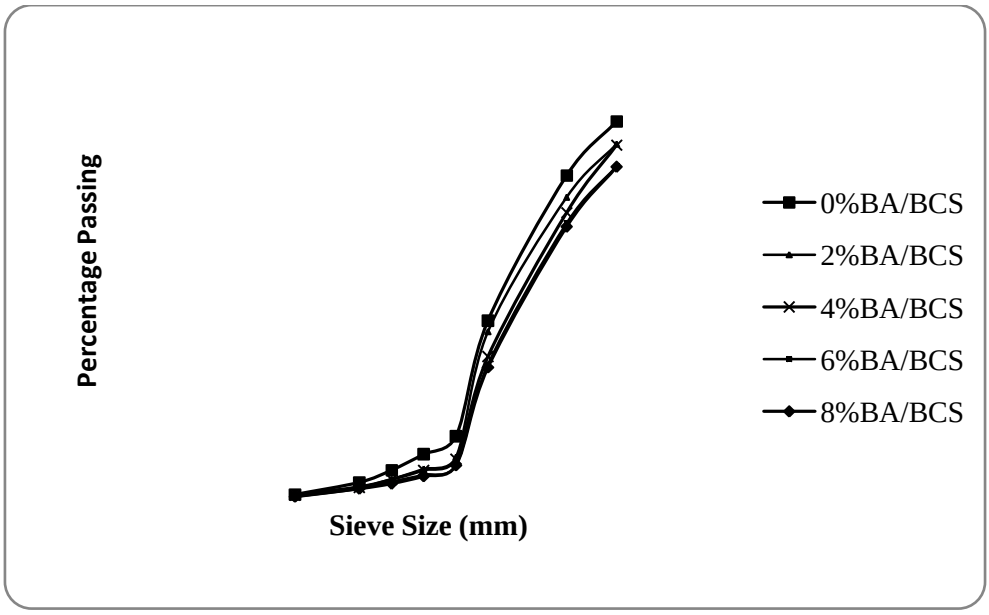


Fig. 4.6a: Particle size distribution curves of black cotton soil – bagasse ash mixtures prepared at optimum moisture content and no compaction delay (BSL compaction).

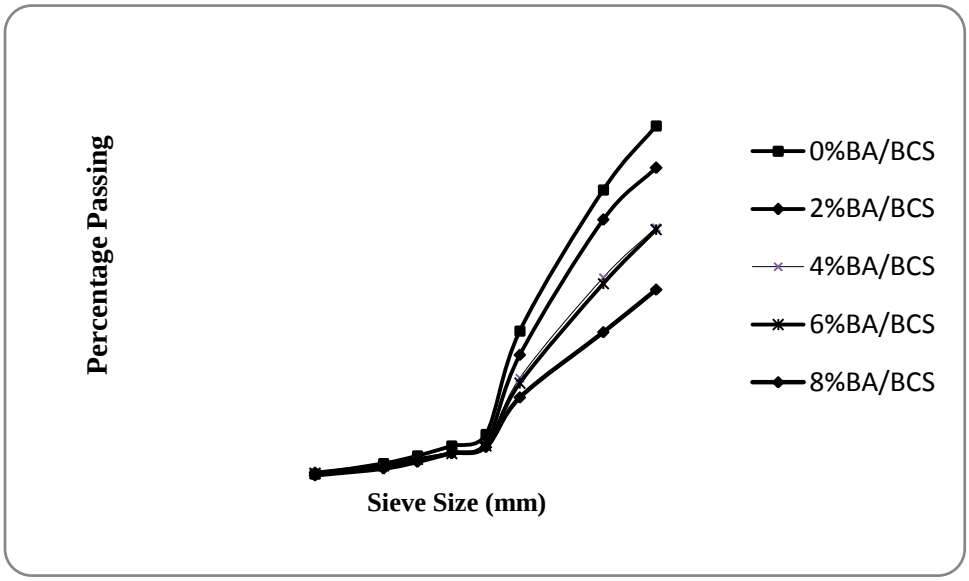


Fig. 4.6b: Particle size distribution curves of black cotton soil – bagasse ash mixtures prepared at optimum moisture content and no compaction delay (WAS compaction).

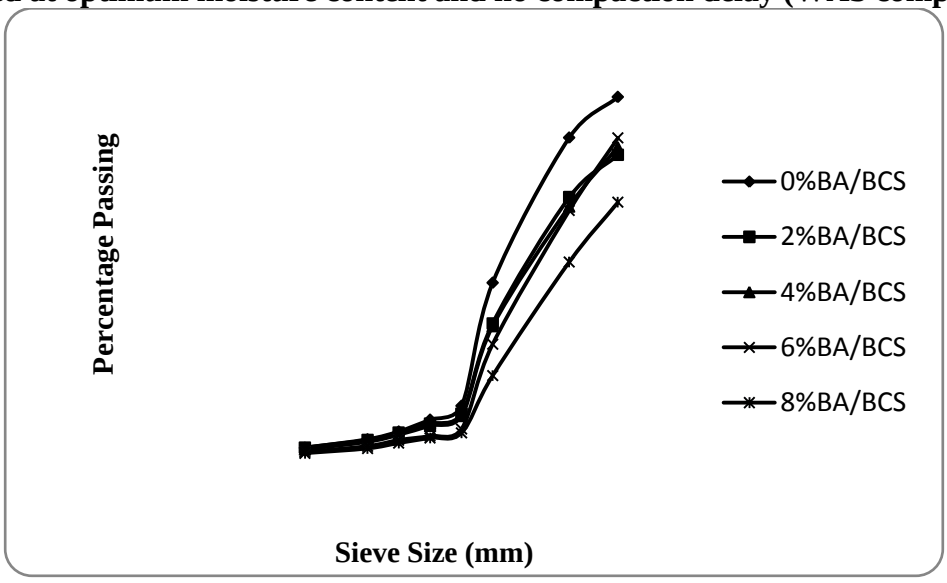


Fig.4.6c: Particle size distribution curves of black cotton soil – bagasse ash mixtures prepared at optimum moisture content and no compaction delay (BSH compaction).

4.2.5 Atterberglimits

The effect of bagasse ash on Atterberg limits (liquid limit, plastic limit, plasticity index and shrinkage limit) of black cotton soil for no delay after mixing are shown in fig 4.7a – 4.7d.

4.2.5.1 *Liquid limit*

The variation of liquid limit of black cotton soil with bagasse ash content is shown in Fig 4.7a.The liquid limit of the natural soil increased from 45.4% to a peak value of 47.8% at 4% bagasse ashcontent before decreasing to 44.8% at 8 %bagasse ash content. The initial increase may be due to the release of Ca^{++}, Si^{++} and Al^{++}cations with increase in bagasse ash content (Ramzi et al 2001).The observed decrease may be due to flocculation and agglomeration arising from cation exchange reactions where by calcium in the admixtures reacted with ions of lower valence in the clay structure(Moses and Afolayan, 2011). The optimum mix of 4 % BA treatment is observed at the peak value of liquid limit obtained. Detailed test results are given in Table A4.9 in the Appendix.

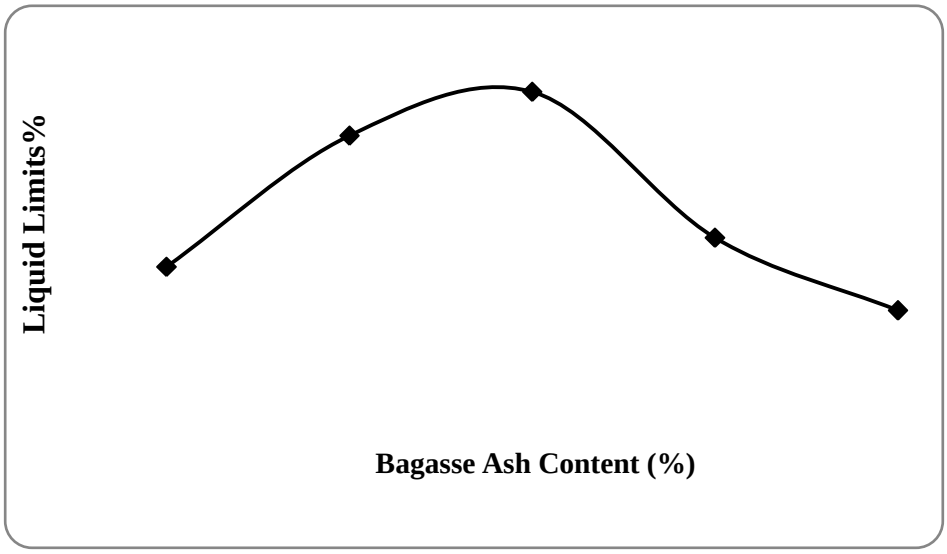


Fig. 4.7a: Variation of liquid limit of black cotton soil with bagasse ash content

The results of the analysis of variance (ANOVA) of Atterberg limits of black cotton soil – bagasse ash mixtures (see Table 4.6)showed that the effect of bagasse ash on the liquid limit of black cotton soil is statistically significant ($F_{Cal} = 768.93 > F_{Crit} = 5.32$).

Table 4.6: Single factor analysis of variance forAtterberg limits of black cotton soil-bagasse ash mixtures

Property	Source of Variation	Degree of Freedom	F_{CAL}	P-value	F_{CRIT}	Remark
Liquid Limit	BA	9	768.93	3.09E-09	5.32	FCAL> FCRIT, Significant effect
Plastic Limit	BA	9	125.27	3.64E-06	5.32	FCAL> FCRIT, Significant effect
Plasticity Index	BA	9	181.61	8.82E-07	5.32	FCAL> FCRIT, Significant effect
Linear Shrinkage	BA	9	25.94	0.000937	5.32	FCAL> FCRIT, Significant effect

4.2.5.2 *Plastic Limit*

The variation of plastic limit of black cotton soil with bagasse ash content is shown in Fig. 4.7b. Plastic limit decreased with increase inbagasse ash content from a value of 21% for the natural black cotton soil to a minimum value of 19.1% at 4% bagasse ash content then consequently increase to a value of 20.5 % at 8 % BA content. The recorded reduction is in agreement with the findings reported by Gandhi (2012). The reduction can be explained to be due to the cation exchange reaction whereby the more active and higher valentcations (i.e. Ca^{2+}) in the admixtures replaced the weakly bonded ions in the clay structure; thereby leading to the flocculation and liberation of water bonded at the outer layers.Detailed test results are given in Table A4.9b in the Appendix.

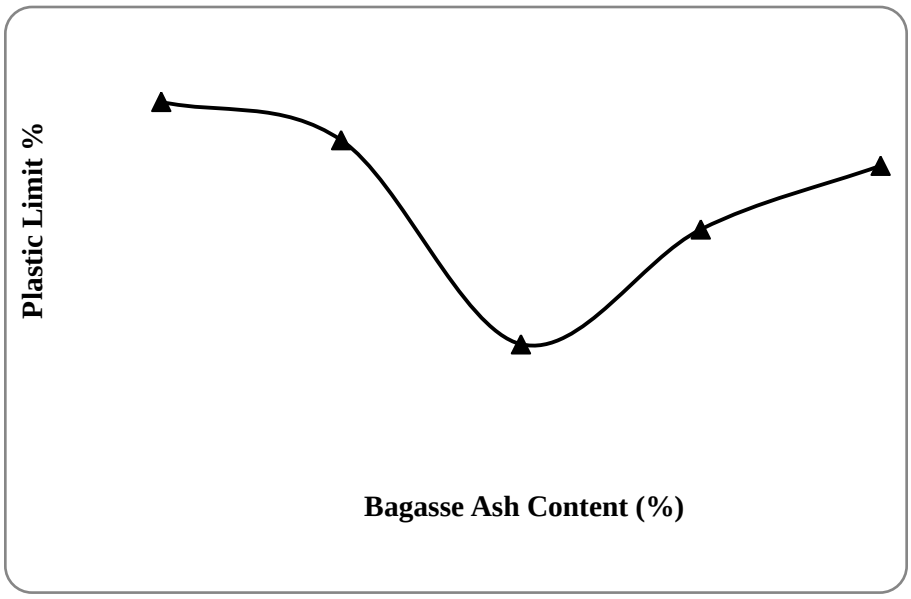


Fig. 4.7b: Variation of plastic limit of black cotton soil with bagasse ash content

The result of the analysis of variance (ANOVA) of the plastic limit of black cotton soil – bagasse ash mixture (see Table 4.6)shows that the effect of bagasse ash had on black cotton soil is statistically significant (F_{Cal} = 125.27>F_{Crit} = 5.32).

4.2.5.3 ***Plasticity Index***

The variation of the plasticity index of black cotton soil with bagasse ash content is shown in Fig. 4.7c. The plasticity index value increased from avalue of 24.4% to a peak value of 28.7% at 4% BA treatment. This same trend was also reported by Stephen (2006) for baggase ash stabilized black cotton soil.Detailed test results are given in Table A4.9c, in the Appendix.

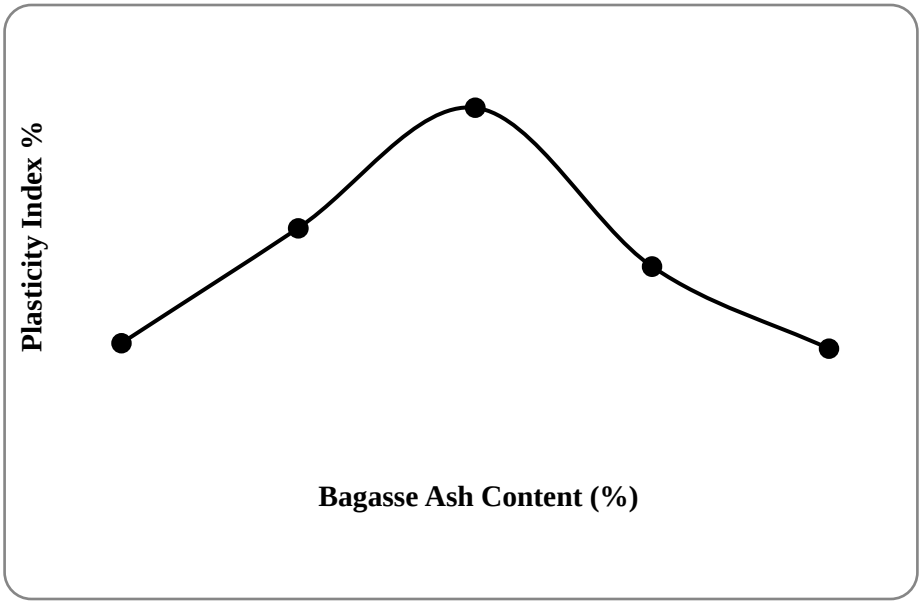
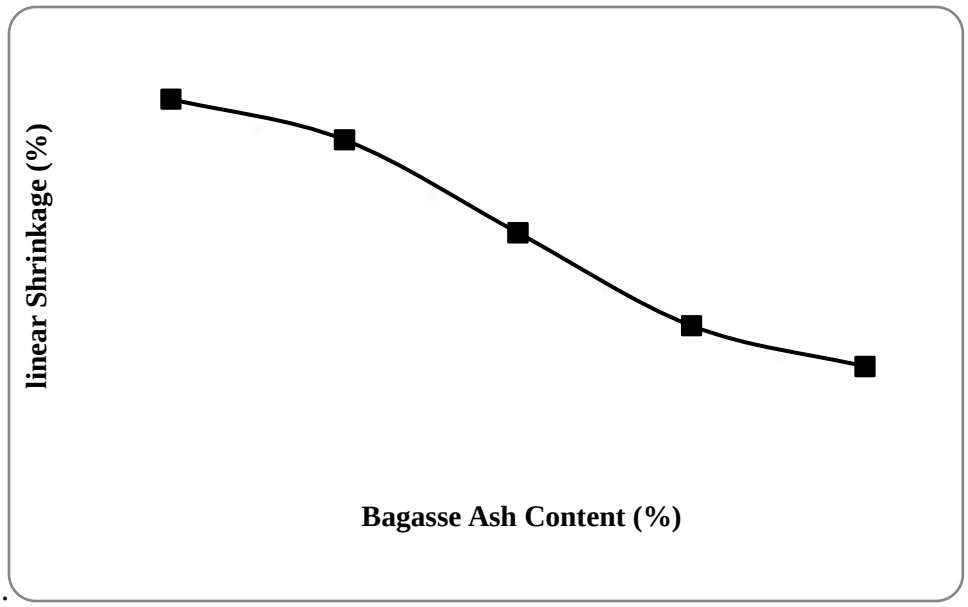


Fig. 4.7c: Variation of plasticity index of black cotton soil with bagasse ash content

The results of the analysis of variance (ANOVA) of plasticity index (see Table 4.6)showed that the effect of bagasse ash on the plasticity index of black cotton soil is statistically significant ($F_{Cal} = 181.61 > F_{Crit} = 5.32$).

4.2.5.4 Linear Shrinkage

The variation of linear shrinkage of black cotton soil with bagasse ash content is shown in Fig. 4.7d. Linear shrinkage was observed to decrease from 14.8% for the natural soil (i.e., at 0% bagasse ash content) to 10.2% at 8% bagasse ash content. The decrease in linear shrinkage could be attributed to flocculation and agglomeration of soil particles and mixture to form coarser particles (Moses and Afolayan, 2011). Detailed test results are given in Table A4.10 in the Appendix.



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Fig. 4.7d: Variation of linear shrinkage of black cotton soil with bagasse ash content

The results of the analysis of variance (ANOVA) of linear shrinkage (see Table 4.6)show that the effect of bagasse ash on black cotton soil is statistically significant (F_{Cal} = 25.94>F_{Crit} = 5.32).

4.2.6 Compaction characteristics

4.2.6.1 *Maximum dry density*

The variation of maximum dry density (MDD) of black cotton soil with bagasse ash contentsfor the three compaction energies (i.e., BSL, WASand BSH) is presented in Fig. 4.8. Generally as expected, MDD values increased with higher compactive effort and decreased with higher bagasse ash content. For BSH, WAS and BSL compactions MDD values decreased from 1.85, 1.72 and 1.66 Mg/m^3 for the natural soil to 1.78, 1.69 and 1.65Mg/m^3 , respectively, at 8 % bagasse ash content corresponding to decreases of 3.9, 2.03 and 0.72 %, respectively.

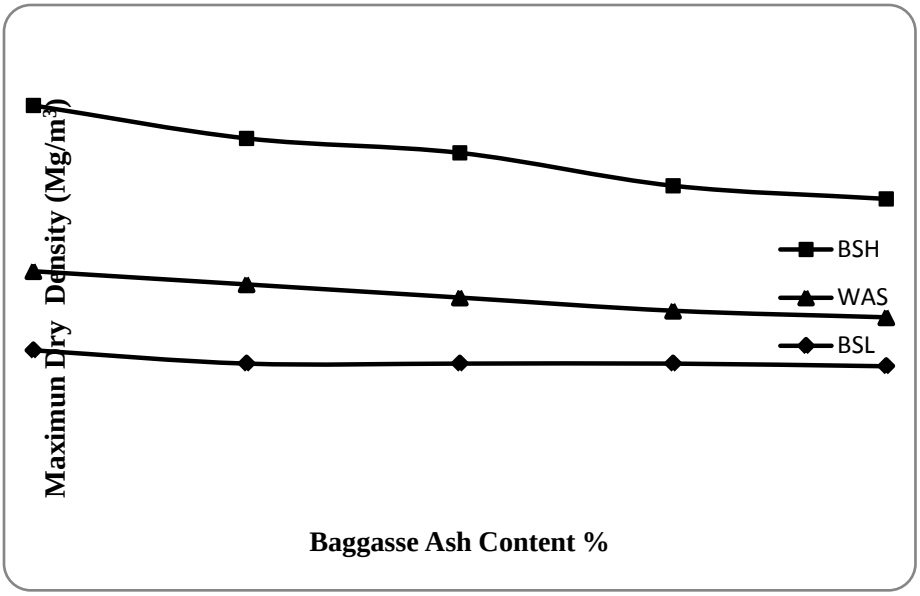


Fig. 4.8: Variation of maximum dry density of black cotton soil (no compaction delay) with bagasse ash content

The observed decrease in MDD values for the three compactiveefforts withhigher bagasse ash treatment is not unconnected with the initial simultaneous flocculationand agglomeration of clay particle caused by cation exchangeleading to increase in volume and decrease in dry density.Also, this was due to the comparatively low specific gravityvalue of bagasse ash (2.20) compared to that of black cotton soil (2.35). This is in agreement with the findings reported by Ola (1991),Osinubi et al. (2007a, b) as well as Osinubi and Eberemu (2011).It was also as a result of initial coating of the soil particles by bagasse ash to form larger aggregates, which consequently occupied larger spaces (Lee, 1974; Ola, 1991; Obeahon, 1993).Detailed test results are given in Table A4.11in the Appendix.

Table 4.7 Single factor analysis of variance for compaction characteristics of black cottonsoil- bagasse ashmixtures

Property		Source of Variation	Degree of Freedom	F_{CAL}	P-value	F_{CRIT}	Remark
BSL	MDD	BA	9	2.74	5.25E-2	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
	OMC	BA	9	127.10	3.44E-06	5.52	$F_{CAL} > F_{CRIT}$, Significant effect
WAS	MDD	BA	9	2.64	0.14268	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
	OMC	BA	9	84.39	1.35E-5	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
BSH	MDD	BA	9	2.40	6.57E-2	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
	OMC	BA	9	67.58	8.17E-5	5.32	$F_{CAL} > F_{CRIT}$, Significant effect

BA – bagasse Ash

The analysis of variance (ANOVA) test on the MDD result for BSL, WAS and BSH compactions (see Table 4.7) shows that the effect of bagasse ash on black cottonsoil was not statistically significant.

4.2.6.2 *Optimum moisture content*

The variation of optimum moisture contentof black cotton soil withbagasse ash content for the three compactive efforts considered is shown in Fig. 4.9.OMC values decreased with higher compactive effort and increased with higher bagasse ash content. For BSH, WAS and BSL compactions OMC values increased from 14.8, 16.3 and 19.5 % for the natural soil to 17.3, 18.0 and 20.8 %, respectively, at 8 % bagasse ash content. Detailed test results are given in Table A4.11 in the Appendix.

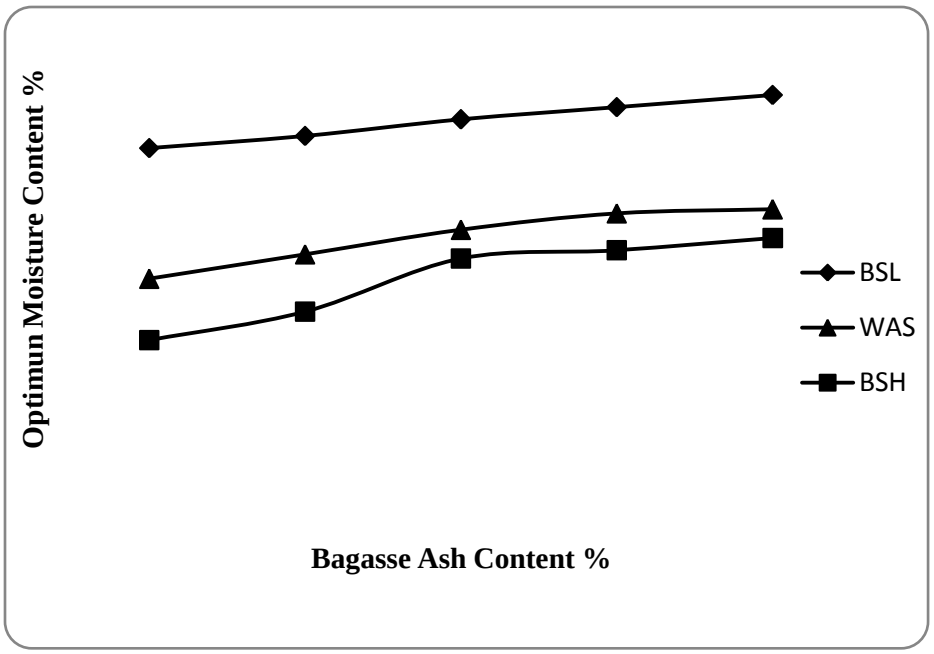


Fig. 4.9: Variation of optimum moisture content of black cotton soil with bagasse ash content at no delay after mixing

Generally OMC increased for all compactive efforts with increase in bagasse ash content. This may be due to the increasingaffinity for water needed for the dissociation of bagasse ash into Ca^{2+} and OH^{-} ions tosupply more cations for the cation exchange reaction (Osinubi and Eberemu, 2011).Another reason could be due to the increasing surface area caused by the higher amount of bagasse ash that required more water for the lubrication of the entire matrix (Osinubi and Moses, 2012). The trend of increasing OMC with bagasse ash content is in agreement with the research findings reported by Osinubi (1999), Moses (2006), Osinubi et al. (2007b), Akinmade (2008) and Ochepo (2008).Detailed test results are given in Table A4.11 in the Appendix.

The analysis of variance (ANOVA) test on the OMC result for BSL, WAS and BSH compactions (see Table 4.7)shows that the effects of bagasse ash on black cotton soil was statistically significant.

4.2.7 Shear strength parameters

The effects of bagasse ash content on cohesion and angle of internal friction forthe compaction energy levels used in this study are shown in Figs.4.10 and 4.11. Therewas an observed reduction in cohesion, while the angle of internal friction increasedwith increasing bagasse ashtreatment. This could probably be due to the reduction in clay sized fractions, a consequence of ion exchange reaction (Osula, 1991; Mu'azu, 2007).

The trend of increase in angle of internal friction with increase inbagasse ashcontent isin agreement with the findings reported by Lees et al. (1982), Osula (1991) and Osinubi(1995), while the reducing trend of cohesion with increasing bagasse ash content agreeswith the findings reported by Osula (1991),Mu'azu, (2007). The reduction in cohesion could be associated with thebreakdown of the weak forces holding the clay particles together to formstronger bonds thereby reducing the cohesive nature of the natural soil.

4.2.7.1 *Cohesion*

The variation of cohesion of black cotton soil with bagasse ash content for BSL, WAS and BSH compactiveefforts isshown inFig.4.10. Results obtained show that for BSL, cohesion of the natural soil decreased with increase in bagasse ash content from 140 to 50 kN/m^2 at 8 % bagasse ash content.For WAS, cohesion decreased from88 to 62 kN/m^2 and for BSH, cohesion decreased from 68 kN/m^2 to 40 kN/m^{2}at 8 % bagasse ash content respectively. The observed

decreasein cohesion with an increase inbagasse ash treatment may be as a result of the ionexchange reaction between the bagasse ash and soil. This trend of decreasing cohesion is in agreement with Nixon and Skipp (1957), Little (1967) and Ovuarume (2011). Detailed test results are given in Table A4.12 in the Appendix.

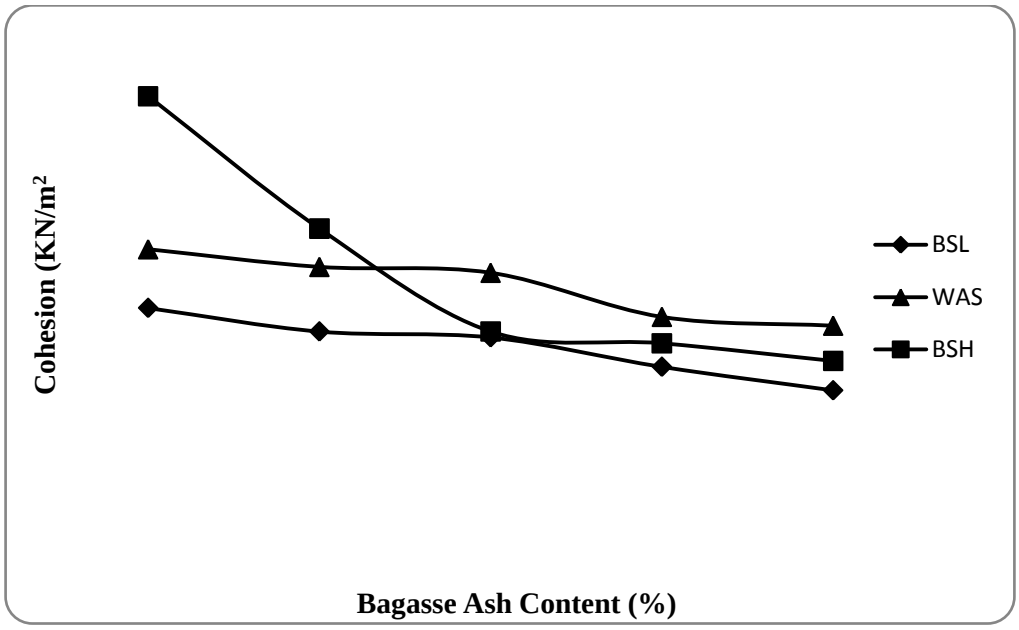


Fig. 4.10: Variation of cohesion of black cotton soil with bagasse ash content at no compaction delay

The analysis of variance (ANOVA) test on cohesion results for BSL, WAS and BSH compaction (see Table 4.8) shows that the effect of bagasse ash on black cotton soil was statistically significant

Table 4.8Single factor analysis of variance for shear strength parameters of black cotton soil-bagasse ashmixtures

Property		Source of Variation	Degree of Freedom	F_{CAL}	P-value	F_{CRIT}	Remark
BSL	Cohesion	BA	9	99.87	5.25E-2	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	Angle of internal friction	BA	9	0.49	3.44E-06	5.52	$F_{CAL} > F_{CRIT}$, No Significant effect
WAS	Cohesion	BA	9	184.98	0.14268	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	Angle of internal friction	BA	9	2.45	1.35E-5	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
BSH	Cohesion	BA	9	20.23	6.57E-2	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	Angle of internal friction	BA	9	17.63	8.17E-5	5.32	$F_{CAL} > F_{CRIT}$, Significant effect

4.2.7.2 *Angle of internal friction*

The variation of angle of internal friction of black cotton soil with bagasse ash BA is shown in Fig. 4.11 for BSL, WAS and BSH compactionenergy levels.From the figure, angle of internal friction of the natural soil for BSL increased with increase in bagasse ash from 8 to 13^o at 8 % bagasse ash content. For WAS, angle of internal friction increased from 1.5 to 13^o and for BSH, angle of internal friction increased from 1^o to 10^oat 8 % bagasse ash content respectively.The increase in the angle of internal friction with increasing bagasse ash content for all compactive efforts can be explained as resulting from the reduction in clay sized fractions due to cation exchange reaction that deposits free limeMu'azu, (2007) and Ovuarume (2011). Detailed test results are given in Table A4.12b, in the Appendix.

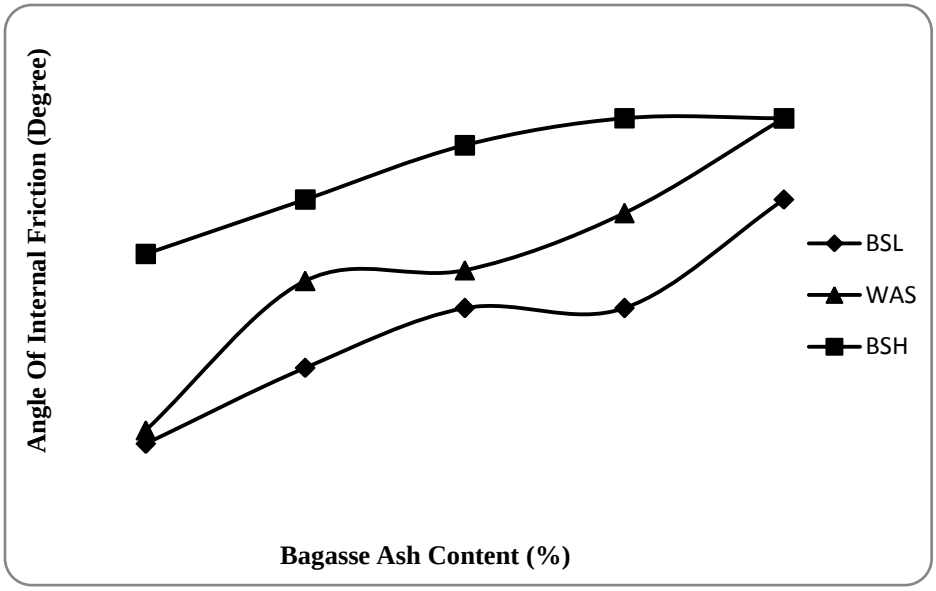


Fig. 4.11: Variation of angle of internal friction of black cotton soil with bagasse ash content at no compaction delay

The analysis of variance (ANOVA) test on the angle of internal friction results for BSL, WAS and BSH compaction 9see Table 4.8) shows that the effect of bagasse ash on black cotton soil was not statistically significant.

4.3 Effect of Elapsed Time After Mixing on Modified Black cotton Soil

4.3.1 Particle size distribution (dry sieving)

4.3.1.1 *Up to 3 hours delay for British Standard light compaction*

The particle size distribution curves for black cotton soil – bagasse ash mixtures prepared using the optimum moisture contentsobtained from BSL, compactions for 1 – 3hours delaysafter mixing are shown in Fig. 4.12a – 4.12e. From the figures, the fines content reduced from 1.3 to 0.5 %, 1.25 to 1 %, and 1.2 to 1.15 % at 3 hours elapsed time after mixing for 0, 2 and 4 % bagasse ash treatment of black cotton soil. However, at 6 and 8 % bagasse ash treatment, there

was no observed reduction in fines. For the elapsed times after mixing considered observed increases in coarse sizes were observed with higher elapsed time.

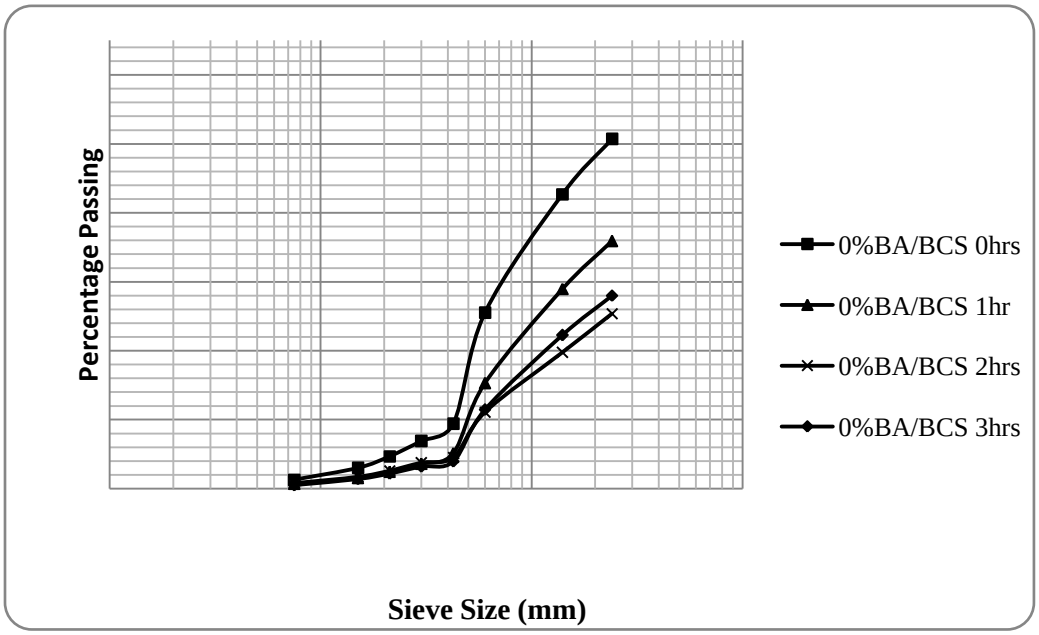


Fig. 4.12a: Particle size distribution curves for black cotton soil - 0 % bagasse ash (BSL compaction)

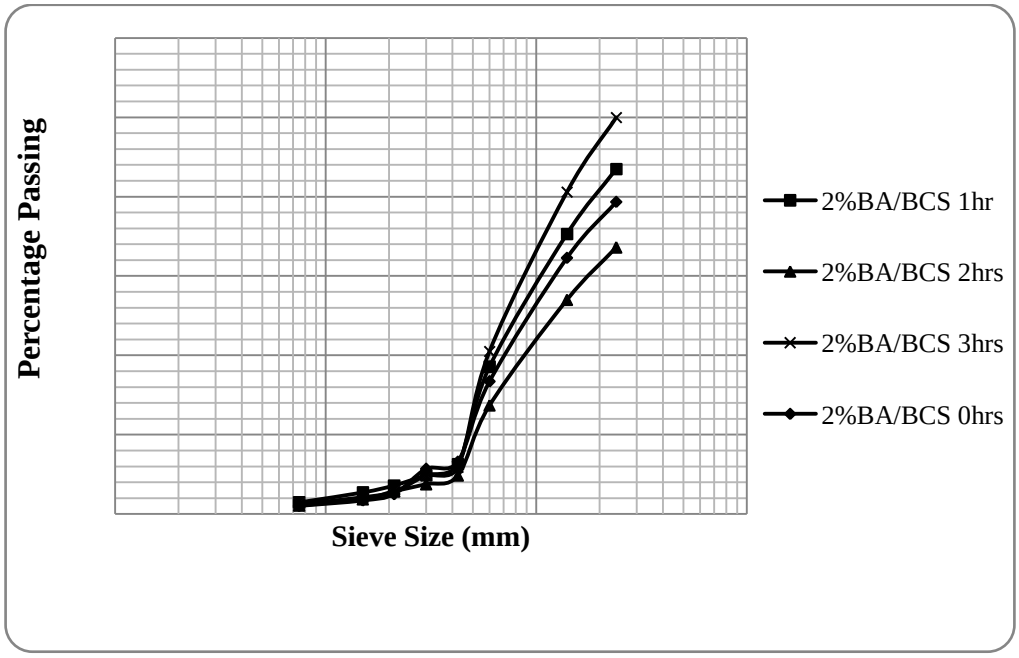


Figure 4.12 (b) Particle Size Distribution Curves for Black Cotton Soil - 2 % Bagasse Ash (BSL Compaction)

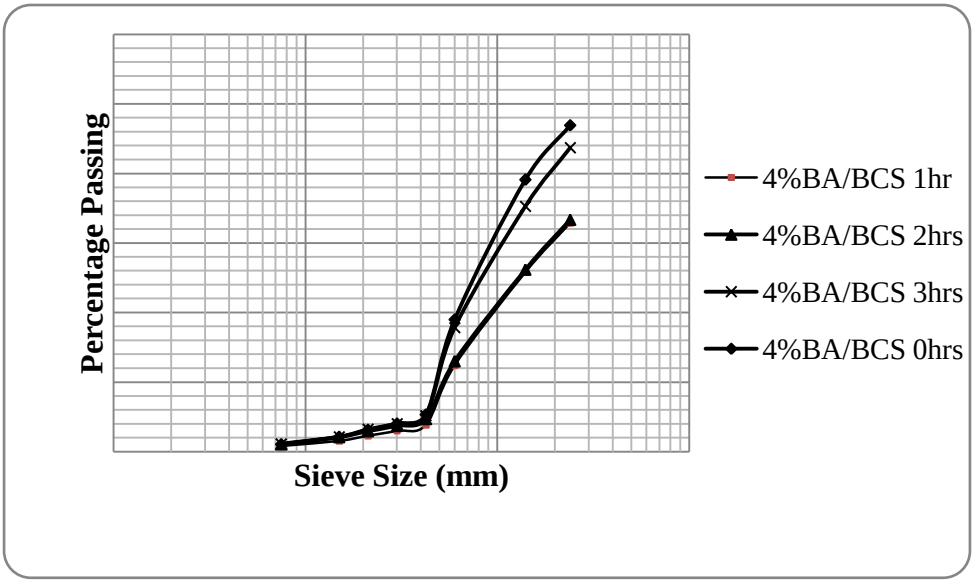


Figure 4.12 (c) Particle Size Distribution Curves for Black Cotton Soil - 4 % Bagasse Ash (BSL Compaction)

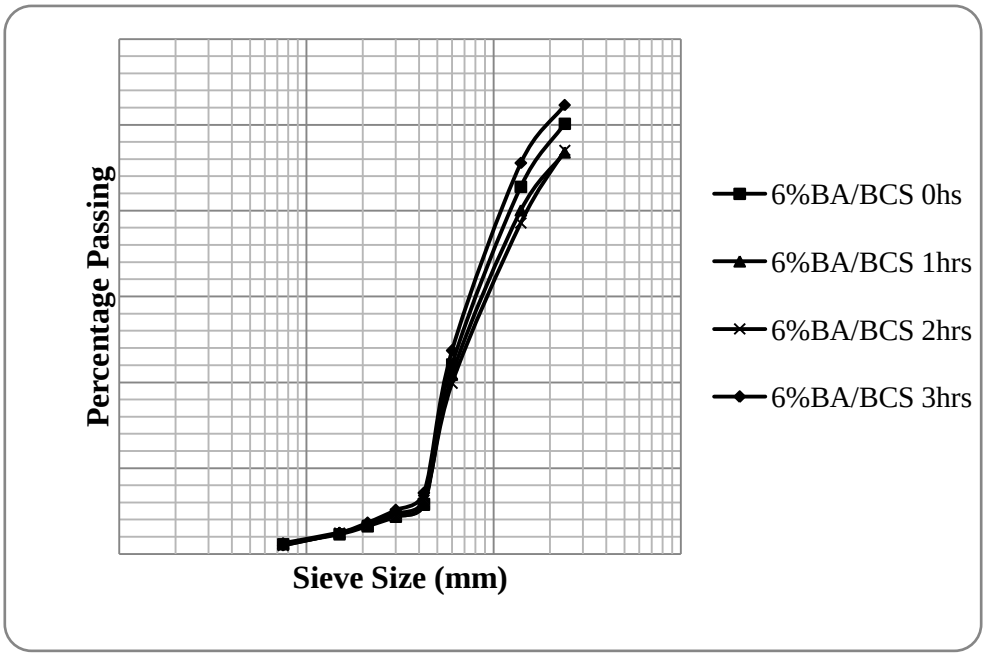


Figure 4.12 (d) Particle Size Distribution Curves For Black Cotton Soil – 6 % Bagasse Ash (BSL Compaction)

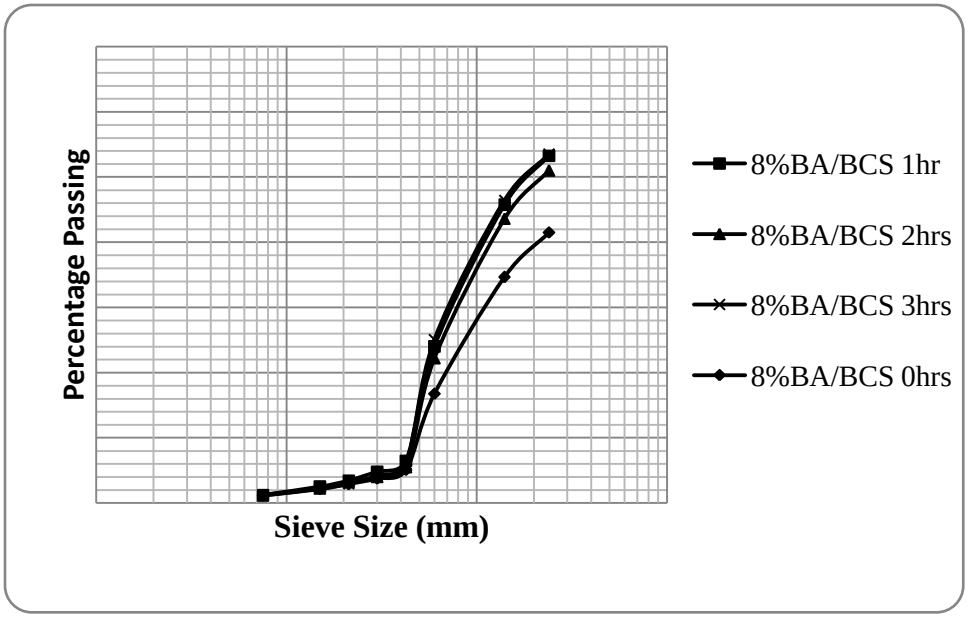


Figure 4.12 (e) Particle Size Distribution Curves For Black Cotton Soil – 8 % Bagasse Ash (BSL Compaction)

There was a reduction in the percentage of fines with increased in bagasse ash content and elapsed time after mixing (see Fig. 4.12a – 4.12e). The black cotton soil – bagasse ash mixture became coarser thus enabling the clay particles to form pseudo silt sizes. The decrease in the percentage passing the various sieves was as a result of the reduction in the proportion of silt sizes to form pseudo – sand sizes and the sand sizes form larger sand sizes (Sarkar, et.al, 2012; Al karagooly, 2012 and Portelinha et al, 2012, Mu'azu, 2007). Detailed test results are given in Table A4.8a in the Appendix.

4.3.1.2 *Up to 3 hours delay for West African Standard compaction*

The particle size distribution curves for black cotton soil – bagasse ash mixtures prepared using the optimum moisture contentsobtained from WAS, compactions for 0 – 3hours delaysafter mixing are shown in Fig. 4.13 (a) – (e). There was no observed decrease in the percentage of fines for natural soil and 8% BA treatment but at 2 % BA treatment, there was a decrease in the percentage of fines from 1.45 % to 1.15 % at 3hrs delayed time. At 4 % BA treatment, there was also a decrease in the percentage of fines from 1.16 % to 1.15 % at 3hrs delayed time. At 6 % BA treatment, there was a decrease in the percentage of fines from 1.1 % to 0.95 % at 3hrs delayed time. For all delayed time considered, there were observed incremental changes in sizes with higher increased elapsed time in the coarse sizes.

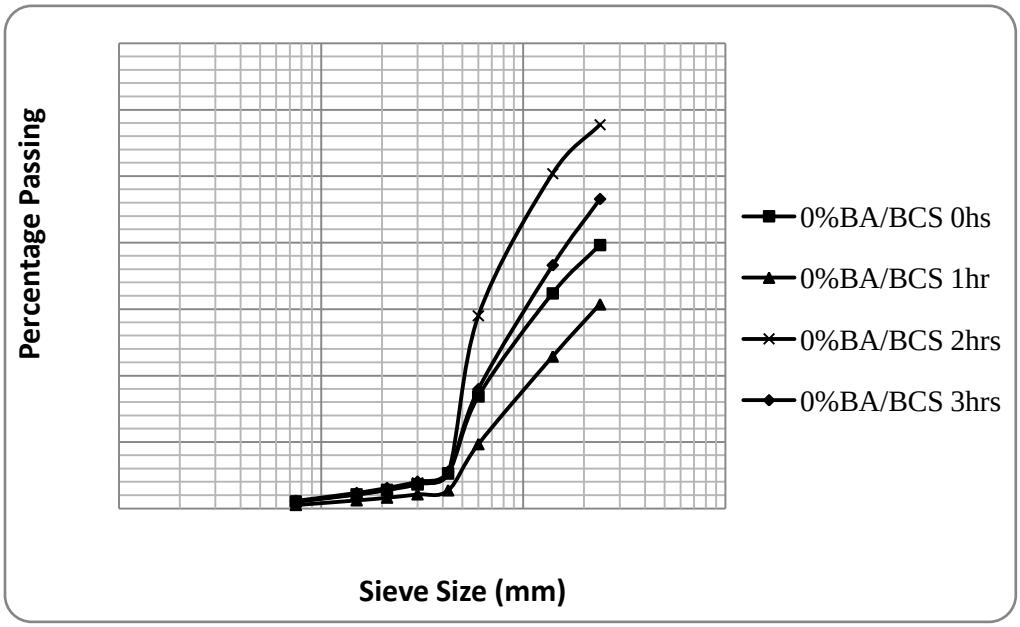


Figure 4.13 (a) Particle Size Distribution Curves for Black Cotton Soil – 0 % Bagasse Ash (WAS Compaction)

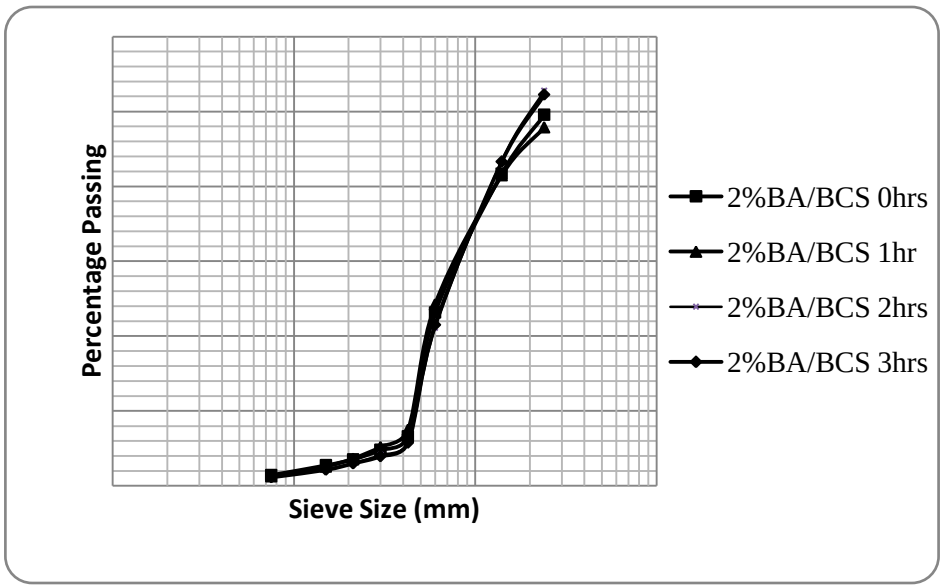


Figure 4.13 (b) Particle Size Distribution Curves For Black Cotton Soil – 2 % Bagasse Ash (WAS Compaction)

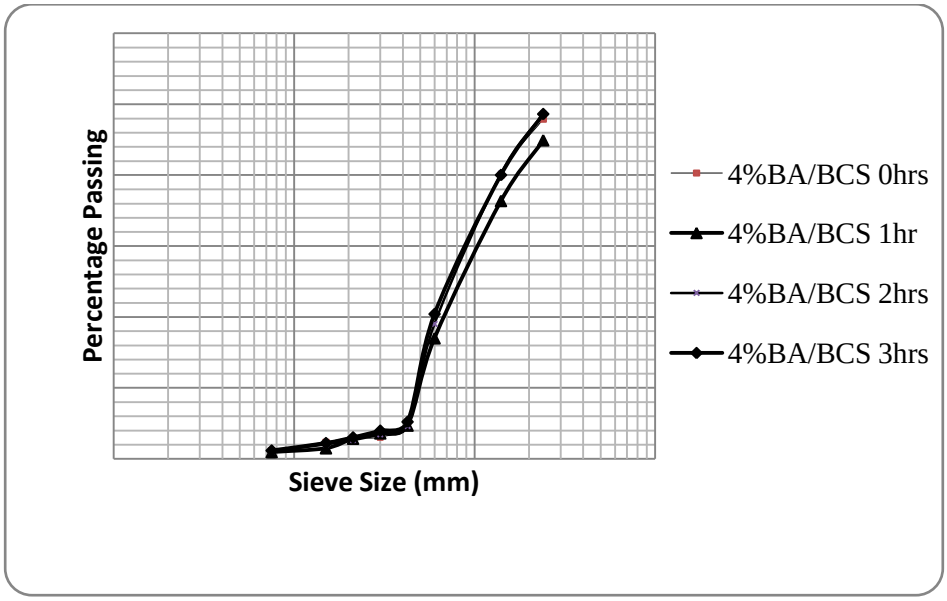


Figure 4.13 (c) Particle Size Distribution Curves For Black Cotton Soil – 4 % Bagasse Ash (WAS Compaction)

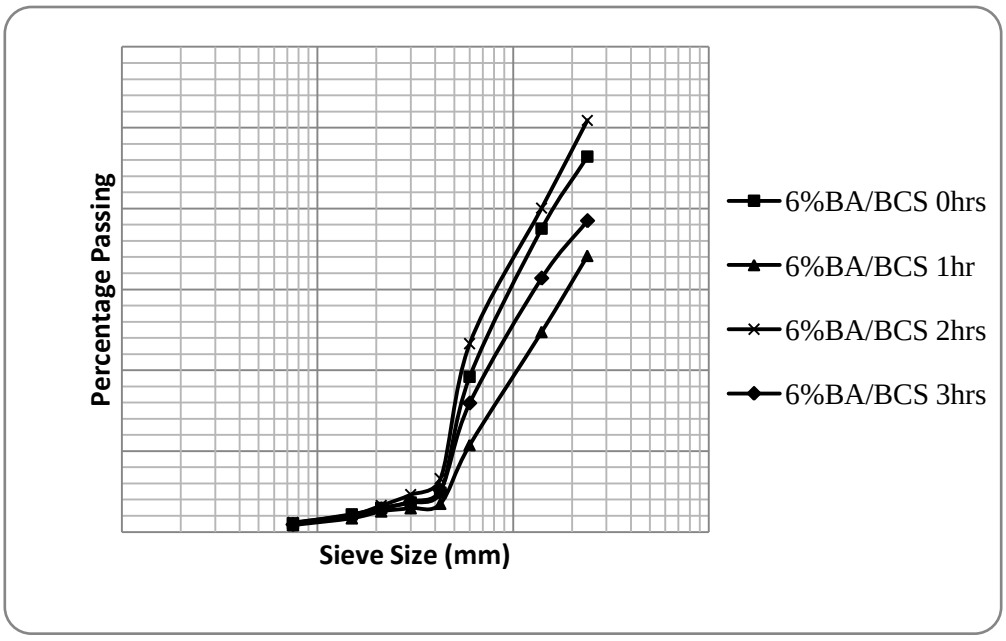


Figure 4.13 (d) Particle Size Distribution Curves For Black Cotton Soil – 6 % Bagasse Ash (WAS Compaction)

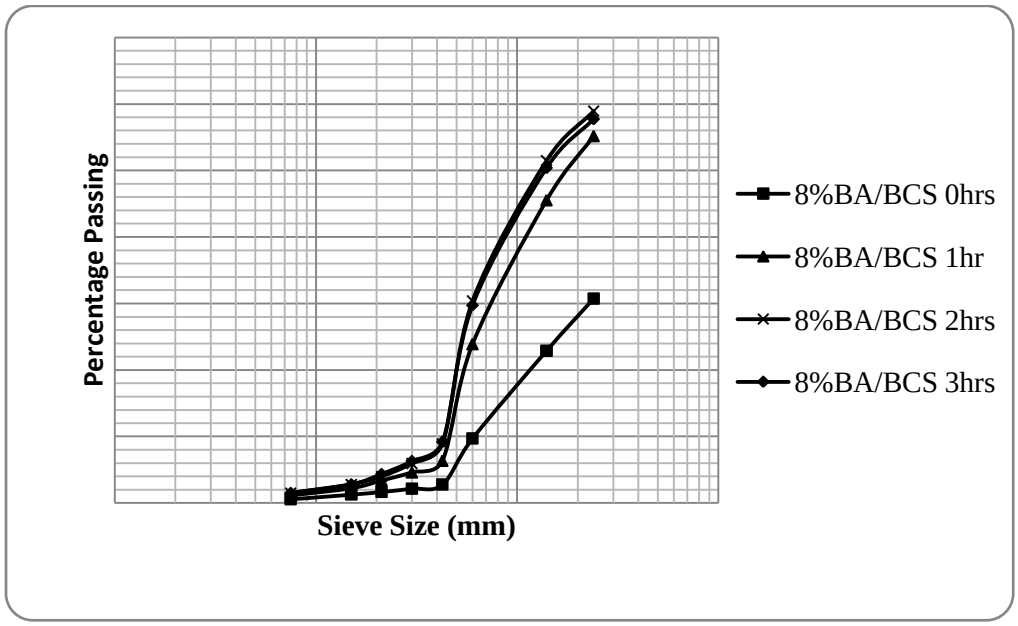


Figure 4.13 (e) Particle Size Distribution Curves for Black Cotton Soil – 8 % Bagasse Ash (WAS Compaction)

Test results generally indicate that the introduction of bagasse ash enhanced the gradation characteristics of the black cotton soil by reducing the amount of clay size particles through flocculation and agglomeration of the clay particles. With increase in bagasse ash contents, the quantity of free silt and clay progressively reduced and coarser material was formed this is in agreement with the findings ofKedzi (1979) and Amadi (2010a).Similarly the increase in the coarser particle could be due to high moisture content available for pozzolanic reaction and hydration of free lime and silica in the additives.Detailed test results are given in Table A4.8b in the Appendix.

4.3.1.3 Up to 3 hours delay for British Standard heavy compaction

The particle size distribution curves for black cotton soil – bagasse ash mixtures at 0 – 3hours compaction delaysusing the optimum moisture contentsobtained from BSH, compactions are shown in Fig. 4.14 (a) – (e) , respectively. There was an observed decrease in the percentage of fines for 0% BA at 0hrs delay time from 1.5 % to 0.7 % at 3hrs delayed time. At 2 % BA treatment, there was also a decrease in the percentage of fines at 0 hrs delayed time from 1.14 % to 0.85 % at 3hrs delayed time. At 4 % BA treatment, there was also a decrease in the percentage of fines at 0 hrs delayed time from 1.25 % to 1.2 % at 3hrs delayed time. At 6 % BA treatment and 8 % BA treatment there was no observed decrease. For all delayed time considered, there were observed incremental changes in sizes with higher increased elapsed time in the coarse sizes.

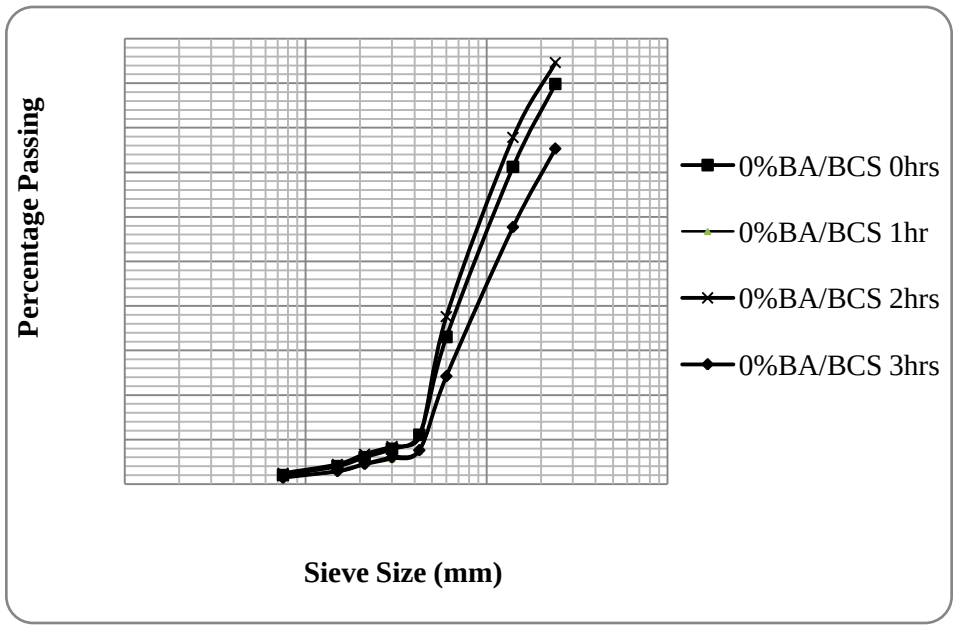


Figure 4.14 (a) Particle Size Distribution Curves for Black Cotton Soil – 0 % Bagasse Ash (BSH Compaction)

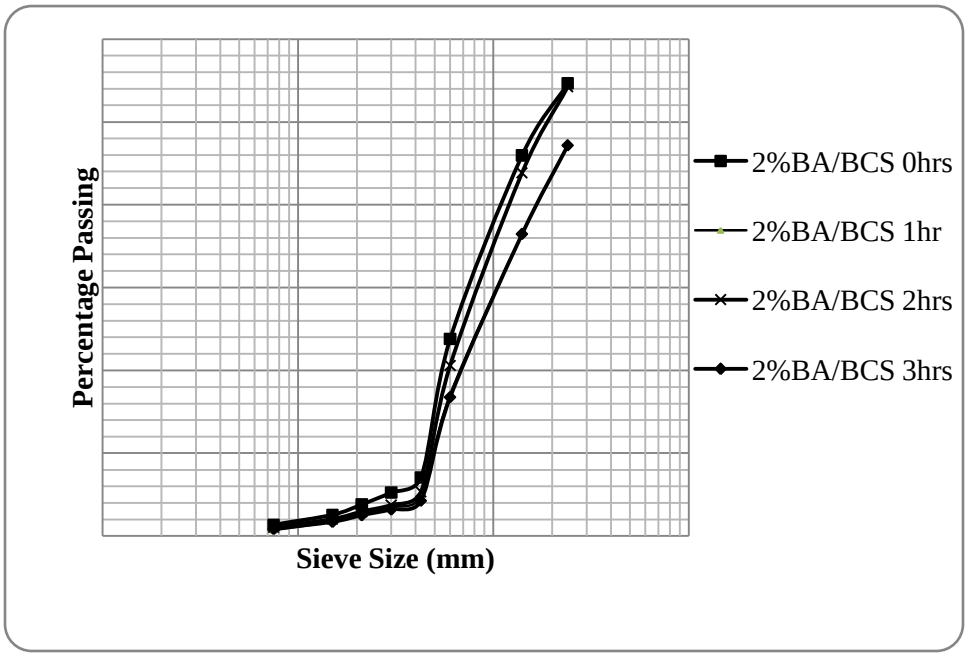


Figure 4.14 (b) Particle Size Distribution Curves for Black Cotton Soil – 2 % Bagasse Ash (BSH Compaction)

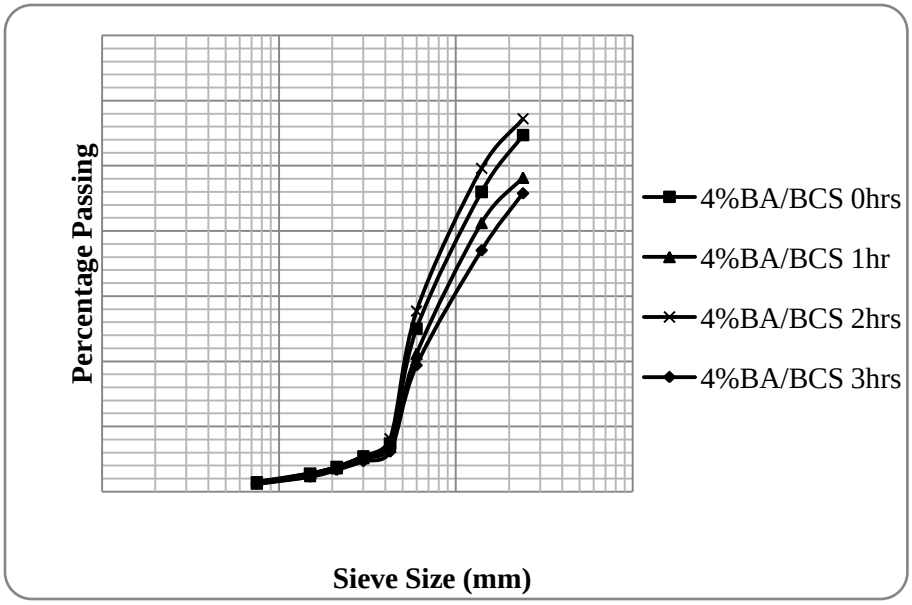


Figure 4.14 (c) Particle Size Distribution Curves for Black Cotton Soil – 4 % Bagasse Ash (BSH Compaction)

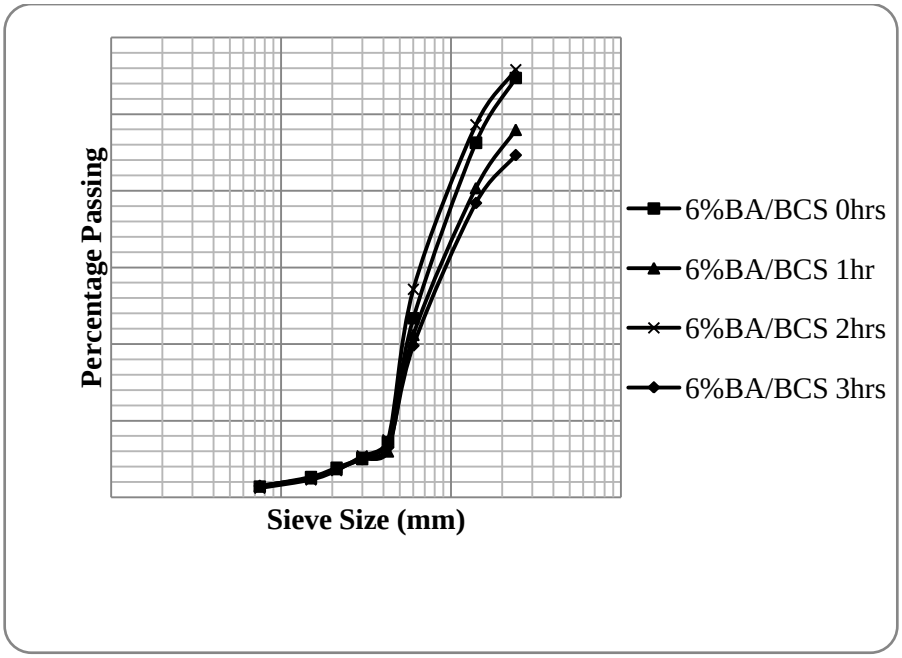


Figure 4.14 (d) Particle Size Distribution Curves for Black Cotton Soil – 6 % Bagasse Ash (BSH Compaction)

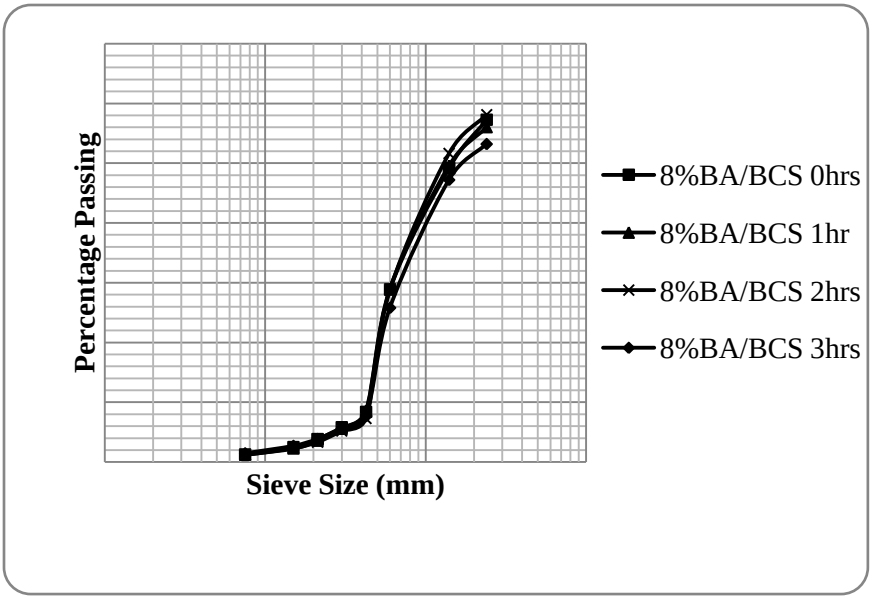


Figure 4.14 (e) Particle Size Distribution Curves for Black Cotton Soil – 8 % Bagasse Ash (BSH Compaction)

Also as observed with BSL and WAS compaction, test results generally indicate that the introduction of bagasse ash enhanced the gradation characteristics of the black cotton soil by reducing the amount of clay size particles through flocculation and agglomeration of the clay particles. With increase in bagasse ash contents, the quantity of free silt and clay progressively reduced and coarser material was formed this is in agreement with the findings ofKedzi (1979) and Amadi (2010a).Similarly the increase in the coarser particle could be due to high moisture content available for pozzolanic reaction and hydration of free lime and silica in the additives.Detailed test results are given in Table A4.8c in the Appendix.

4.3.2 Atterberg limits

The variations of the Atterberg limits of black cotton soil – bagasse ash mixtures with elapsed time after mixing are shown in Figs. 4.15 – 4.17

4.3.2.1 *Liquid limit*

The variation of liquid limit of black cotton soil – bagasse ash mixtures with elapsed time after mixing is shown in Fig. 4.15. The Liquid limit value of the natural black cotton soil increased from 45.4 to 48 % when delayed for 2 hrs then decreased to 46.8 % on further delay by 3 hrs. At 2 %BA treatment, the liquid limit increased from 47.2 % at no delayed time to 48.8 % when delayed for 2 hrs then decreased to 48.5 % on further delay by 3 hrs. Similar trends of increased liquid limit when delayed for 2 hours and consequent decrease on further delay by 3 hours was observed for 4 % BA, 6 % BA and 8 % BA treatment. The initial increase of liquid limit values may be due to the release of Ca^{++}, Si^{++} and Al^{++}cations with increased in bagasse ash content (Ramzi et al 2001).The subsequent decrease of liquid limit values may be due to flocculation and agglomeration arising from cation exchange reactions whereby calcium in bagasse ash reacted with ions of lower valence in the clay structure (Ochepo2008, Moses and Afolayan, 2011). Detailed test results are given in Table A4.9aof the Appendix.

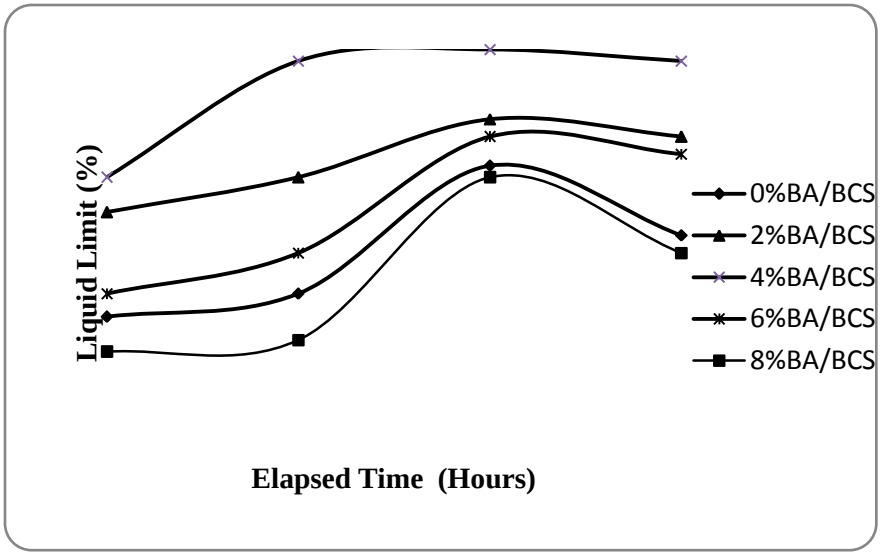


Fig.4.15: Variation of liquid limit of black cotton soil – bagasse ash mixtures with elapsed time after mixing

The analysis of variance (ANOVA) test on the liquid limit results (see Table 4.9) shows that the effect of bagasse ash on black cotton soil is statistically significant.

Table 4.9 Single factor analysis of variance for Atterberglimits of black cotton soil – bagasse ash mixtures with elapsed time after mixing

Elapsed time	Property	Source of Variation	Degree of Freedom	F_{CAL}	P-value	F_{CRIT}	Remark
1hr	Liquid Limit	BA	9	682.06	4.96E-09	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	Plastic Limit	BA	9	106.73	6.65E-06	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	Plasticity Index	BA	9	195.95	6.58E-07	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
2hrs	Liquid Limit	BA	9	925.85	1.48E-09	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	Plastic Limit	BA	9	110.32	5.88E-06	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	Plasticity Index	BA	9	278.57	1.68E-07	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
3hrs	Liquid Limit	BA	9	818.64	2.41E-09	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	Plastic Limit	BA	9	106.35	6.74E-06	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	Plasticity Index	BA	9	247.29	2.67E-07	5.32	$F_{CAL} > F_{CRIT}$, Significant effect

4.3.2.2 *Plastic limit*

The variation ofplastic limitof black cotton soil – bagasse ash mixtures with elapsed time after mixing is shown in Fig 4.16.

The Plastic limit value of the natural black cotton soil decreased from 21 to 19.5 % when delayed for 1 hr then increased to 19.8 % when delayed for 2 hrs then consequently decrease to 19.4 on further delay by 3 hrs. At 2 % BA treatment, the Plastic limits decreased from 20.7 to 19.1 % when delayed for 1 hr then increased to 19.4 % when delayed for 2 hrs then consequently decrease to 19.1 on further delay by 3 hrs. Similar trends of decreased liquid limit when delayed for 1 hours increase when delayed for 2 hours and consequent decrease on further delay by 3 hours was observed for 4 % BA, 6 % BA and 8 % BA treatment.The decrease of the plastic limit can be explained to be due to cation exchange reaction that liberated adsorbed water particles in the soil that leads to further flocculation and aggregation (Ochepo 2008 and Osinubi, 1998). Detailed test results are given in Table A4.9b of the Appendix

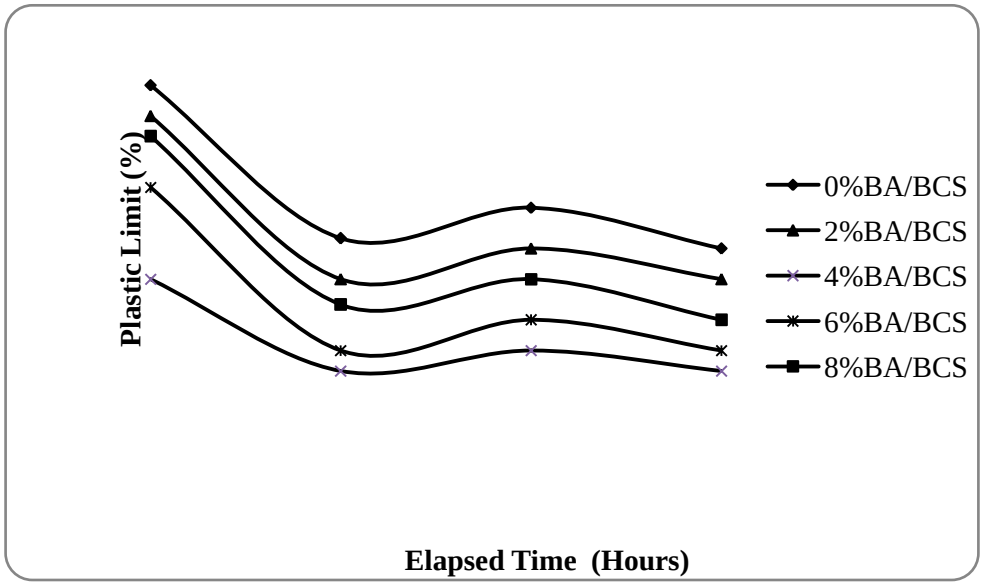


Figure 4.16:Variation of Plastic limit of black cotton soil – bagasse ash mixtures with elapsed time after mixing

The analysis of variance (ANOVA) test on the plastic limit result for 0hrs, 1hr, 2hrs and 3hrs shows that the effects of BA on black cotton soil is statistically significant. See table 4.5 for summarized results. Detailed test results are given in Table A4.16, A4.34, A4.35 and table A4.36 of the Appendix.

4.3.2.3 Plasticity index

The variation of plasticity index of black cotton soil – bagasse ash mixtures with elapsed time after mixing is shown in Fig 4.17.

The Plasticity index value of the natural black cotton soil increased from 26.3 to 28.3 % when delayed for 2 hrs then decreased to 27.4 % on further delay by 3 hrs. At 8 % BA treatment, the Plasticity index increased from 24.3 % at no delayed time to 28.7 % when delayed for 2 hrs then decreased to 27.8 % on further delay by 3 hrs. Similar trends of increased liquid limit when delayed for 2 hours and consequent decrease on further delay by 3 hours was observed for 2 % BA, 4 % BA and 6 % BA treatment.The reduction in plastic limit and increase in liquidlimit were accompanied by a general increase in the plasticity index value at 0hrs – 3hrs delay time. This trend as was said earlier was also reported by Osinubi and Nwaiwu (2006) when he researched into theeffect of baggase ash on the stabilization of black cotton soil.

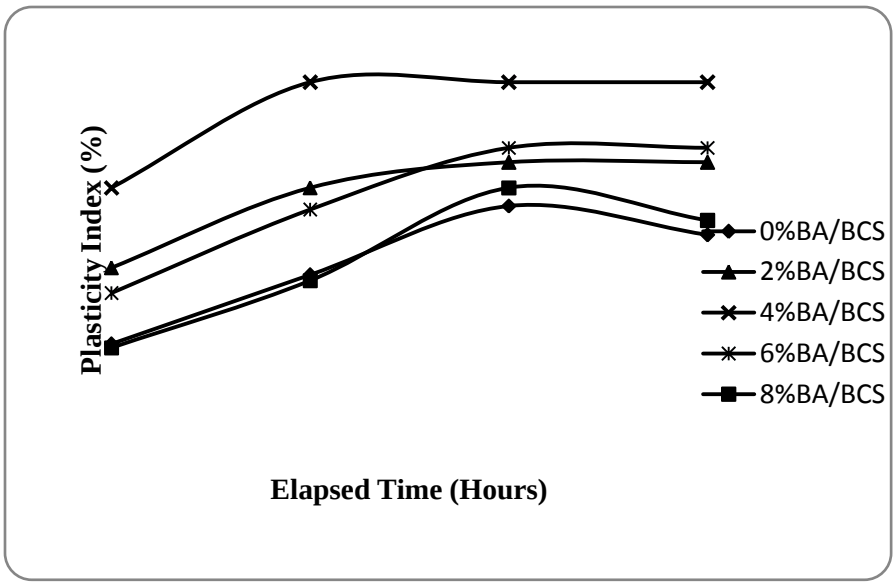


Figure 4.17: Variation of Plasticity index of black cotton soil – bagasse ash mixtures with elapsed time after mixing

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The analysis of variance (ANOVA) test on the plasticity index result for 0hrs, 1hr, 2hrs and 3hrs shows that the effects of BA on black cotton soil is statistically significant. See table 4.5 for summarized results. Detailed test results are given in Table A4.17, A4.37, A4.38 and table A4.39 of the Appendix.

4.3.3 Compaction characteristics

4.3.3.1 *Maximum dry density*

The variation of maximum dry density (MDD)of black cotton soil - bagasse ash mixtures with elapsed time after mixing for the three compaction energies (i.e., BSL, WASand BSH) considered is presented in Fig. 4.18a – 4.18b. For BSL compaction MDD values for the natural soil, 2 % BA, 4 % BA, 6 % BA and 8 % BA treatment increased when delayed for 2 hours thereafter decreased at 3 hoursdelayed time (fig 4.18a). For WAS and BSH compactions MDD values for the natural soil, 2 % BA, 4 % BA, 6 % BA and 8 % BA treatment initially decreased

at 1 hour delayed time, later increased between 1 and 2 hours and thereafter decreased between 2 and 3 hours elapsed time after mixing (Fig. 4.18b and 4.18c).

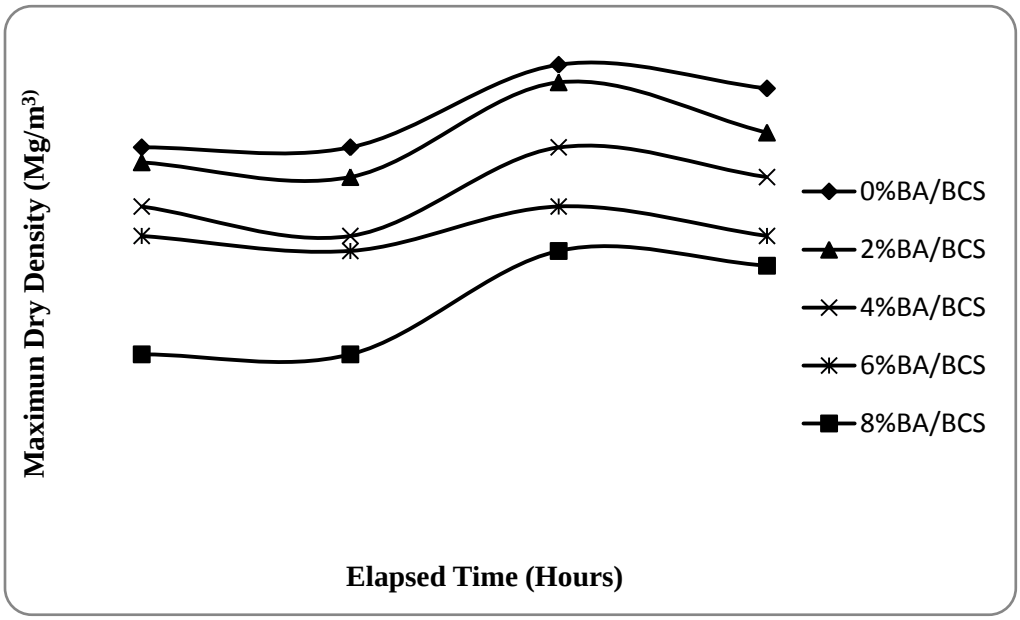


Fig. 4.18a: Variation of maximum dry density of black cotton soil – bagasse ash mixtures with elapsed time after mixing (BSL compaction)

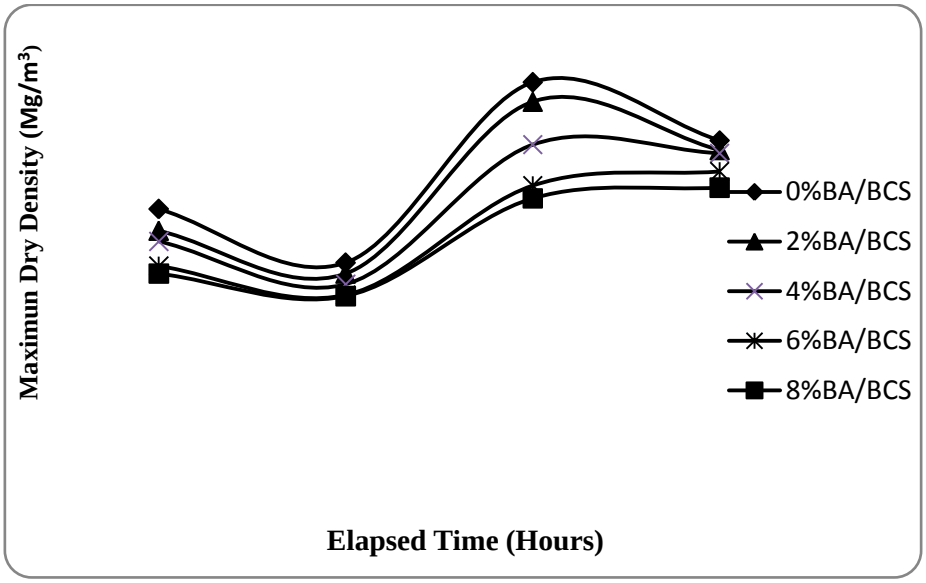


Fig. 4.18b Variation of Maximum Dry Density of black cotton soil – bagasse ash mixtures with elapsed time after mixing (WAS compaction)

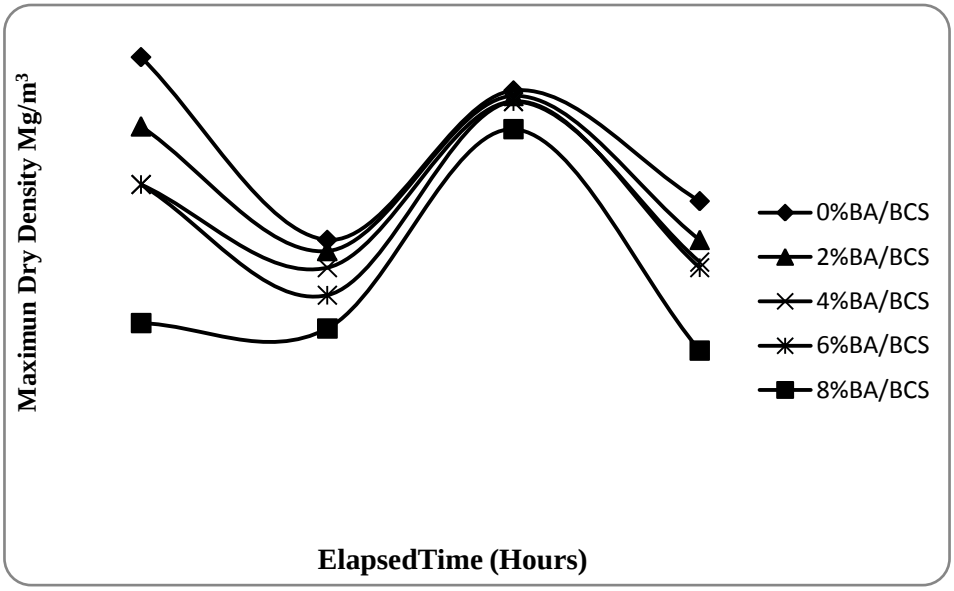


Fig. 4.18cVariation of Maximum Dry Density of black cotton soil – bagasse ash mixtures with elapsed time after mixing (BSH compaction)

For BSL compaction of black cotton soil – bagasse ash mixtures, the initial 1.7 % increase in MDD at all bagasse ash percentage mixtures to peak values at 2 hours elapsed time after mixing (Fig. 4.18a) was due to tocation exchange reactions and also due toBA occupying the void within the soil matrixand in addition, it could also be due to the flocculation and agglomeration of the clay particle due to exchange of ions (Okonkwo, 2009,Osinubi 1998; Vincy and Muttharam 2009).The subsequent 0.5 % decrease at all bagasse ash mixtures recorded at 3 hours elapsed time after mixing was due to the comparatively low specific gravityvalue of the bagasse ash compared to that of the soil. This is in agreement with results reported for no delay time earlier and also in agreement withVincy and Muttharam (2009), Okonkwo, (2009). Osinubi (1998), Osinubi and Nwaiwu (2006). The initial decreases in MDD of 2and 3% for WAS and BSH compaction for all bagasse ash mixtures at 0 - 1 and 2 – 3 hours elapsed time (Fig. 4.18b – c) werenot unconnected to the initial simultaneous flocculationand agglomeration of clay particle caused by cation exchangeleading to increase in volume and decrease in dry density.The observed 10 % increase between 1 and 2 hours compaction delays for both WAS and BSH may

be due to cation exchange reactions with bagasse ash occupying the void within the soil matrix(Okonkwo, 2009,Osinubi 1998; Vincy and Muttharam 2009). The observed decreases in MDD values for BSL, WAS and BSH compactions between 2 and 3 hours compaction delayswere due to flocculationand agglomeration of clay particle caused by cation exchangeleading to increase in volume and decrease in dry density (Osinubi, 1998a, b). Detailed test results are given in Table A4.11 of the Appendix.

The analysis of variance (ANOVA) test on the maximum dry density results (see Fig. 4.10) shows that the effect of bagasse ash on black cotton soil is not statistically significant.

Table 4.10: Single factor analysis of variance for compaction characteristics of black cotton soil – bagasse ash mixtures

Energy	Elapsed time	Property	Source of Variation	Degree of Freedom	F_{CAL}	P-value	F_{CRIT}	Remark
BSL	0HRS	MDD	BA	9	2.74	5.25E-2	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
		OMC	BA	9	127.10	3.44E-06	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	1HR	MDD	BA	9	2.81	0.13245	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
		OMC	BA	9	118.31	4.52E-06	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	2HRS	MDD	BA	9	2.75	0.13570	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
		OMC	BA	9	86.91	1.43E-05	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	3HRS	MDD	BA	9	2.76	0.13502	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
		OMC	BA	9	89.41	1.29E-05	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
WAS	0HRS	MDD	BA	9	2.64	0.14268	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
		OMC	BA	9	84.39	1.35E-5	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	1HR	MDD	BA	9	2.76	0.135411	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
		OMC	BA	9	92.40	1.14E-05	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	2HRS	MDD	BA	9	2.46	0.15547	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
		OMC	BA	9	53.11	8.49E-05	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	3HRS	MDD	BA	9	2.50	0.152712	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
		OMC	BA	9	55.92	7.07E-05	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
BSH	0HRS	MDD	BA	9	2.40	6.57E-2	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
		OMC	BA	9	67.58	8.17E-5	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	1HR	MDD	BA	9	2.49	0.15297	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
		OMC	BA	9	70.72	3.04E-05	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	2HRS	MDD	BA	9	2.49	0.15347	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
		OMC	BA	9	52.98	8.56E-05	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	3HRS	MDD	BA	9	2.47	0.154335	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
		OMC	BA	9	71.69	2.9E-05	5.32	$F_{CAL} > F_{CRIT}$, Significant effect

4.3.3.2 *Optimum moisture content*

The variation of optimum moisture content (OMC) of black cotton soil - bagasse ash mixtures with elapsed time after mixing for the three compaction energies (i.e., BSL, WASand BSH) considered is presented in Fig. 4.19 (a)-(c). For all compactive efforts, values generally increased from 0 hours to 1hr delayed time thereafter decreased at 2 hours and consequently increased at 3 hours delayed time after mixing. (See Fig. 4.19a – c).

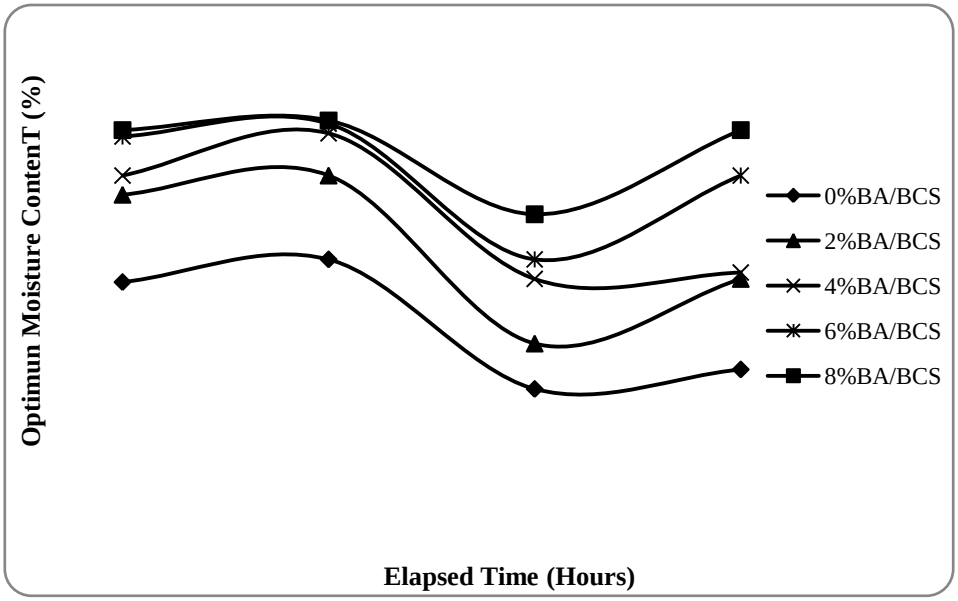


Fig. 4.19a Variation of Optimum Moisture Content of black cotton soil – bagasse ash mixtures with elapsed time after mixing (BSL compaction)

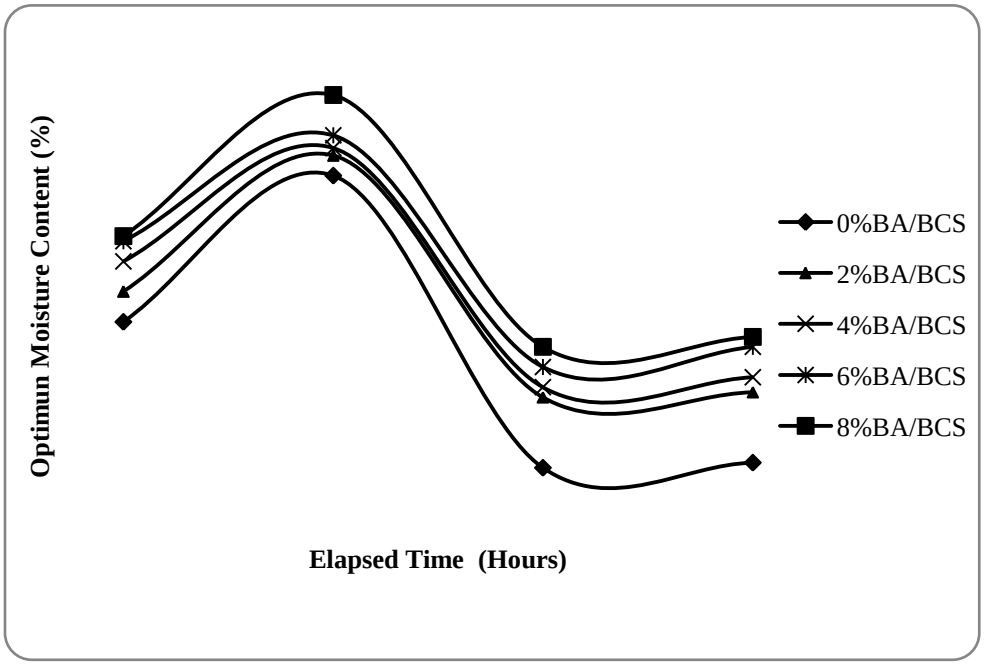


Fig.4.19bVariation of Optimum Moisture Content of black cotton soil – bagasse ash mixtures with elapsed time after mixing (WAS compaction)

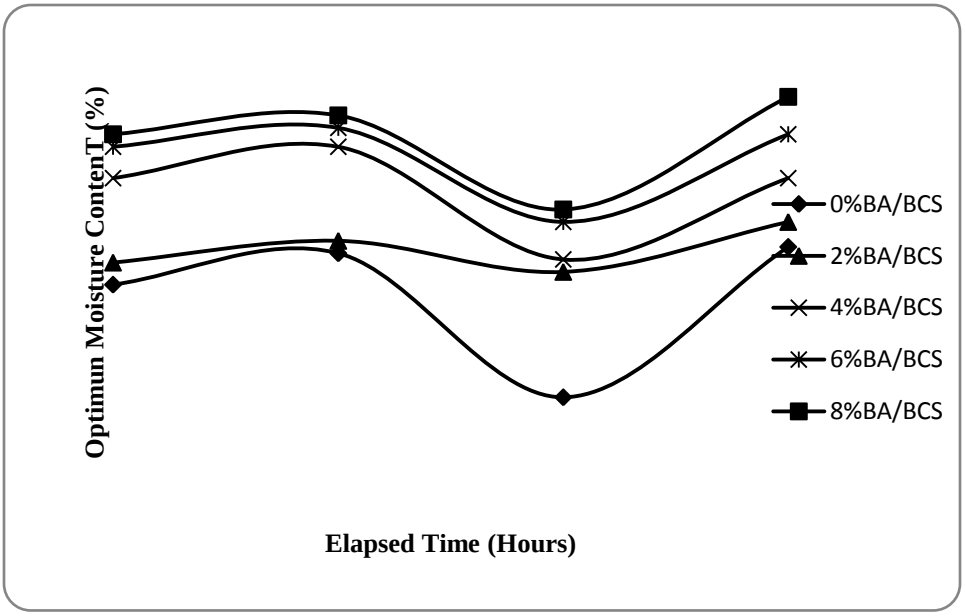


Fig. 4.19cVariation of Optimum Moisture Content of black cotton soil – bagasse ash mixtures with elapsed time after mixing (BSH compaction)

For BSL compaction of black cotton soil – bagasse ash mixtures, there was an observed average increase of 1.5 % for all mixtures at 0 – 1 hour delayed time thereafter an average 10 % decrease for all mixtures at 1 - 2 hours delayed time and subsequently a 5 % average decrease for all mixtures at 2 - 3 hours delayed time. For WAS compaction there was an observed average increase of 11 % for all mixtures at 0 – 1 hour delayed time thereafter an average 24 % decrease for all mixtures at 1 - 2 hours delayed time and subsequently a 5 % average decrease for all mixtures at 2 - 3 hours delayed time. While for BSH compaction there was an observed average increase of 2 % for all mixtures at 0 – 1 hour delayed time thereafter an average 9 % decrease for all mixtures at 1 - 2 hours delayed time and subsequently a 9 % average decrease for all mixtures at 2 - 3 hours delayed time. The observed increase for BSL, WAS and BSH at 0 – 1 hour delayed time and 2 – 3 hours delayed time is due the increasingaffinity for water needed for the dissociation of bagasse ash into Ca^{2+} and OH^- ions tosupply more cations for the cationexchange

reaction (Ola, 1983 and Osula,1991).Another reason could be due to the increasing surface area caused by the higher amount of the additives at that delay time that required more water for the lubrication of the entire matrix.The trend of increasing OMC with bagasse ash contents is in agreement with the research findings of Vincy and Muttharam (2009), George (2006), Osinubi(1998), Akinmade (2008) and Ochepo (2008).The observed decrease for BSL, WAS and BSH at 1 – 2 hour delayed time might be due to cation exchange reaction that caused the flocculation of clay particles.The analysis of variance (ANOVA) test on the optimum moisture content result for BSL, WAS and BSH at 0hrs 1hr, 2hrs and 3hrs delayed time shows that the effects of BA on black cotton soil is statistically significant. See Table A4.11 for summarized results and detailed test results are given in Table A4.22,A4.21, A4.49, A4.50, A4.51, A4.52, A4.53, A4.54, A4.55 A4.56 and A4.57 of the Appendix.

4.3.4 Shear strength parameters

4.3.4.1*Cohesion*

The variation of cohesion of black cotton soil - bagasse ash mixtures with elapsed time after mixing for the three compaction energies (i.e., BSL, WASand BSH) considered is presented in Fig. 4.20. For BSL compaction of black cotton soil – bagasse ash mixtures, there was an observed average decrease of 23 % in the cohesion values for all mixtures at 0 – 1 hour delayed time thereafter an average 24 % increase in the cohesion values for all mixtures at 1 - 2 hours delayed time and subsequently a 29 % average decrease in the cohesion values for all mixtures at 2 - 3 hours delayed time. For WAS compaction there was an observed average decrease of 23 % in the cohesion values for all mixtures at 0 – 1 hour delayed time thereafter an average 100 % increase in the cohesion values for all mixtures at 1 - 2 hours delayed time and subsequently a 55

% average decrease in the cohesion values for all mixtures at 2 - 3 hours delayed time. While for BSH compaction there was an observed average decrease of 34 % in the cohesion values for all mixtures at 0 – 1 hour delayed time thereafter an average 36 % increase in the cohesion values for all mixtures at 1 - 2 hours delayed time and subsequently a 46 % average decrease in the cohesion values for all mixtures at 2 - 3 hours delayed time. The observed decrease for BSL, WAS, and BSH at 0 – 1hour, and 2 – 3 hours in the cohesion may be due the ionexchange reaction between the bagasse ash and soilMu'azu (2007) and Obeahon (1993). (Fig. 4.20a – 4.20c).Detailed test results are given in Table A4.12 of the Appendix.

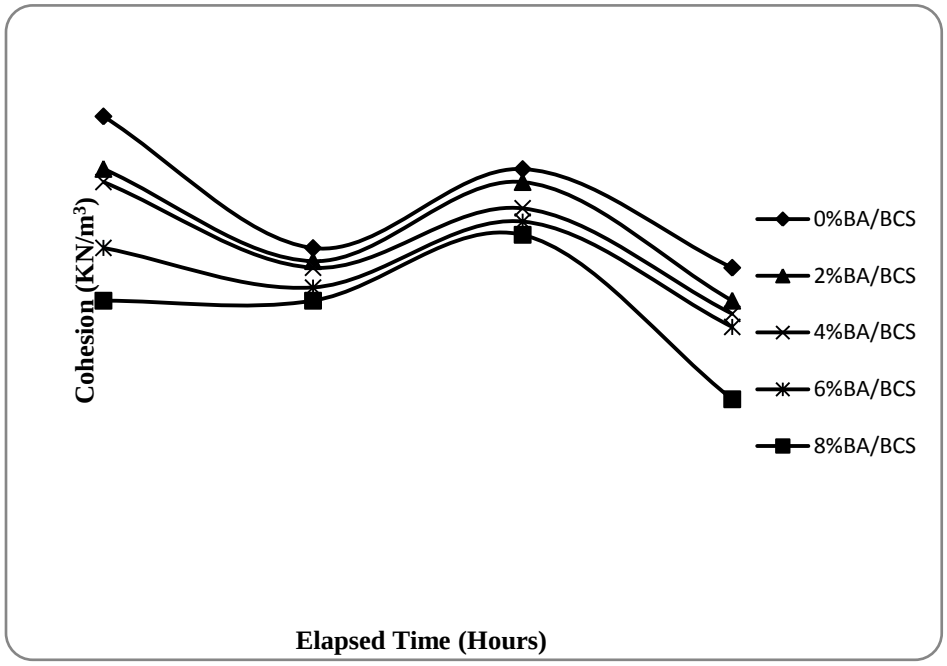


Fig. 4.20a Variation of cohesion of black cotton soil – bagasse mixtures with elapsed time after mixing (BSL compaction)

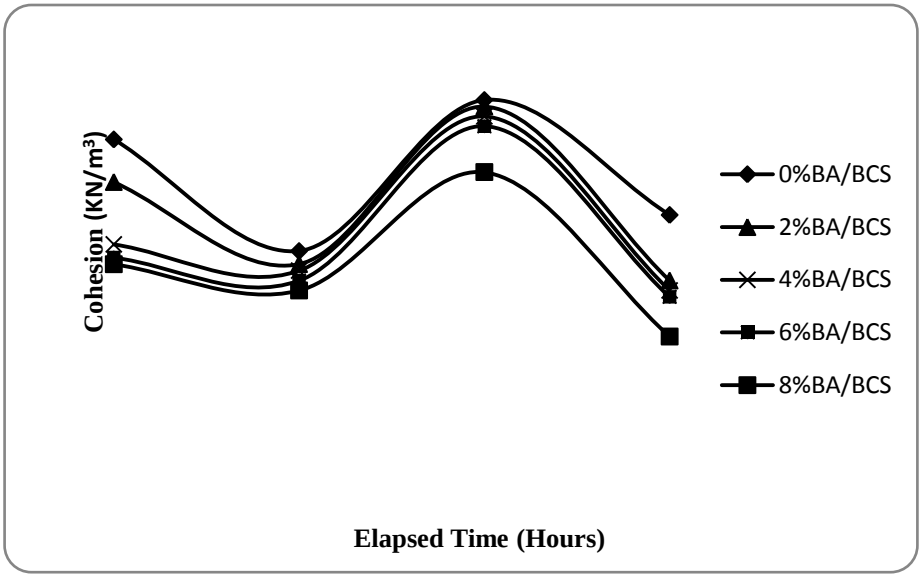


Fig. 4.20b Variation of cohesion of black cotton soil – bagasse mixtures with elapsed time after mixing (WAS compaction)

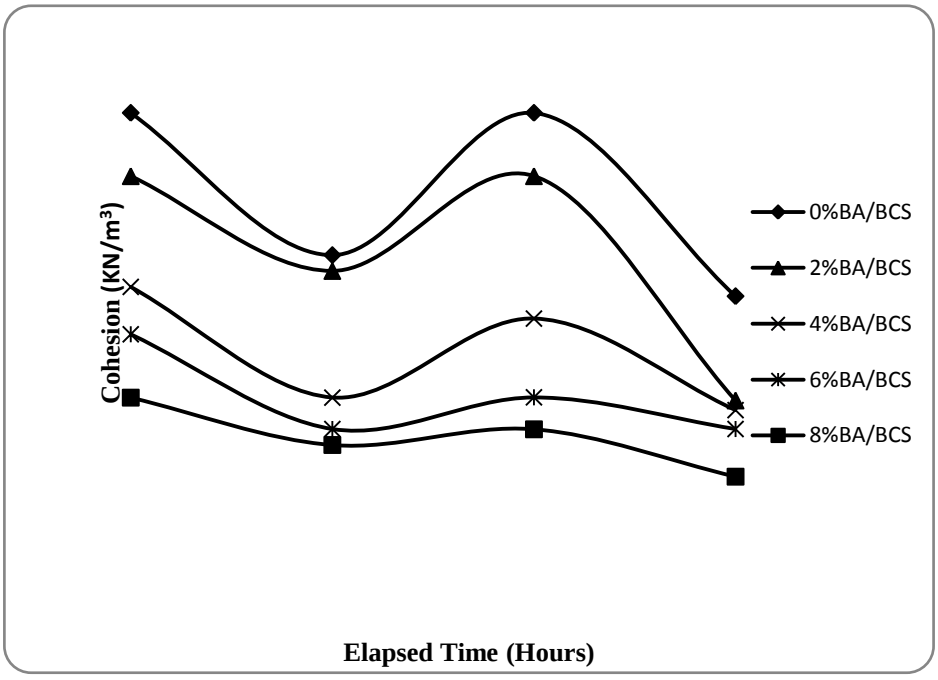


Fig.4.20cVariation of cohesion of black cotton soil – bagasse mixtures with elapsed time after mixing (BSH compaction)

The analysis of variance (ANOVA) test on shear strength parameters (see Table 4.11) shows that the effect of bagasse ash on black cotton soil is statistically significant.

Table 4.11 Single factor analysis of variance for shear strength parameters of black cotton soil – bagasse ash mixtures

Energy	Elapsed time	Property	Source of Variation	Degree of Freedom	F_{CAL}	P-value	F_{CRIT}	Remark
BSL	0HRS	Cohesion	BA	9	99.87	8.53E-06	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
		Angle of internal friction	BA	9	0.49	0.50327	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
	1HR	Cohesion	BA	9	400.01	4.07E-08	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
		Angle of internal friction	BA	9	4.01	0.0803	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
	2HRS	Cohesion	BA	9	474.38	2.08E-08	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
		Angle of internal friction	BA	9	2.08	0.1869	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
	3HRS	Cohesion	BA	9	41.28	2.04E-04	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
		Angle of internal friction	BA	9	7.79	0.02353	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
WAS	0HRS	Cohesion	BA	9	184.98	8.21E-07	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
		Angle of internal friction	BA	9	2.45	0.1558	5.32	$F_{CAL} > F_{CRIT}$, No Significant effect
	1HR	Cohesion	BA	9	307.44	1.14E-07	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
		Angle of internal friction	BA	9	6.17	0.03784	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	2HRS	Cohesion	BA	9	457.46	2.4E-08	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
		Angle of internal friction	BA	9	3.77	0.0881	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	3HRS	Cohesion	BA	9	42.22	1.89E-04	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
		Angle of internal friction	BA	9	9.03	0.0169	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
BSH	0HRS	Cohesion	BA	9	20.23	2.0E-03	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
		Angle of internal friction	BA	9	17.63	3E-03	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	1HR	Cohesion	BA	9	20.57	1.9E-03	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
		Angle of internal friction	BA	9	41.65	1.97E-04	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	2HRS	Cohesion	BA	9	24.78	1.08E-03	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
		Angle of internal friction	BA	9	25.80	9.54E-04	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
	3HRS	Cohesion	BA	9	21.99	1.56E-03	5.32	$F_{CAL} > F_{CRIT}$, Significant effect
		Angle of internal friction	BA	9	36.51	3.08E-04	5.32	$F_{CAL} > F_{CRIT}$, Significant effect

4.3.4.2 Angle of internal friction

The variation of angle of internal friction of black cotton soil - bagasse ash mixtures with elapsed time after mixing for the three compaction energies (i.e., BSL, WASand BSH) considered is presented in Fig. 4.21. For BSL compaction of black cotton soil – bagasse ash

mixtures, there was an observed average increase of 91 % in the angle of internal friction values for all mixtures at 0 – 1 hour delayed time thereafter an average 13 % decrease in the angle of internal friction values for all mixtures at 1 - 2 hours delayed time and subsequently a 34 % average increase in the angle of internal friction values for all mixtures at 2 - 3 hours delayed time. For WAS compaction there was an observed average increase of 11 % in the angle of internal friction values for all mixtures at 0 – 1 hour delayed time thereafter an average 18.5 % decrease in the angle of internal friction values for all mixtures at 1 - 2 hours delayed time and subsequently a 40.5 % average increase in the angle of internal friction values for all mixtures at 2 - 3 hours delayed time. While for BSH compaction there was an observed average increase of 12 % in the angle of internal friction values for all mixtures at 0 – 1 hour delayed time thereafter an average 14.4 % decrease in the angle of internal friction values for all mixtures at 1 - 2 hours delayed time and subsequently a 23 % average increase in the angle of internal friction values for all mixtures at 2 - 3 hours delayed time. The increase in the angle of internal friction with time at 0 – 1 hour and 2 – 3 hours could also be explained as resulting from the further reduction in clay size fraction Mu'azu (2007) and Obeahon (1993).

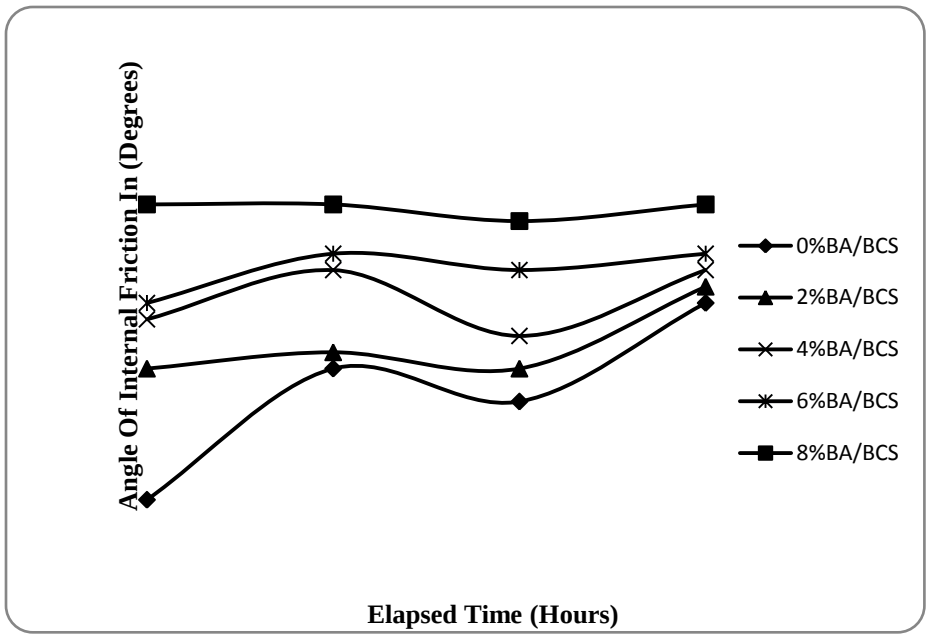


Fig. 4.21a: Variation of angle of internal friction of black cotton soil – bagasse ash mixtures with elapsed time after mixing (BSL compaction)

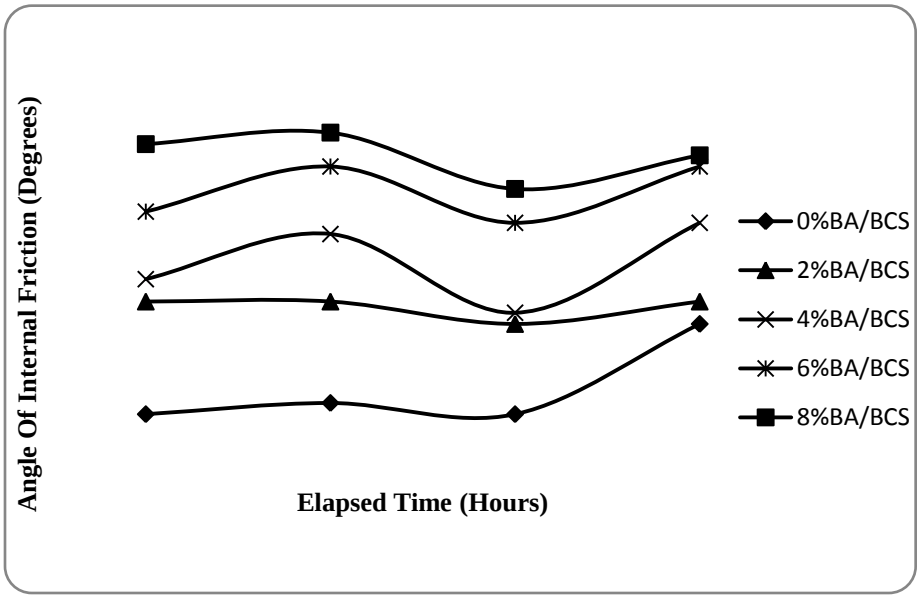


Fig. 4.21 (b) Variation of angle of internal friction of black cotton soil – bagasse ash mixtures with elapsed time after mixing (WAS compaction)

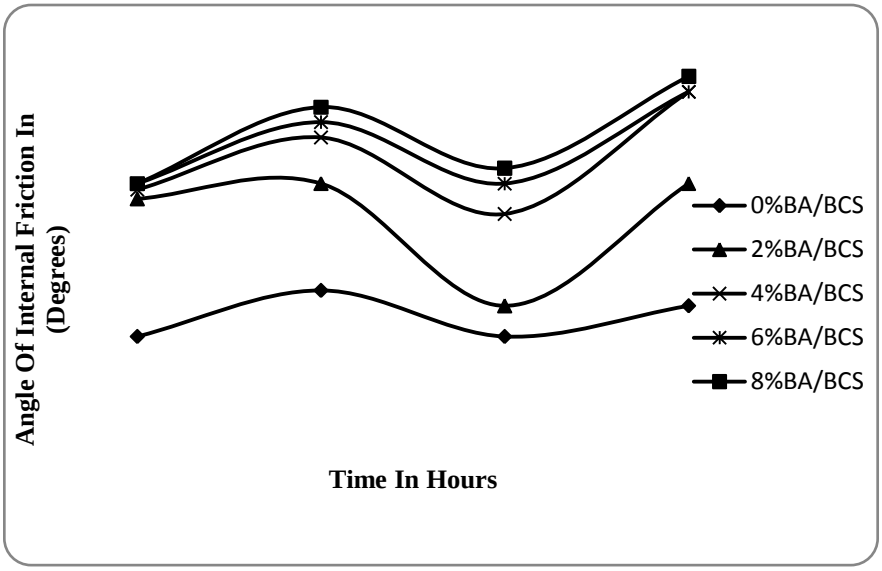


Figure 4.21(c)Variation of angle of internal friction of black cotton soil – bagasse ash mixtures with elapsed time after mixing (BSH compaction)

The analysis of variance (ANOVA) test on the angle of internal friction result for BSL, WAS and BSH at 0hrs 1hr, 2hrs and 3hrs delayed time shows that the effects of BA on black cotton soil is not statistically significant. See Table A4.7 for summarized results and detailed test results are given in Table A4.28,A4.29, A4.30, A4.67, A4.68, A4.69, A4.70, A4.71, A4.72, A4.73 A4.74 and A4.75 of the Appendix.

4.3.5 Microanalysis of specimens

4.3.5.1 Micrographs of natural and optimally treated specimens

Scanning electron microscopy (SEM) provides data on surface morphology and, together withenergy dispersive spectrometry (EDS),it can be used to determine the chemical composition ofany mineral particles attached. The main chemical composition of black cotton soil is montmorillonite,Velasco (2013) reported that montmorillonite can be identified using SEM by its microstructure. Montomorillonitestend to occur in thin equidimensional flakes that have a

film-like appearance. Theparticles can have thicknesses ranging from 1-nm to about 1/100 of the particle width.The long particle axis is usually less than 1 to 2-µm. In addition to flakes, some platy orneedle particles may be seen. This occurs when there is large isomorphous substitutionwith the aluminum being exchanged for magnesium or iron. These ions are larger thanthe aluminum ions and are reflected as such in the microstructure (Mitchell and Soga,2005).

The micrographs of natural soil and 4 % bagasse ash optimally treated black cotton soil for up to 3 hours compaction delay are shown on Plates 4.1a – 4.1d and plates 4.2a – 4.2d.The untreated and treated samples were analyzed by SEM to determine its morphological characteristics. Micrograph of the samples at magnifications of 5µm and zoomed to 1000xand 12500x was considered to get the best representations.

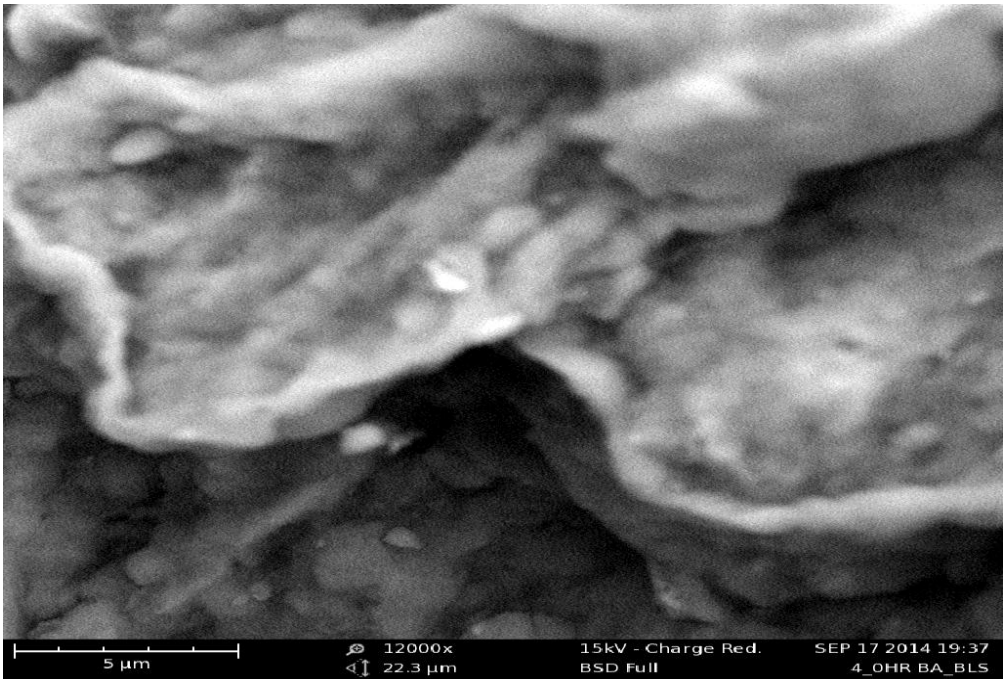


Plate 4.1a: Micrograph of natural black cotton soil for 0 hour compaction delay at 5 µm magnification

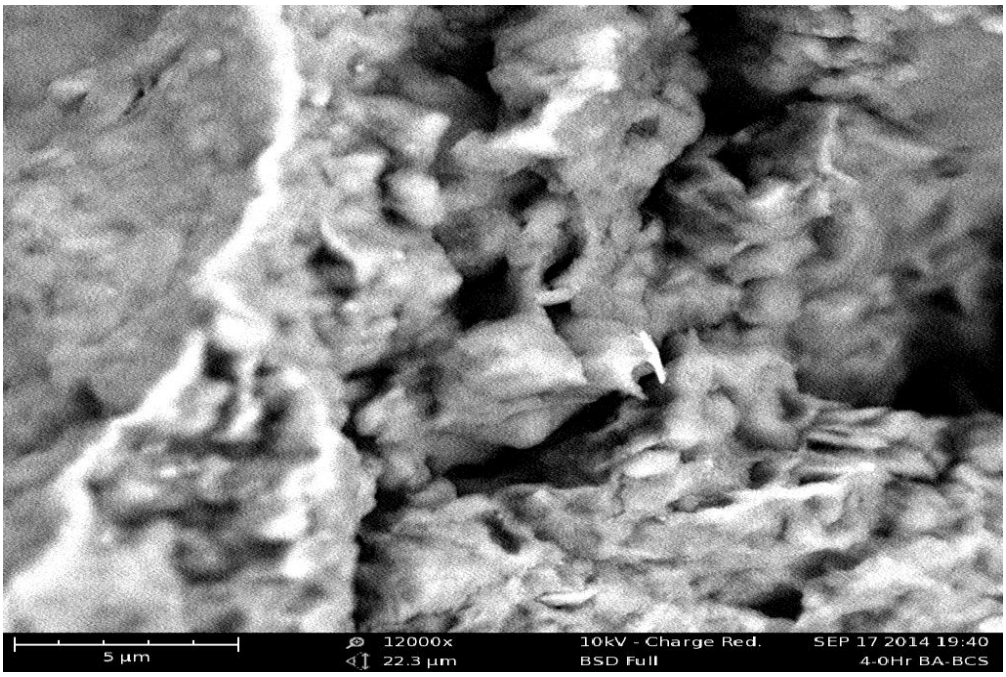


Plate 4.1b: Micrograph of natural black cotton soil for 1 hour compaction delay at 5 µm magnification

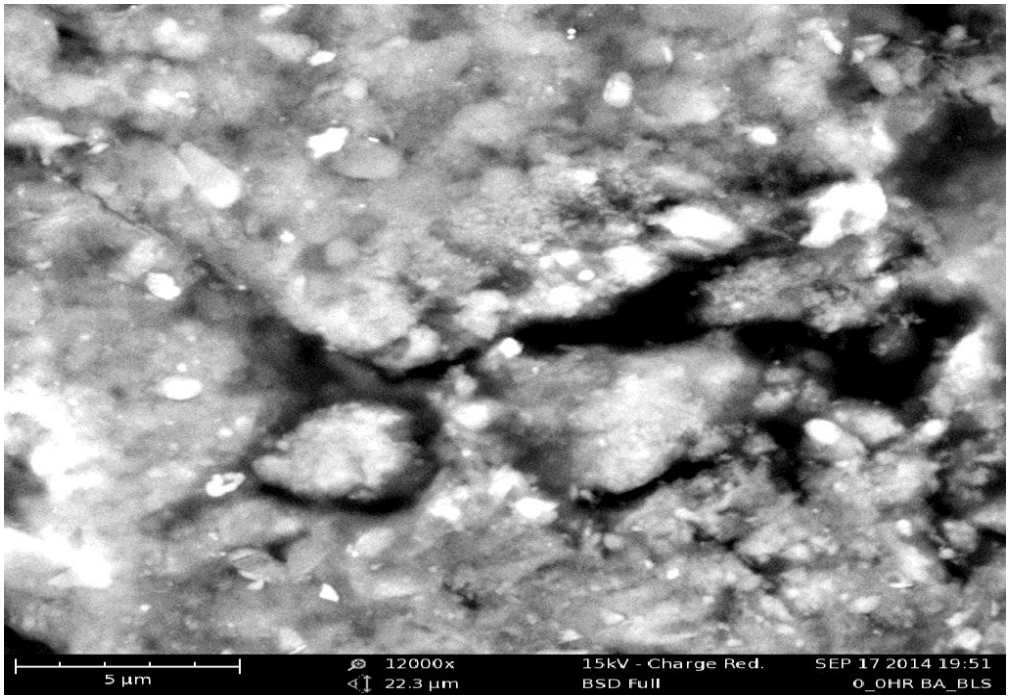


Plate 4.1c: Micrograph of natural black cotton soil for 2 hours compaction delay at 5 µm magnification

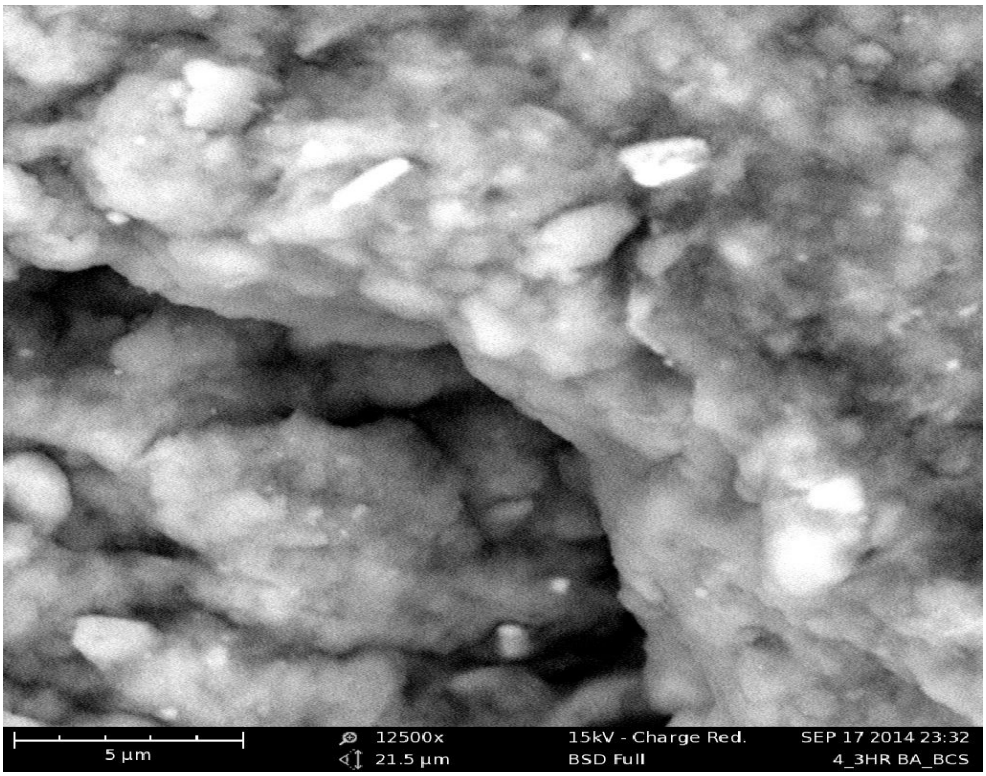


Plate 4.1d: Micrograph of natural black cotton soil for 3 hours compaction delay at 5 µm magnification

There was is an observed flakes, platy or needle like structures captured in the micrographs of the natural soil prepared at no compaction delays and compaction delays up to 3 hours.It was more pronounced at 2 and 3 hours compaction delay probably due to minimal agglomeration and liberation of water bonded at the outer layers. The observed structures are in agreement with reports by Velasco (2013) on the structures of montomorillonite which is the clay mineral found in black cotton soils.

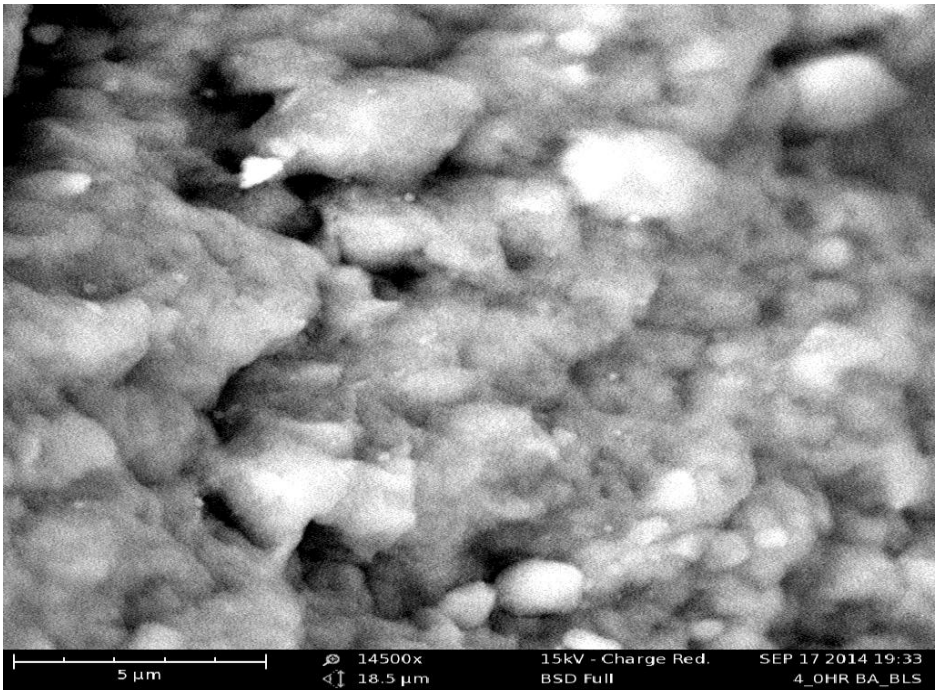


Plate 4.2a: Micrograph of 4 % bagasse ash optimally modified black cotton soil for 0 hour compaction delay at 5 µm magnification

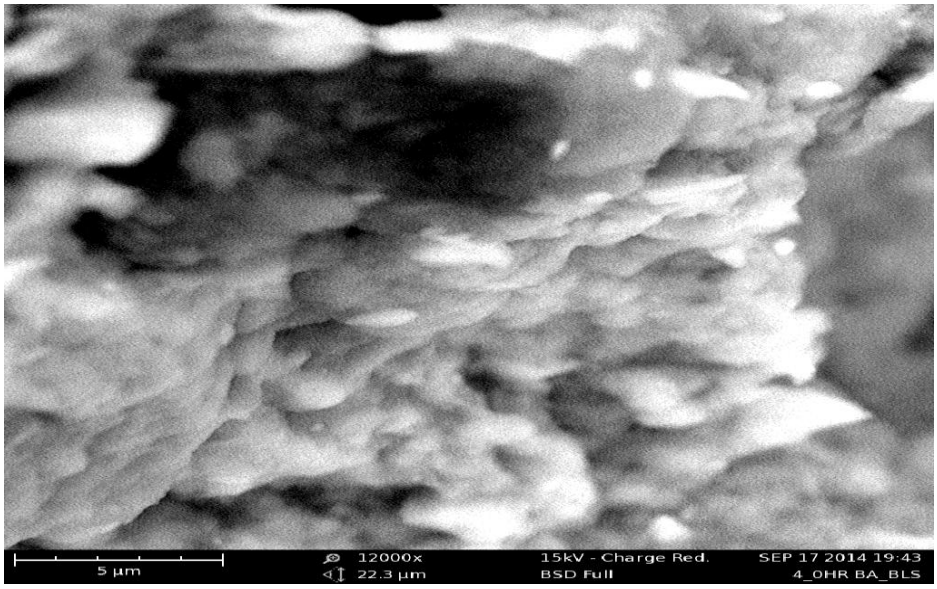


Plate 4.2b: Micrograph of 4 % bagasse ash optimally modified black cotton soil for 1 hour compaction delay at 5 µm magnification

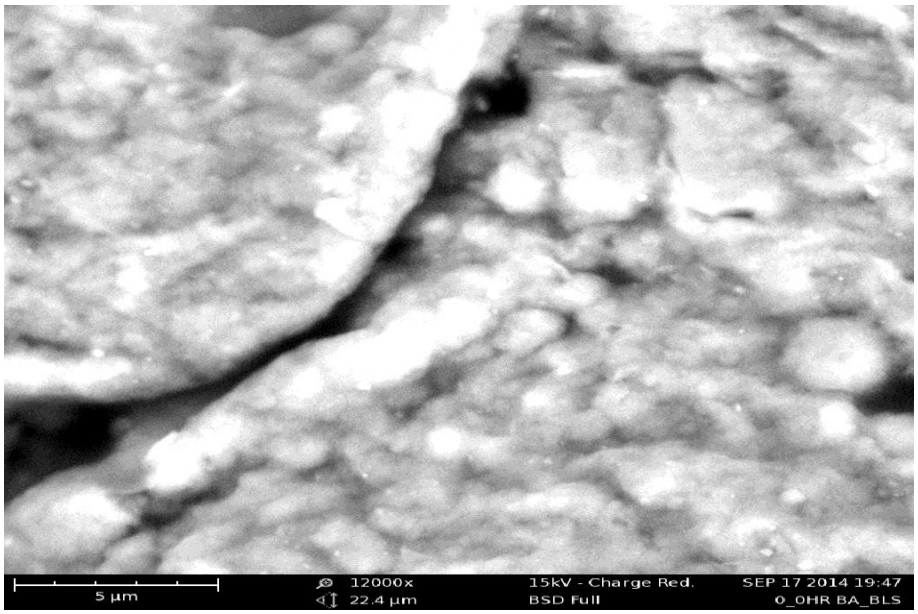


Plate 4.2c: Micrograph of 4 % bagasse ash optimally modified black cotton soil for 2 hours compaction delay at 5 µm magnification

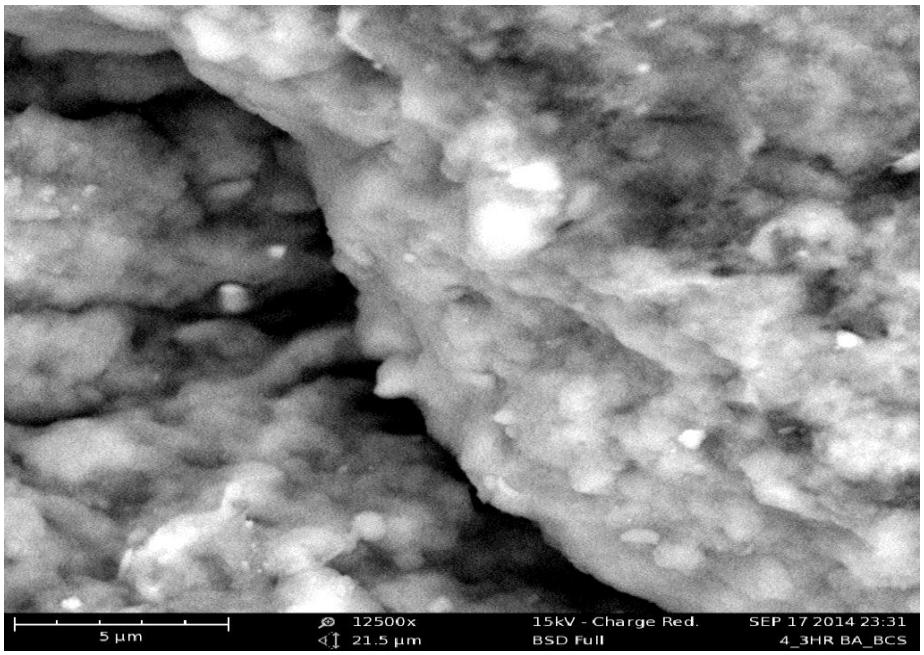


Plate 4.2d: Micrograph of 4 % bagasse ash optimally modified black cotton soil for 3 hours compaction delay at 5 µm magnification

From plates 4.2a – 4.2d there was an observed disintegration of the montomorillonite structure due to the addition of baggasse ash which confirms the reduction in the cohesion as earlier reported and the increase in the angle of internal friction. Thisshowed that the clay particles became more flocculated with increase in baggasse ash contents. The flocculation of clays is caused by negative particle surface to positive particle edge electrostatic attractive forces, resulting in random particle orientation (Mitchell, 1956). Hydration and ionic exchange could have led to the breaking of electrostatic and molecular bonds that led to this flocculent state with a reduction in the cohesiveness for both the naturaland the modified soil at 0 – 3hrs. These also suggest a reduction in the pore spaces between the soil particles with modification and increase in elapsed time.

4.3.5.2Fibermetric analysis

Fibermetric application produces accurate size information from micro and nano fiber samples. It is a statistical package incorporated in SEMthat generates all the statistical data needed for analysis. The automated image characterization generates hundreds of measurements in seconds and detects fibers ranging from 40 μm to 100 nm. It can be used for a wide rangeof applications, like investigation of filtration materials, diaperpaddings, fiber research, and fiber and filter production control(www.phenom-world.com). This techniques could be used to make qualitative and quantitative inferences about unsaturated behaviour of soils such as water retention and water permeability properties, evolution of pore size density functions along different hydro-mechanical paths, macroscopic volume change behavior, micro and macro scale interactions, and so on (Romero and Simms,2008).

4.3.5.2.1Fiber metric histogram

The fabric histograms of the natural black cotton soil specimens prepared at 0 – 2 hours compaction delays using a scanning electron microscope are shown on Plate 4.3a- 4.3c.

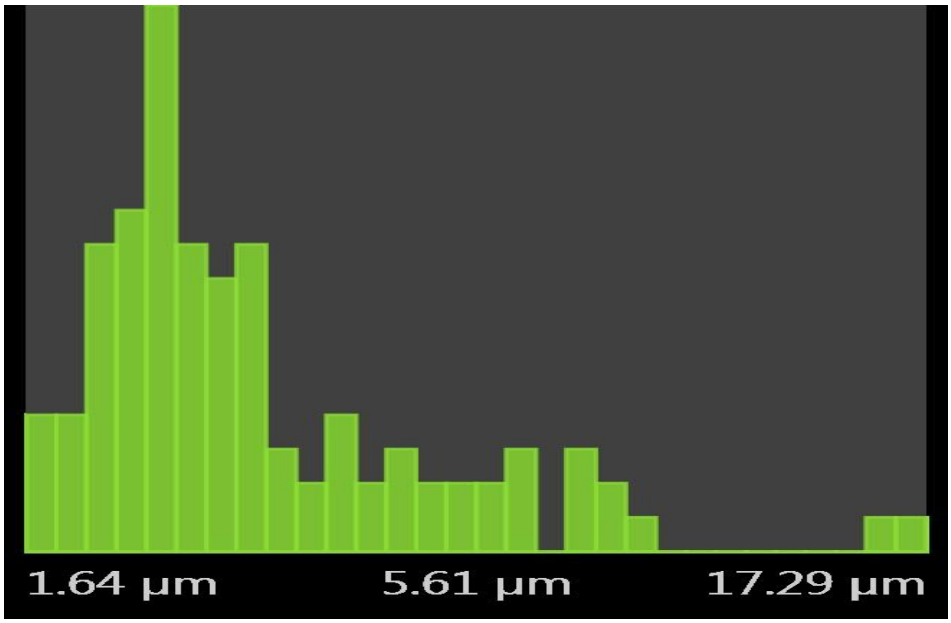


Plate 4.3a: Fibre histogram of natural black cotton soil for 0 hour compaction delay.

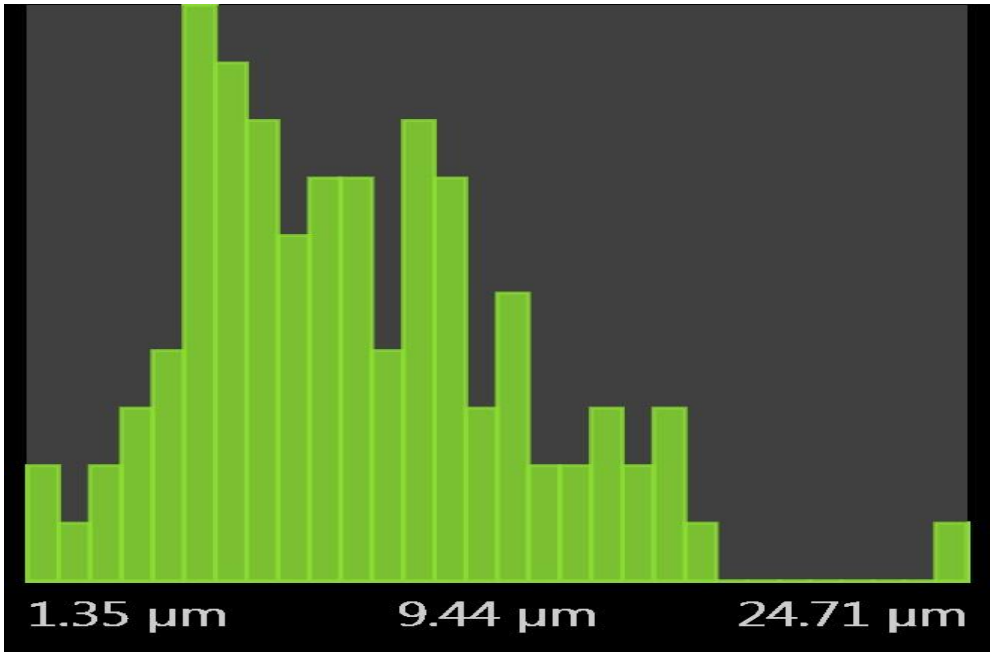


Plate 4.3b: Fibre histogram of natural black cotton soil for 1 hour compaction delay.

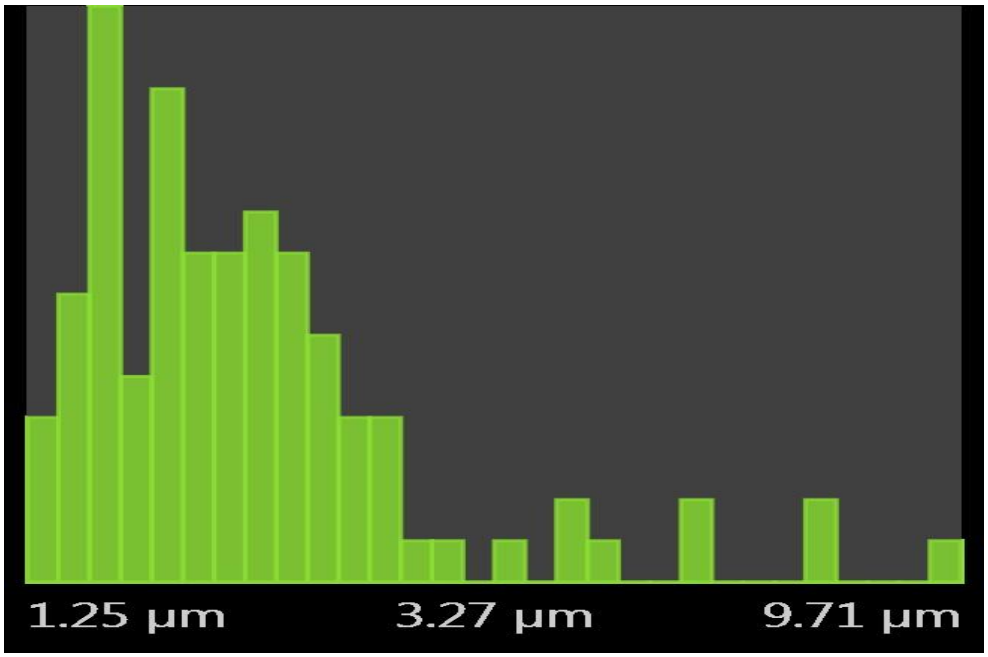


Plate 4.3c: Fibre histogram of naturalblack cotton soil at 2 hours compaction delay

From the fiber analysis,it was observed that the soil fabric of natural black cotton soil decreased from the value of 1.64 µmat 0 hour compaction delay to a value of 1.35 µm at 1 hour elapsed time after mixing (i.e., 17.7 % decrease) then further decreased to 1.25 µm at 2 hours compaction delay (i.e., 7.4 % decrease). The possible explanation for the decrease in black cotton soil fabric with higher compaction delay may be due to change in particle orientation, or the positions of adjacent particles relative to each other, and texture or appearance of group particles(Mitchell, 1956).

The fabrichistograms for 4 % bagasse ash optimally modified black cotton soil prepared at 0 – 3 hours elapsed time after mixing using a scanning electron microscope are shown on Plate 4.4a –4.4d.

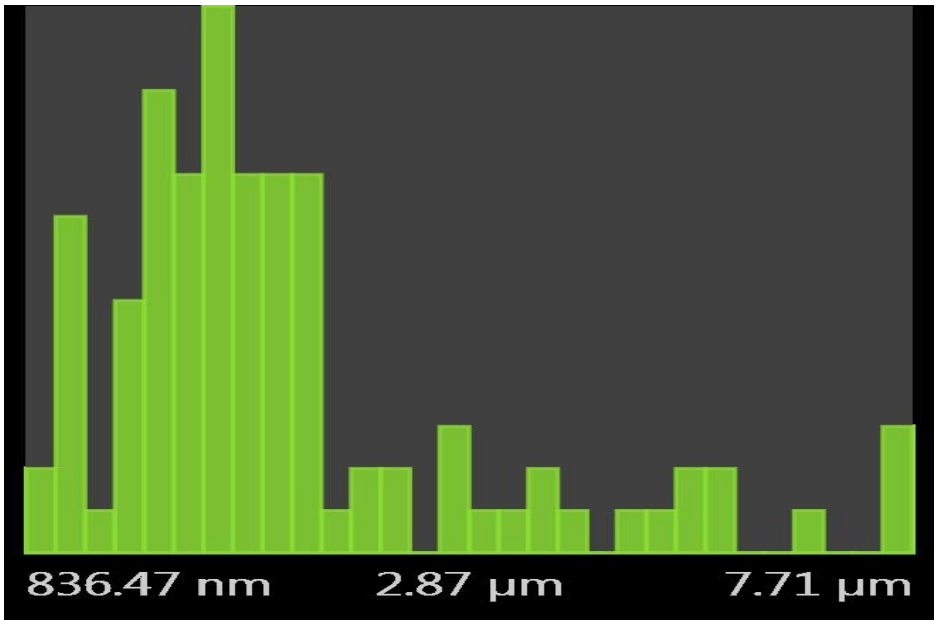


Plate 4.4a: Fibre histogram for 4% baggasse ash optimally modified black cotton soil at 0 hour compaction delay

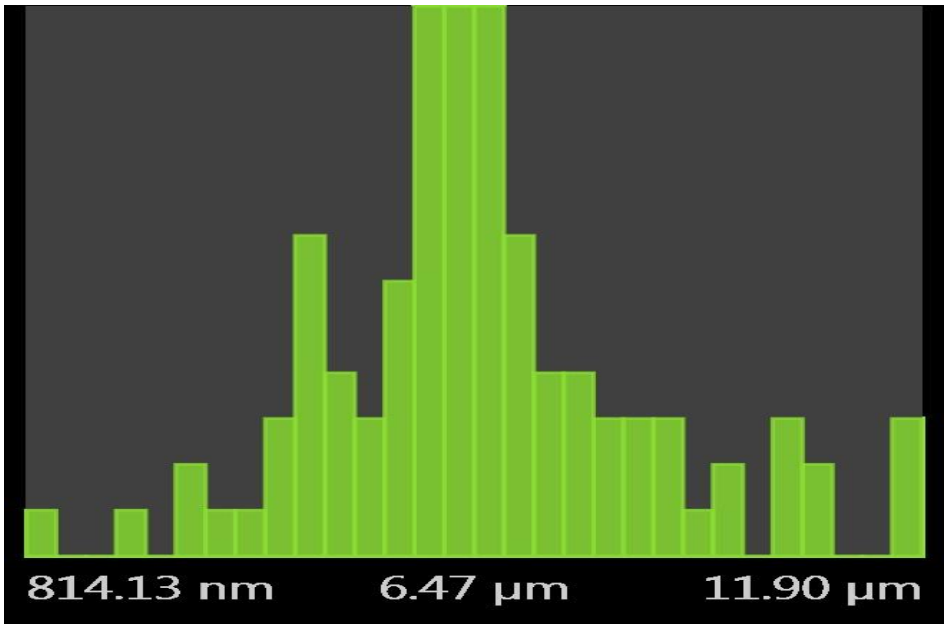


Plate 4.4b: Fibre histogram for 4% baggasse ash optimally modified black cotton soil at 1 hour compaction delay

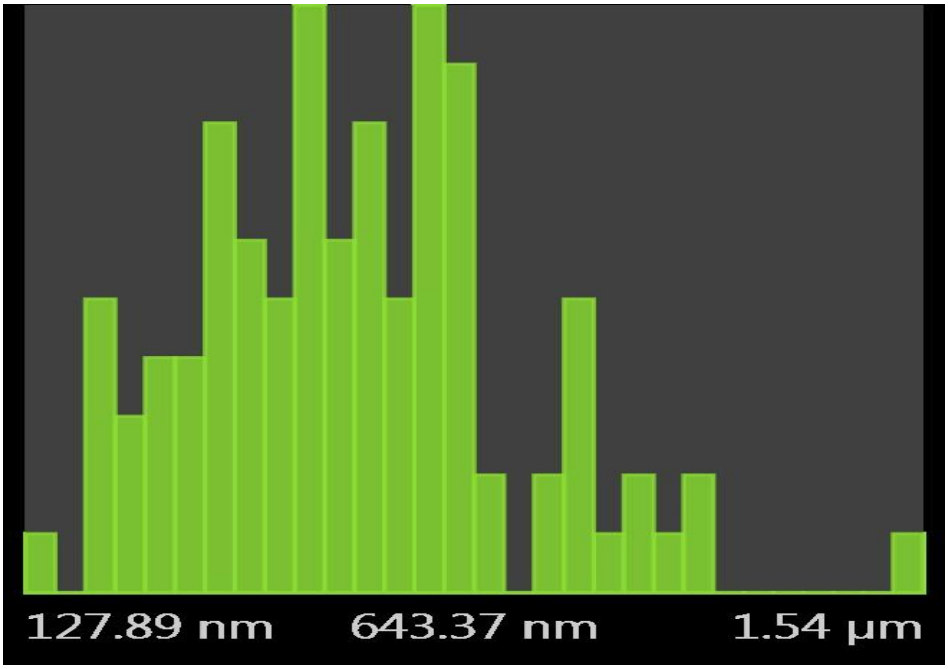


Plate 4.4c: Fibre histogram for 4% baggasse ash optimally modified black cotton soil at 2 hours compaction delay

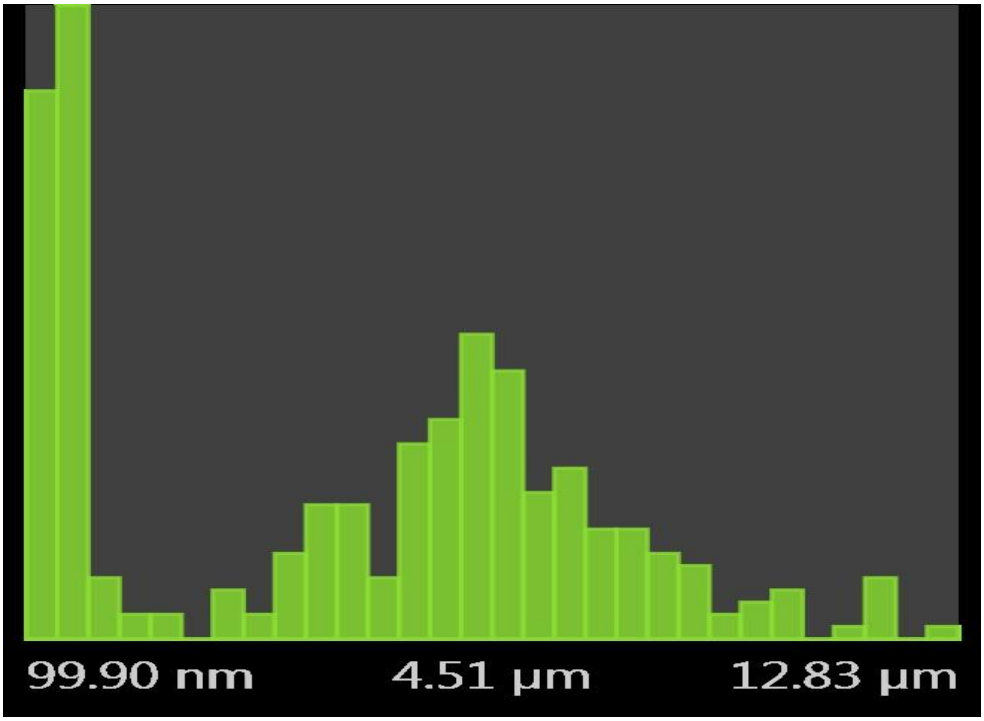


Plate 4.4d: Fibre histogram for 4% baggasse ash optimally modified black cotton soil at 3 hours compaction delay

The fiber analysis showed that the fabric of black cotton soil – 4 % baggasse ash mixturedecreased from a value of 836.47 nm to 814.13 nm (i.e., 2.7 % decrease), then to 127.89 nm (i.e., 84.3 % decrease), and 99.90 nm (i.e., 22.6 % decrease) at 1, 2 and 3 hours compaction delay, respectively. The decrease in length of soil fabric could be due to cation exchange reaction that resulted in the formation of calcium silicatehydrate in the soil matrix. Also the decrease in soil fabric could be due to change in particle orientation, or the positions of adjacent particles relative to each other, and texture or appearance of group particles(Mitchell, 1956).

4.3.5.2.1Pore histogram

The pore histograms of the natural black cotton soil prepared at 0 – 2 hours compaction delays using a scanning electron microscope are shown on Plate 4.5a-c.

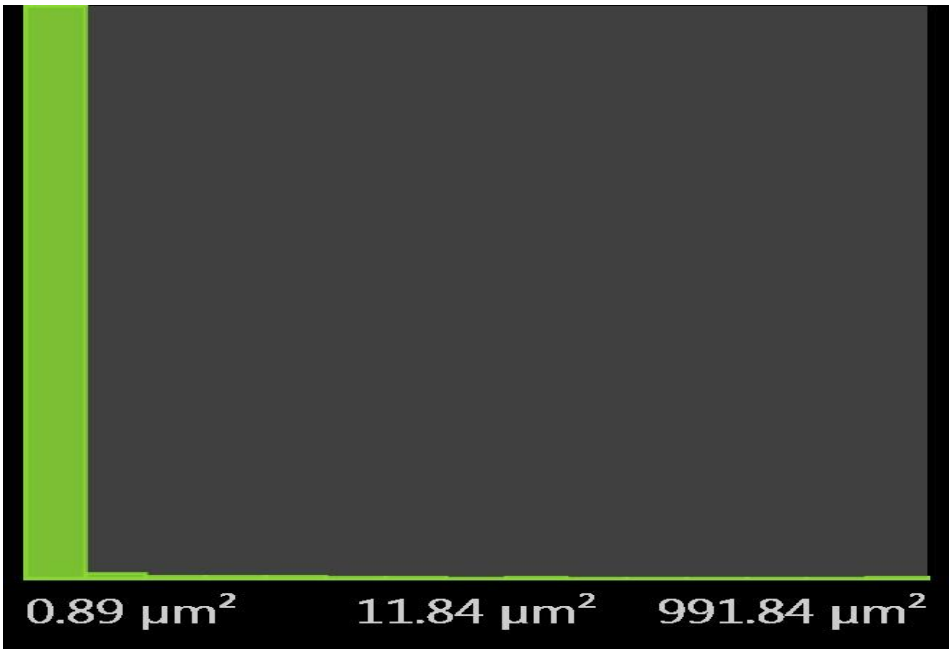


Plate 4.5a Pore histogram for natural black cotton soil at 0 hour compaction delay.

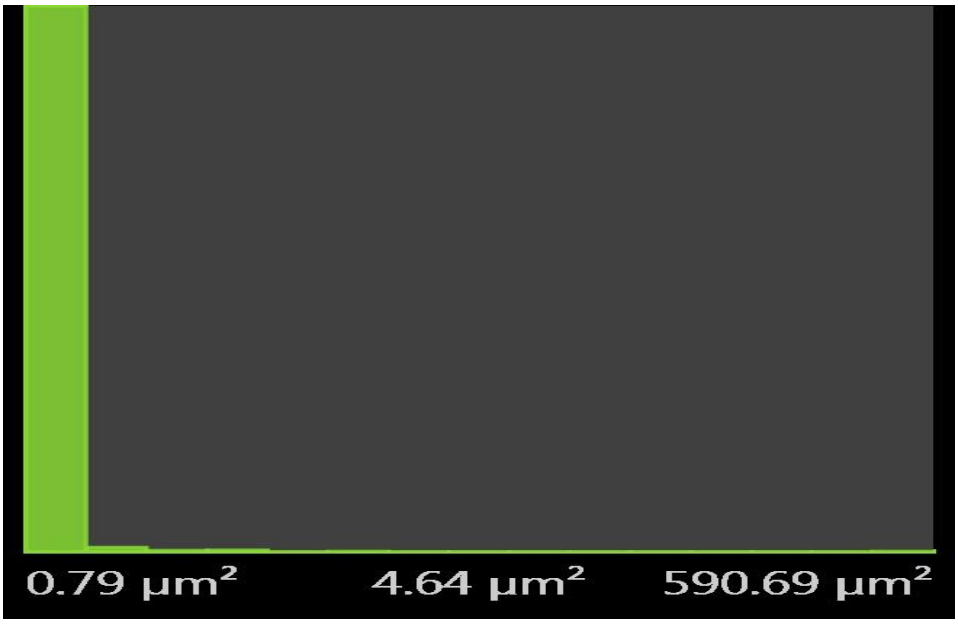


Plate 4.5b Pore histogram for natural black cotton soil at 1 hour compaction delay.

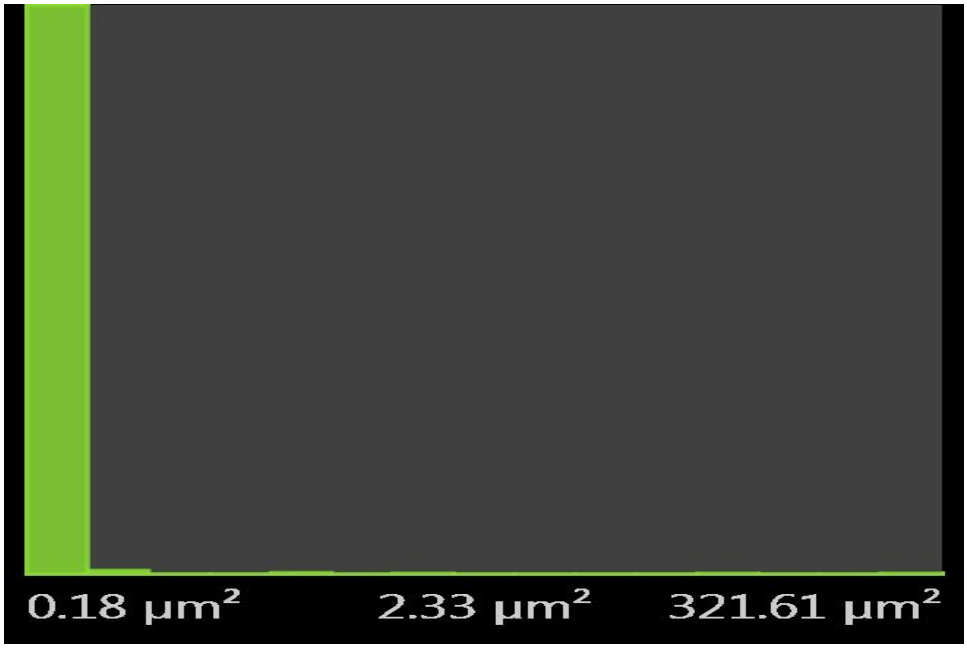


Plate 4.5c Pore histogram for natural black cotton soil at 2 hours compaction delay

The result of pore analysis shows thatthe surface area of pores within the natural black soil decreasedfrom 0.89 µmat 0 hour to 0.79 and 0.18 µm at 1 and 2 hours compaction delays, respectively.The decrease in pores was due to the re-arrangement and distribution of particles,

particle assemblies and pores and their contacts and connectivity in different soils.Mitchell and Soga (2005).

The pore histograms for 4 % bagasse ash optimally modified black cotton soil prepared at up to 3 hours compaction delay are shown on Plate 4.6a d.

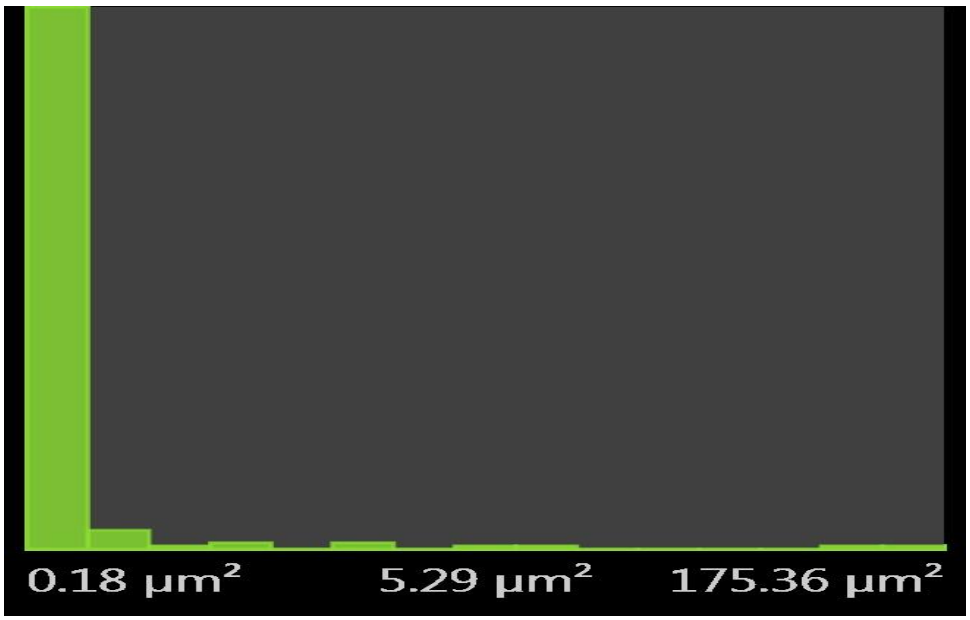


Plate 4.6aPore histogram for 4 % baggasse ash optimally modified black cotton soil at 0 hour compaction delay.

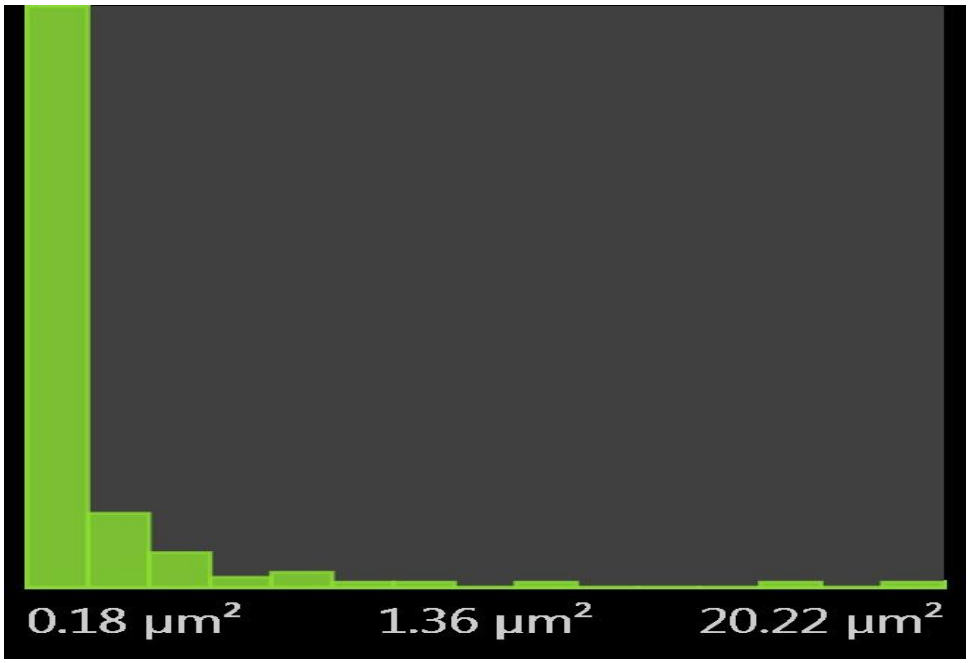


Plate 4.6bPore histogram for 4 % baggasse ash optimally modified black cotton soil at 1 hour compaction delay

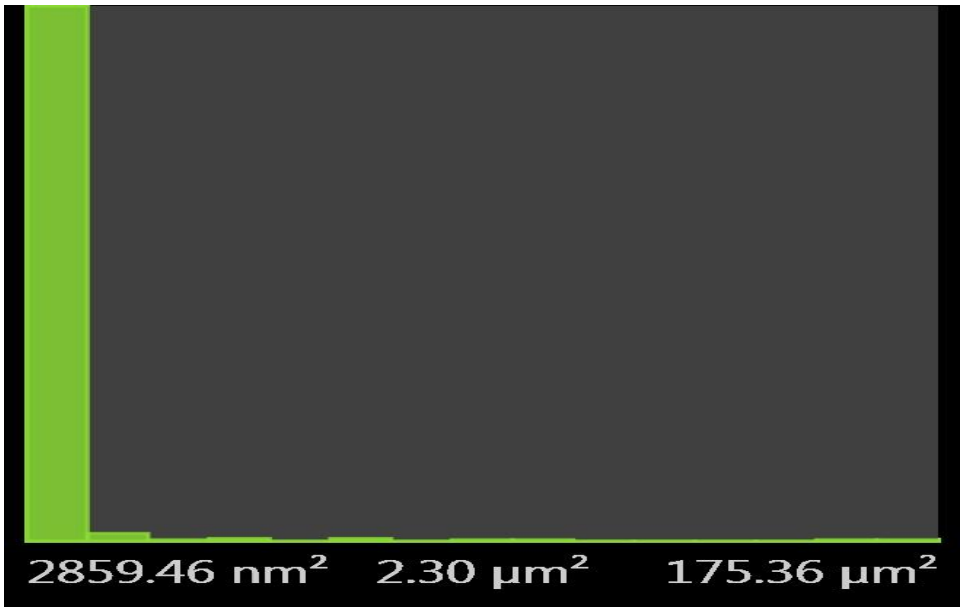


Plate 4.6cPore histogram for 4 % baggasse ash optimally modified black cotton soil at 2 hours compaction delay

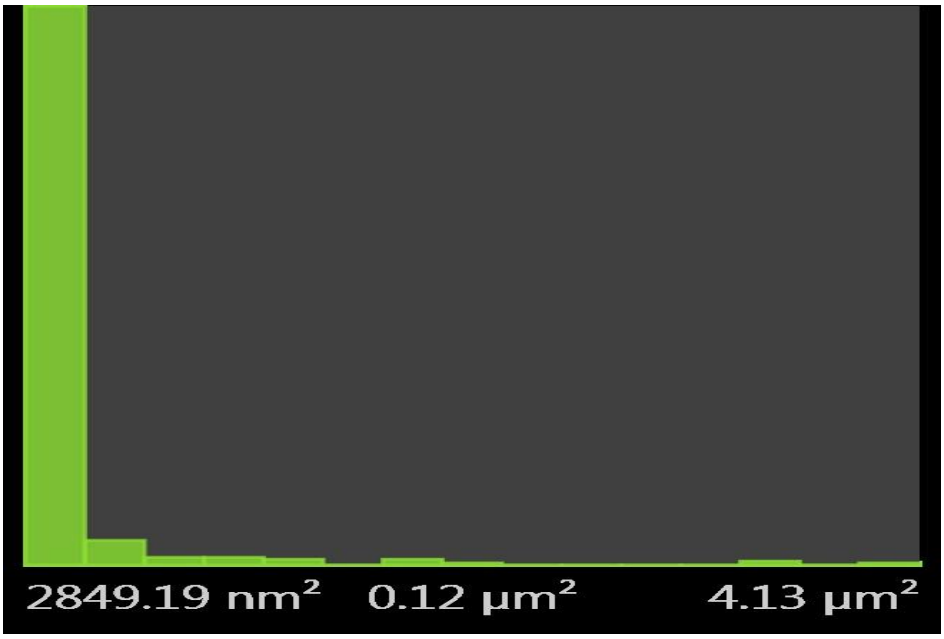


Plate 4.6dPore histogram for 4 % baggasse ash optimally modified black cotton soil at 3 hours compaction delay

The pore analysis result shows that the surface area of pores of 4 % bagasse ashoptimally modified black cotton decreased from a value of 0.18 µm at 0 hour compaction delay to 2859.4 and 2849.19 nm at 2 hours and 3 hours compaction delay, respectively. This technique gives more information on the relationship between the dominant pore sizes observed directly with SEM and the pore size distribution (PSD) measured as shown on the histograms. The decrease in pores was due to the re-arrangement and distribution of particles, particle assemblies and pores and their contacts and connectivity. Similar behavior was observed by Delage et al. (1996), Al-Rawas and McGown (1999) as well as Mitchell and Soga (2005).

CHAPTER FIVE
SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 SUMMARY

The preliminary investigation carried out on the natural black cotton soil collected at Deba, Deba Local Government Area of Gombe State showed that the soil falls under A-7-6(16) classification for AASHTO (1986) and CL according to Unified Soil Classification System (ASTM, 1992). The natural soil has low moisture content of 21.0% because the samples were collected in early March, at the beginning of the rainy season. The natural soil has liquid limit of 45.4%, plastic limit of 21%, plasticity index of 24.4%, linear shrinkage of 14.8%, free swell of 55%, specific gravity of 2.35cation exchange capacity of 40cmol/kg about 69.4% of the soil particles passed the BS. No 200 sieve.

Test results of the black cotton soil - bagasse ash mixtures considered showed a decrease in specific gravity of the natural soil from 2.35 to 2.22 with increase in bagasse ash treatment. The low cation exchange capacity(CEC) of bagasse ash (31.5Cmol/kg) initially reduced the CEC of the natural soilfrom 40 Cmol/kg to 32.7 Cmol/kgthen consequently increased to 39.6 32.7 Cmol/kg.The liquid limit at no compaction delay initially increased up to an optimum bagasse ash mix of 4 % the due to flocculation and agglomeration arising from cation exchange reactions the liquid limit decreased with further increase in bagasse ash treatment. The effect of elapsed time after mixing on the liquid limit value of the natural soil, 2 % BA, 4 % BA, 6 % BA and 8 % BA mixtures showed an initial increase in their liquid limits atno delayed time and when delayed to 2 hours thereafter the liquid limit decreasedwhen delayed further for 3hours.The plastic limit at no compaction delay decreased with higher bagasse ash content which may be due to cation exchange reactions. The effect of elapsed time after mixing on theplastic limitvalueof natural

soil, 2 % BA, 4 % BA, 6 % BA and 8 % BA mixtures showed that the plastic limit values decreased at 1 hour elapsed time thereafter increasedat 2 hours elapsed time and consequently decreased at 3 hours elapsed time.

Test results showed that maximum dry density (MDD)values decreased for all compactive effortswith increase in BA content which may be due to the low specific gravity of bagasse ash used.With elapsed time after mixing for BSL compaction MDD values of natural soil, 2 % BA, 4 % BA, 6 % BA and 8 % BA mixtures generally increased at 2 hours elapsed time after mixing and thereafter slightly decreased at 3 hours elapsed time after mixing. For WAS and BSH compactions MDD values of natural soil, 2 % BA, 4 % BA, 6 % BA and 8 % BA mixtures initially decreased when delayed for 1 hour, later increased between 1 and 2 hours and thereafter decreased between 2 and 3 hours elapsed time after mixing. Optimum moisture content (OMC) values where observed to increase for all compactive effortswith increase in BA content. The variation of optimum moisture content (OMC) of black cotton soil - bagasse ash mixtures with elapsed time after mixing showed thatOMC valuesfor all compactive efforts (i.e., BSL, WASand BSH)increased at 0 hours to 1hr delayed time thereafter decrease at 2 hours and consequently increased at 3 hours delayed time after mixing.

Generally cohesion values decreased for all compactive effortswith increase in BA content which may have been due to ion exchange reaction between the bagasse ash and soil. The variation of cohesion of black cotton soil - bagasse ash mixtures with elapsed time after mixingshowed thatfor BSL, WAS and BSH compaction, there was a decrease in cohesion values at 0, 1 and 3 hours delayed time while at 2 hours delayed time there was an observed increase in the cohesion values.The angle of internal friction for the three compactive efforts was observed to increasewith increase in BA content. The variation of angle of internal frictionof black cotton

soil - bagasse ash mixtures with elapsed time after mixingshowed thatfor BSL, WAS and BSH compaction, there was a increase in angle of internal friction values at 0, 1 and 3 hours delayed time while at 2 hours delayed time there was an observed decrease in the angle of internal friction values.

From micrographs,there was an observed disintegration of the montomorillonite structure of natural soil when optimally treated with 4 % bagasse ash and a further disintegration with delayed timewhich confirmed the reduction in the cohesion of the natural soil. There was an observed decrease in soil fabric from the fiber metric histograms of the natural soil when optimally treated with 4 %bagasse ashand a further decrease with delayed time which could have been due to cation exchange reaction that resulted in the formation of calcium silicate hydrate in the soil matrix. Also an observed decrease in pores areas were observed in the pore histogramof the natural soil when optimally treated with 4 %bagasse ashand a further decrease with delayed time which could have been due to the re-arrangement and distribution of particles, particle assemblies, pores, their contacts and connectivity.

5.2 CONCLUSION

From the preliminary investigation carried out on the natural black cotton soil collected at Deba, Deba Local Government Area of Gombe Stateit showed that the soil is highly plastic and of poor engineering benefit.

The plasticity indices of all the test samples at no compaction delay and at elapsed time were within the 30 % value prescribed for sub grade by the Nigeria General Specifications (1997).

The modified soil with an optimum 4 % BA did not meet the value of not more than 35% passing sieve No.200 (0.075mm aperture) but met the 30 % maximum standard plasticity index value recommendation for most geotechnical construction work.

5.3 RECOMMENDATIONS

Based on the results of the study carried out the following are recommended:

1. An optimal 4 % bagasse ash treatment of black cotton soil when compacted with British Standard heavy energy is recommended for use as a sub-grade material in the construction of lightly trafficked roads.
2. A maximum elapsed time of 2hours after mixing of black cotton soil and bagasse ash should not be exceeded

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APPENDIX

Table A4.1: TEST RESULTS FOR NATURAL MOISTURE CONTENT OF BLACK COTTON SOIL

Container Number.	S1	S2	S3
Container + wet Sample(M2)	14.90	21.20	16.80
Container + Dry Sample(M3)	13.90	19.30	15.60
Empty Container(M1)	9.50	9.60	9.80
Dry Weight(M3-M1)	4.40	9.70	5.80
Moisture Loss(M2-M3)	1.00	1.90	1.20
Moisture Content (%)	22.73	19.59	20.69
Average Moisture Content (%)		21.00	

Table A4.2; TEST RESULTS FOR SPECIFIC GRAVITY OF BAGASSE ASH

% BAGASSE ASH	SPECIFIC GRAVITY
0	2.35
2	2.32
4	2.31
6	2.29
8	2.22

Table A4.3: TEST RESULT OF CATION EXCHANGE CAPACITY OF BLACK COTTON SOIL

% BAGASSE ASH	**CATION EXCHANGE CAPACITYCmol//Kg**
0	40
2	37.7
4	32.7
6	39.6
8	39.1

Table A4.4: TEST RESULTS FOR COMBINEDWET SEIVE ANALYSIS FOR VARIOUS BAGASSE ASH CONTENTS

Table A4.4a: Natural black cotton soil

BS Sieve Size	Weight Retained g	% Retained	Total % passing
No 7 (2.8mm)	6.3	3.2	96.8
No 14 (1.4mm)	5.6	2.8	94
No 25 (0.71mm)	7.8	3.9	90.1
No 36 (0.435mm)	24.3	12.2	77.9
No 52 (0.36mm)	4.8	2.4	75.5
No 72 (0.212mm)	4.6	2.3	73.2
No 100 (0.15mm)	3.1	1.6	71.6
No 200 (0.075mm)	3.8	1.9	69.7
Passing 200 (0.075mm)	0.8	0.4	69.3

Table A4.4b: Hydrometer results for natural black cotton soil

Day & clock time	Local time in minutes	Hydrometer reading	Temp ^{o}C	Factor from tables	Effective depth (cm)	Corrected hydrometer reading (R)	Particle sizes (mm)	Percentage of particles passing Fines P	Whole
12.50	10 secs	70.25	27.2	0.4234	5.306	70.05	0.236543	1.71	59.89275
	15 secs	60.50	27.2	"	7.022	60.3	0.224394	"	51.5565
	30 secs	60.50	"	"	7.022	60.3	0.158671	"	51.5565
12.51	1min	60.25	"	"	7.066	60.05	0.112548	"	51.3428
12.52	2	60.00	"	"	7.11	59.8	0.079831	"	51.129
12.54	4	50.50	"	"	8.782	50.3	0.062736	"	43.0065
12.58	8	50.50	"	"	8.782	50.3	0.044301	"	43.0065
1.05	15	50.50	"	"	8.782	50.3	0.032397	"	43.0065
1.20	30	50.25	"	"	8.826	50.05	0.022965	"	42.7928
1.50	1hr	40.75	"	"	10.498	40.55	0.01771	"	34.6703
2.50	2	30.00	"	"	12.39	29.8	0.013605	"	25.479
4.50	4	20.25	27.1	0.4239	14.106	20.05	0.010277	"	17.1428
6.50	6	20.00	27	0.0424	14.15	19.8	0.008414	"	16.929
12.50	12	10.00	25.5	0.4315	15.91	9.8	0.006414	"	8.4
12.50	24	10.00	27	0.0411	15.91	9.8	0.004315	"	8.4

Table A4.4c: Black cotton soil- 2%bagasse ash mixture

BS Sieve Size	Weight Retained g	% Retained	Total % passing
No 7 (2.8mm)	7.4	3.79	96.3
No 14 (1.4mm)	5.3	2.7	93.6
No 25 (0.71mm)	8.1	4.1	89.5
No 36 (0.435mm)	23.7	11.9	77.6
No 52 (0.36mm)	4.6	2.3	75.3
No 72 (0.212mm)	4.8	2.4	72.9
No 100 (0.15mm)	4.2	2.1	70.8
No 200 (0.075mm)	2.8	1.4	69.4
Passing 200 (0.075mm)	0.6	0.3	69.1

Table A4.4d: Hydrometer results for black cotton soil - 2%bagasse ash mixture

Day & clock time	Local time in minutes	Hydrometer reading	Temp ^{o}C	Factor from tables	Effective depth (cm)	Corrected hydrometer reading (R)	Particle sizes (mm)	Percentage of particles passing Fines P	Whole
12.50	10 secs	70.0	27.2	0.4234	5.306	69.8	0.237522	1.71	59.679
	15 secs	60.75	27.2	"	7.022	60.55	0.22369	"	51.77
	30 secs	60.50	"	"	7.022	60.3	0.158671	"	51.5565
12.51	1min	60.25	"	"	7.066	60.05	0.112548	"	51.3428
12.52	2	60.00	"	"	7.11	59.8	0.079831	"	51.129
12.54	4	50.75	"	"	8.782	50.55	0.062579	"	43.220
12.58	8	50.50	"	"	8.782	50.3	0.044361	"	43.0065
1.05	15	50.25	"	"	8.782	50.05	0.032478	"	42.7927
1.20	30	50.25	"	"	8.826	50.05	0.22965	"	42.7927
1.50	1hr	40.75	"	"	10.498	40.55	0.01771	"	34.670
2.50	2	20.75	"	"	12.39	20.55	0.014471	"	17.570
4.50	4	20.00	27.1	0.4239	14.106	19.8	0.010293	"	16.929
6.50	6	10.75	27	0.0424	14.15	10.55	0.00885	"	9.020
12.50	12	10.00	25.5	0.4315	15.91	9.8	0.006414	"	8.4
12.50	24	0.75	27	0.0411	15.91	0.55	0.004513	"	0.470

Table A4.4e:Black cotton soil -4%bagasse ash mixture

BS Sieve Size	Weight Retained g	% Retained	Total % passing
No 7 (2.8mm)	9.9	5.0	95
No 14 (1.4mm)	6.4	3.2	91.8
No 25 (0.71mm)	9.1	4.6	87.2
No 36 (0.435mm)	26.7	13.4	73.8
No 52 (0.36mm)	5.9	3.0	70.8
No 72 (0.212mm)	5.8	2.9	67.9
No 100 (0.15mm)	4.6	2.3	65.6
No 200 (0.075mm)	3.3	1.7	63.9
Passing 200 (0.075mm)	1.3	0.7	63.2

Table A4.4f: Hydrometer results for black cotton soil -4%bagasse ash mixture

Day & clock time	Local time in minutes	Hydrometer reading	Temp ^{o}C	Factor from tables	Effective depth (cm)	Corrected hydrometer reading (R)	Particle sizes (mm)	Percentage of particles passing Fines P	Whole
12.50	10 secs	60.50	27.2	0.04234	5.306	60.3	0.272118	1.71	51.5565
	15 secs	60.25	27.2	"	7.022	60.05	0.225096	"	51.34275
	30 secs	60.25	"	"	7.022	60.05	0.159167	"	51.34275
12.51	1min	60.00	"	"	7.066	59.8	0.112898	"	51.129
12.52	2	50.50	"	"	7.11	50.3	0.088722	"	43.0065
12.54	4	50.00	"	"	8.782	49.8	0.06305	"	42.579
12.58	8	40.75	"	"	8.782	40.55	0.048502	"	34.670
1.05	15	40.75	"	"	8.782	40.55	0.035421	"	34.670
1.20	30	40.50	"	"	8.826	40.30	0.25099	"	34.457
1.50	1hr	30.50	"	"	10.498	30.30	0.019172	"	25.907
2.50	2	20.00	"	0.04234	12.39	19.8	0.014539	"	16.929
4.50	4	10.25	27.1	0.04239	14.106	10.05	0.010899	"	8.593
6.50	6	10.00	27	0.04244	14.15	9.8	0.008922	"	8.4
12.50	12	0.25	25.5	0.04315	15.91	0.05	0.006751	"	0.04275
12.50	24	0.25	27	0.04165	15.91	0.05	0.004542	"	0.04275

Table A4.4g: Black cotton soil – 6%bagasse ash mixture

BS Sieve Size	Weight Retained g	% Retained	Total % passing
No 7 (2.8mm)	8.8	4.4	95.6
No 14 (1.4mm)	4.6	2.3	93.3
No 25 (0.71mm)	7.1	3.6	89.7
No 36 (0.435mm)	22.2	11.1	78.6
No 52 (0.36mm)	4.8	2.4	76.2
No 72 (0.212mm)	4.4	2.2	7.4
No 100 (0.15mm)	2.1	1.1	72.9
No 200 (0.075mm)	3.9	2	70.9
Passing 200 (0.075mm)	0.9	0.5	70.4

Table A4.4h: Hydrometer results for black cotton soil -6%bagasse ash mixture

Day & clock time	Local time in minutes	Hydrometer reading	Temp ^{o}C	Factor from tables	Effective depth (cm)	Corrected hydrometer reading (R)	Particle sizes (mm)	Percentage of particles passing	
								Fines P	Whole
12.50	10 secs	60.75	27.2	0.4234	5.306	60.55	0.271264	1.71	51.770
	15 secs	60.25	27.2	"	7.022	60.05	0.225096	"	51.3428
	30 secs	60.00	"	"	7.022	59.8	0.159662	"	51.129
12.51	1min	50.75	"	"	7.066	50.55	0.125157	"	43.220
12.52	2	50.50	"	"	7.11	50.3	0.088722	"	43.0065
12.54	4	50.25	"	"	8.782	50.05	0.062893	"	42.79
12.58	8	50.00	"	"	8.782	49.8	0.044583	"	42.579
1.05	15	40.75	"	"	8.782	40.55	0.035421	"	34.670
1.20	30	40.50	"	"	8.826	40.3	0.025099	"	34.457
1.50	1hr	40.00	"	"	10.498	39.8	0.017821	"	34.029
2.50	2	20.25	"	"	12.39	20.05	0.014597	"	17.143
4.50	4	10.75	27.1	0.4239	14.106	10.55	0.010869	"	9.020
6.50	6	10.25	27	0.0424	14.15	9.8	0.00891	"	8.4
12.50	12	0.75	25.5	0.4315	15.91	0.55	0.006731	"	0.04275
12.50	24	0.75	27	0.0411	15.91	0.55	0.004542	"	0.04275

Table A4.4i: Black cotton soil – 8%bagasse ash mixture

BS Sieve Size	Weight Retained g	% Retained	Total % passing
No 7 (2.8mm)	7.9	4.0	96
No 14 (1.4mm)	5.9	3.0	93
No 25 (0.71mm)	8.2	4.1	88.9
No 36 (0.435mm)	26.2	13.1	75.8
No 52 (0.36mm)	5.7	2.9	72.9
No 72 (0.212mm)	5.5	2.8	70.1
No 100 (0.15mm)	4.4	2.2	67.9
No 200 (0.075mm)	4.7	2.4	65.5
Passing 200 (0.075mm)	1.3	0.7	64.8

Table A4.4j: Hydrometer results for black cotton soil - 8%bagasse ash mixture

Day & clock time	Local time in minutes	Hydrometer reading	Temp ^{o}C	Factor from tables	Effective depth (cm)	Corrected hydrometer reading (R)	Particle sizes (mm)	Percentage of particles passing	
								Fines P	Whole
12.50	10 secs	70.0	27.2	0.4234	5.306	69.8	0.237522	1.71	59.679
	15 secs	60.75	27.2	"	7.022	60.55	0.22369	"	51.770
	30 secs	60.50	"	"	7.022	60.3	0.158671	"	51.5565
12.51	1min	60.25	"	"	7.066	60.05	0.12548	"	51.3428
12.52	2	60.00	"	"	7.11	59.8	0.079831	"	51.129
12.54	4	50.50	"	"	8.782	50.3	0.062736	"	43.0065
12.58	8	50.25	"	"	8.782	50.05	0.044472	"	42.793
1.05	15	50.25	"	"	8.782	50.05	0.032478	"	42.793
1.20	30	50.25	"	"	8.826	50.05	0.22965	"	42.793
1.50	1hr	40.75	"	"	10.498	40.55	0.01771	"	34.670
2.50	2	30.00	"	"	12.39	29.8	0.013605	"	25.5479
4.50	4	20.00	27.1	0.4239	14.106	19.8	0.010293	"	16.929
6.50	6	20.00	27	0.0424	14.15	19.8	0.008414	"	16.929
12.50	12	10.00	25.5	0.4315	15.91	9.8	0.006734	"	8.4
12.50	24	0.75	27	0.0411	15.91	0.55	0.00453	"	0.470

Table A4.5 TEST RESULTS FOR DRY SIEVE ANALYSIS FOR BLACK COTTON SOIL -BAGASSE ASH MIXTURES AT NO DELAY AFTER MIXING (BSL COMPACTION)

BS SIEVE SIZE	No delay time (0hrs)				
	0%BA % PASSING	2%BA % PASSING	4%BA % PASSING	6%BA % PASSING	8%BA % PASSING
No 7 (2.8mm)	53.3	50.7	50	47.05	46.95
No 14 (1.4mm)	45.75	42.7	40.6	39.1	38.6
No 25 (0.71mm)	25.5	24	20.5	19.4	19
No 36 (0.435mm)	9.4	6.5	6.25	5.4	5.35
No 52 (0.36mm)	6.9	4.85	4.7	4.05	3.85
No 72 (0.212mm)	4.7	3.45	3.4	3.1	2.8
No 100 (0.15mm)	3	2.4	2.3	2.1	2.1
No 200 (0.075mm)	1.3	1.25	1.2	1	1
Passing 200 (0.075mm)	0	0	0	0	0

Table A4.6 TEST RESULTS FOR DRY SIEVE ANALYSIS FOR BLACK COTTON SOIL -BAGASSE ASH MIXTURES AT NO DELAY AFTER MIXING (WAS COMPACTION

BS SIEVE SIZE	No delay time (0hrs)				
	0%BA % PASSING	2%BA % PASSING	4%BA % PASSING	6%BA % PASSING	8%BA % PASSING
No 7 (2.8mm)	57.75	48.6	47.9	46.4	30.75
No 14 (1.4mm)	50.4	41.5	40	37.5	22.9
No 25 (0.71mm)	29	24.25	20.4	19.2	9.7
No 36 (0.435mm)	5.35	7.5	5.2	4.9	2.75
No 52 (0.36mm)	3.85	5.2	3.05	3.65	2.15
No 72 (0.212mm)	2.8	3.65	3	3	1.65
No 100 (0.15mm)	2.1	2.6	2.35	2.2	1.25
No 200 (0.075mm)	1	1.3	1.16	1.1	0.55
Passing 200 (0.075mm)	0	0	0	0	0

Table A4.7: TEST RESULTS FOR DRY SIEVE ANALYSIS FOR BLACK COTTON SOIL -BAGASSE ASH MIXTURES AT NO DELAY AFTER MIXING (BSH COMPACTION)

BS SIEVE SIZE	No delay time (0hrs)				
	0%BA % PASSING	2%BA % PASSING	4%BA % PASSING	6%BA % PASSING	8%BA % PASSING
No 7 (2.8mm)	57.25	57.2	54.7	47.15	37.65
No 14 (1.4mm)	49.6	49.15	46.25	36.45	28.85
No 25 (0.71mm)	28.85	27.7	25.3	16.75	12.1
No 36 (0.435mm)	8.35	8.1	7.2	4.25	3.65
No 52 (0.36mm)	5.8	5.45	5.15	3.2	2.9
No 72 (0.212mm)	3.85	3.8	3.8	2.6	2.15
No 100 (0.15mm)	2.8	2.65	2.45	1.7	1.35
No 200 (0.075mm)	1.5	1.4	1.25	0.85	0.55
Passing 200 (0.075mm)	0	0	0	0	0

Table A4.8: TEST RESULTS FOR DRY SIEVE ANALYSIS FOR BLACK COTTON SOIL - BAGASSE ASH MIXTURES WITH ELAPSED TIME AFTER MIXING

Table A4.8a: Dry sieving using optimum moisture content from values for British Standard light compaction

BS SIEVE SIZE	0%BA				2%BA			
	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING
No 7 (2.8mm)	53.3	35.9	25.4	28	50.7	33.6	50	39.35
No 14 (1.4mm)	45.75	28.95	19.75	22.25	42.7	27	40.6	32.3
No 25 (0.71mm)	25.5	15.3	11.1	11.45	24	13.7	20.5	16.7
No 36 (0.435mm)	9.4	5.15	4.55	3.95	6.5	4.85	5.4	5.6
No 52 (0.36mm)	6.9	3.6	3.75	3.2	4.85	3.75	5.85	5.7
No 72 (0.212mm)	4.7	2.45	2.6	2.2	3.45	2.85	2.8	2.5
No 100 (0.15mm)	3	1.55	1.7	1.4	2.4	1.85	2.1	1.7
No 200 (0.075mm)	1.3	0.7	0.8	0.5	1.25	1.05	1.2	1
Passing 200 (0.075mm)	0	0	0	0	0	0	0	0

BS SIEVE SIZE	4%BA				6%BA			
	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING
No 7 (2.8mm)	50	33.35	43.7	46.95	47.05	46.8	52.3	47.05
No 14 (1.4mm)	40.6	26.2	35.3	39.1	39.1	40.05	45.55	38.6
No 25 (0.71mm)	20.5	13	17.85	19	19.4	20.9	23.7	19.9
No 36 (0.435mm)	6.25	4.7	5.2	5.35	5.4	5.75	7.1	6.25
No 52 (0.36mm)	4.7	3.7	4.05	4.05	4.05	4.45	5.15	4.7
No 72 (0.212mm)	3.4	2.95	3.2	3.2	3.1	3.35	3.65	3.4
No 100 (0.15mm)	2.3	2.1	2.15	2.15	2.1	2.5	2.25	2.4
No 200 (0.075mm)	1.2	1.05	1.15	1.15	1	1.25	1	1
Passing 200 (0.075mm)	0	0	0	0	0	0	0	0

BS SIEVE SIZE	8%BA			
	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING
No 7 (2.8mm)	46.95	51	53.5	41.5
No 14 (1.4mm)	38.6	43.6	46.45	34.65
No 25 (0.71mm)	19	22.2	25.1	16.75
No 36 (0.435mm)	5.35	5.5	6.05	5.1
No 52 (0.36mm)	3.85	4	4.2	3.75
No 72 (0.212mm)	2.8	3.2	2.95	2.9
No 100 (0.15mm)	2.1	2.25	2.25	2.15
No 200 (0.075mm)	1	1.15	1.25	1.15
Passing 200 (0.075mm)	0	0	0	0

Table A4.8 b: Dry sieving using optimum moisture content from values for West African Standard compaction

BS SIEVE SIZE	0%BA				2%BA			
	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING
No 7 (2.8mm)	39.65	30.75	57.75	46.55	49.55	47.9	52.8	52.25
No 14 (1.4mm)	32.4	22.9	50.4	36.6	41.7	41.5	43.45	43.3
No 25 (0.71mm)	16.9	9.7	29	17.95	23.15	24.25	21.1	21.5
No 36 (0.435mm)	5.3	2.75	5.35	5.55	6.6	7.5	5.85	5,75
No 52 (0.36mm)	3.65	2.15	3.85	4.05	4.8	5.2	4.15	3.95
No 72 (0.212mm)	2.8	1.65	2.8	3.1	3.55	3.65	3.05	3
No 100 (0.15mm)	2.15	1.25	2.1	2.35	2.75	2.6	2.25	2.15
No 200 (0.075mm)	1.1	0.55	1	1.15	1.45	1.3	1.15	1.15
Passing 200 (0.075mm)	0	0	0	0	0	0	0	0

BS SIEVE SIZE	4%BA				6%BA			
	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING
No 7 (2.8mm)	47.9	44.9	48.7	48.6	46.4	34.15	50.9	38.5
No 14 (1.4mm)	40	36.35	40.2	40	37.5	24.75	40.05	31.4
No 25 (0.71mm)	20.4	17	19.02	20.4	19.2	10.75	23.3	15.95
No 36 (0.435mm)	5.2	4.7	4.6	5.2	4.9	3.5	6.6	5.15
No 52 (0.36mm)	3.05	3.6	3.45	3.95	3.65	2.95	4.65	3.8
No 72 (0.212mm)	3	2.85	2.65	3	3	2.55	3.3	2.85
No 100 (0.15mm)	2.35	1.5	2.05	2.2	2.2	1.7	2.15	1.95
No 200 (0.075mm)	1.16	0.95	1.05	1.15	1.1	0.85	1.2	0.95
Passing 200 (0.075mm)	0	0	0	0	0	0	0	0

BS SIEVE SIZE	8%BA			
	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING
No 7 (2.8mm)	30.75	55,2	58.95	57.75
No 14 (1.4mm)	22.9	45.55	51.5	50.4
No 25 (0.71mm)	9.7	23.9	30.4	29.75
No 36 (0.435mm)	2.75	6.35	8.9	9.2
No 52 (0.36mm)	2.15	4.6	5.95	6.3
No 72 (0.212mm)	1.65	3.35	4	4.35
No 100 (0.15mm)	1.25	2.2	2.8	2.8
No 200 (0.075mm)	0.55	1.1	1.5	1.5
Passing 200 (0.075mm)	0	0	0	0

Table A4.8c: Dry sieving using optimum moisture content from values for British Standard heavy compaction

BS SIEVE SIZE	0%BA				2%BA			
	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING
No 7 (2.8mm)	57.25	37.65	47.3	37.65	57.2	47.15	54.65	47.15
No 14 (1.4mm)	49.6	28.85	38.9	28.85	49.15	36.45	45.95	36.45
No 25 (0.71mm)	28.85	12.1	18.8	12.1	27.7	17.05	23.8	16.75
No 36 (0.435mm)	8.35	3.65	5.25	3.8	8.1	4.75	7.05	4.25
No 52 (0.36mm)	5.8	2.8	4.2	3	5.45	3.5	5.25	3.2
No 72 (0.212mm)	3.85	2.15	3.35	2.25	3.8	2.6	3.8	2.5
No 100 (0.15mm)	2.8	1.35	2.2	1.45	2.65	1.75	2.55	1.7
No 200 (0.075mm)	1.5	0.85	1.2	0.7	1.4	0.7	1.35	0.85
Passing 200 (0.075mm)	0	0	0	0	0	0	0	0

BS SIEVE SIZE	4%BA				6%BA			
	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING
No 7 (2.8mm)	54.7	48.2	57.2	45.8	47.15	55.8	55.8	44.65
No 14 (1.4mm)	46.25	41.25	49,6	37.05	36.45	48.6	48.6	38.4
No 25 (0.71mm)	25.3	21.15	27.7	19.4	16.75	27.15	27.15	19.8
No 36 (0.435mm)	7.2	6.9	8.1	6.15	4.25	7.5	7.5	6.5
No 52 (0.36mm)	5.15	5.15	5.45	4.7	3.2	5.15	5.4	5
No 72 (0.212mm)	3.8	3.6	3.8	3.35	2.6	3.85	3.5	3.7
No 100 (0.15mm)	2.45	2.4	2.8	2.3	1.7	2.65	2.3	2.5
No 200 (0.075mm)	1.25	1.25	1.5	1.2	0.85	1.4	1.2	1.5
Passing 200 (0.075mm)	0	0	0	0	0	0	0	0

BS SIEVE SIZE	8%BA			
	0HRS % PASSING	1HR % PASSING	2HRS % PASSING	3HRS % PASSING
No 7 (2.8mm)	37.65	56	58.1	53.2
No 14 (1.4mm)	28.85	49.55	51.6	47.2
No 25 (0.71mm)	12.1	29	28.75	25.8
No 36 (0.435mm)	3.65	8.6	7.25	7.65
No 52 (0.36mm)	2.9	5.55	5.15	5.6
No 72 (0.212mm)	2.15	3.55	3.3	3.85
No 100 (0.15mm)	1.35	2.25	2.25	2.7
No 200 (0.075mm)	0.55	1.2	1.15	1.45
Passing 200 (0.075mm)	0	0	0	0

Table A4.9: TEST RESULTS FOR ATTERBERG LIMITS

Table A4.9a: Liquidlimit for black cotton soil - bagasse ash mixtures at various elapsed times

% Bagasse ash	Elapsed times	Liqiud Limit (LL) %
0	0	45.4
	1	45.8
	2	48
	3	46.8
2	0	47.2
	1	47.8
	2	48.8
	3	48.5
4	0	47.8
	1	49.8
	2	50
	3	49.8
6	0	45.8
	1	46.5
	2	48.5
	3	48.2
8	0	44.8
	1	45
	2	47.8
	3	46.5

Table A4.9b: Plasticlimitfor black cotton soil - bagasse ash mixtures at various elapsed times

% Bagasse ash	Elapsed times	Plastic limit (PL) %
	0	21
0	1	19.5
	2	19.8
	3	19.4
	0	20.7
2	1	19.1
	2	19.4
	3	19.1
	0	19.1
4	1	18.2
	2	18.4
	3	18.2
	0	20
6	1	18.4
	2	18.7
	3	18.4
	0	20.5
8	1	18.85
	2	19.1
	3	18.7

Table A4.9c:Plasticity indexfor black cotton soil - bagasse ash mixtures at various elapsed times

% Bagasse ash	Elapsed times	Plasticity Index (PI) %
	0	24.4
0	1	26.3
	2	28.2
	3	27.4
	0	26.5
2	1	28.7
	2	29.4
	3	29.4
	0	28.7
4	1	31.6
	2	31.6
	3	31.6
	0	25.8
6	1	28.1
	2	29.8
	3	29.8
	0	24.3
8	1	26.15
	2	28.7
	3	27.8

Table A4.10: TEST RESULTS OF LINEAR SHRINKAGE AND FREE SWELL OF BLACK COTTON SOIL

% BAGASSE ASH	Linear Shrinkage (%)	Free swell (%)
0	14.8	55
2	14.1	54
4	12.5	53.5
6	10.9	52
8	10.2	50

Table A4.11: TEST RESULTS OF MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE CONTENT OF BLACK COTTN SOIL FOR VARIOUS ELAPSED TIMES

%	HRS	BSL		WAS		BSH	
		MDD	OMC	MDD	OMC	MDD	OMC
0	0	1.66	18.15	1.72	16.3	1.846	14.8
	1	1.66	18.5	1.67	16.5	1.78	15.3
	2	1.675	16.5	1.838	13.8	1.834	13
	3	1.68	16.8	1.784	13.5	1.794	15.4
2	0	1.655	19.5	1.70	16.9	1.821	15.15
	1	1.65	19.8	1.66	19.6	1.776	15.5
	2	1.66	17.2	1.82	14.2	1.832	15
	3	1.665	18.2	1.775	14.9	1.78	15.8
4	0	1.64	19.8	1.69	17,5	1.80	16.5
	1	1.63	20.45	1.65	19.75	1.77	17
	2	1.654	18.2	1.78	14.5	1.83	15.2
	3	1.65	18.3	1.772	15.2	1.772	16.5
6	0	1.63	20.4	1.667	17.9	1.8	17
	1	1.625	20.6	1.64	20	1.76	17.3
	2	1.642	18.5	1.742	14.8	1.83	15.8
	3	1.63	19.8	1.755	15.8	1.77	17.2
8	0	1.59	20.5	1.66	18	1.75	17.2
	1	1.59	20.65	1.639	20.8	1.748	17.5
	2	1.638	19.2	1.73	16.0	1.82	16.
	3	1.62	20.5	174	16.0	1.74	17.8

Table A4.12: TEST RESULTS FOR SHEAR STRENGTH PARAMETERS

Table A4.12a Cohesion of blackcotton soil – bagasse ash mixtures at various elapsed times

% BAGASSES ASH	ELAPSED TIME (HOURS)	COHESION (C)		
		BSL	WAS	BSH
0	0	68	88	140
	1	48	54	95
	2	60	100	140
	3	45	65	82
2	0	60	75	120
	1	46	50	90
	2	58	98	120
	3	40	45	49
4	0	58	56	85
	1	45	48	50
	2	54	95	75
	3	38	42	46
6	0	48	52	70
	1	42	45	40
	2	52	92	50
	3	36	40	40
8	0	40	50	50
	1	40	42	35
	2	50	78	40
	3	25	28	25

Table A4.12b Angle of internal friction of blackcotton soil – bagasse ash mixtures at various elapsed times

% BAGASSES ASH	ELAPSED TIME (HOURS)	ANGLE OF INTERNAL FRICTION (θ)		
		BSL	WAS	BSH
0	0	1	3	10
	1	5	3.5	11.5
	2	4	3	10
	3	7	7	11
2	0	5	8	14.5
	1	5.5	8	15
	2	5	7	11
	3	7.5	8	15
4	0	6.5	9	14.8
	1	8	11	16.5
	2	6	7.5	14
	3	8	8.5	18
6	0	7	12	15
	1	8.5	14	17
	2	8	11.5	15.5
	3	8.5	14	18
8	0	10	15	15
	1	10	15.5	17.5
	2	9.5	13	15.5
	3	10	14.5	18.5

Table A4.13a: Analysis of Variance for Cation Exchange Capacity of Natural and Bagasse ash- Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
CEC	5	189.1	37.82	8.947

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2859.481	1	2859.481	301.84	1.23E-07	5.317655
Within Groups	75.788	8	9.4735			
Total	2935.269	9				

Table A4.13 (b): Analysis of Variance for Free Swell of Natural and BA - Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
SG	5	264.5	52.9	3.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5978.025	1	5978.025	866.3804	1.92E-09	5.317655
Within Groups	55.2	8	6.9			
Total	6033.225	9				

Table A4.14: Analysis of Variance for Specific Gravity of Natural and BA - Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
SG	5	11.49	2.298	0.00237

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.24201	1	7.24201	1.448059	0.263238	5.317655
Within Groups	40.00948	8	5.001185			
Total	47.25149	9				

Table A4.15: Analysis of Variance for Liquid Limit of Natural and BA - Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	231	46.2	1.58

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4452.1	1	4452.1	768.9292	3.09E-09	5.317655
Within Groups	46.32	8	5.79			
Total	4498.42	9				

Table A4.16: Analysis of Variance for Plastic Limit of Natural and BA - Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	101.3	20.26	0.553

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	660.969	1	660.969	125.2666	3.64E-06	5.317655
Within Groups	42.212	8	5.2765			
Total	703.181	9				

Table A4.17: Analysis of Variance for Linear Shrinkage of Natural and BA - Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	62.5	12.5	3.925

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	180.625	1	180.625	25.94255	0.000937	5.317655
Within Groups	55.7	8	6.9625			
Total	236.325	9				

Table A4.18: Analysis of Variance for Plasticity Index of Natural and BA - Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	129.7	25.94	3.253

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1203.409	1	1203.409	181.6055	8.82E-07	5.317655
Within Groups	53.012	8	6.6265			
Total	1256.421	9				

Table A4.19: Analysis of Variance for Maximum Dry Density (BSL) of Natural and BA-Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	8.275	1.655	0.000021

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13.74756	1	13.74756	2.749507	0.135871	5.317655
Within Groups	40.00008	8	5.000011			
Total	53.74765	9				

Table A4.20: Analysis of Variance for Maximum Dry Density (WAS) of Natural and BA-Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	8.505	1.701	0.000205

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13.2135	1	13.2135	2.642646	0.142683	5.317655
Within Groups	40.00082	8	5.000103			
Total	53.21432	9				

Table A4.21: Analysis of Variance for Maximum Dry Density (BSH) of Natural and BA-Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	9.037	1.8074	0.000808

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12.01874	1	12.01874	2.403553	0.159656	5.317655
Within Groups	40.00323	8	5.000404			
Total	52.02197	9				

Table A4.22: Analysis of Variance for Optimum Moisture Content (BSL) of Natural and BA-Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	100.8	20.16	0.273

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	652.864	1	652.864	127.1029	3.44E-06	5.317655
Within Groups	41.092	8	5.1365			
Total	693.956	9				

Table A4.23: Analysis of Variance for Optimum Moisture Content (WAS) of Natural and BA- Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	86.6	17.32	0.512

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	443.556	1	443.556	84.39041	1.59E-05	5.317655
Within Groups	42.048	8	5.256			
Total	485.604	9				

Table A4.24: Analysis of Variance for Optimum Moisture Content (BSH) of Natural and BA-Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	81.4	16.28	1.157

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	376.996	1	376.996	67.58017	3.59E-05	5.317655
Within Groups	44.628	8	5.5785			
Total	421.624	9				

Table A4.25: Analysis of Variance for Cohesion (BSL) of Natural and BA-Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	274	54.8	119.2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6451.6	1	6451.6	99.86997	8.53E-06	5.317655
Within Groups	516.8	8	64.6			
Total	6968.4	9				

Table A4.26: Analysis of Variance for Cohesion (WAS) of Natural and BA-Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	377	75.4	127.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12744.9	1	12744.9	184.9768	8.21E-07	5.317655
Within Groups	551.2	8	68.9			
Total	13296.1	9				

Table A4.27: Analysis of Variance for Cohesion (BSH) of Natural and BA-Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	401	80.2	1425.2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	14516.1	1	14516.1	20.22868	0.002008	5.317655
Within Groups	5740.8	8	717.6			
Total	20256.9	9				

Table A4.28: Analysis of Variance for Angle of Internal Friction (BSL) of Natural and BA-Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	27.2	5.44	11.108

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.184	1	5.184	0.491188	0.503269	5.317655
Within Groups	84.432	8	10.554			
Total	89.616	9				

Table A4.29: Analysis of Variance for Angle of Internal Friction (WAS) of Natural and BA-Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	38.4	7.68	17.587

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	33.856	1	33.856	2.454489	0.155824	5.317655
Within Groups	110.348	8	13.7935			
Total	144.204	9				

Table A4.30: Analysis of Variance for Angle of Internal Friction (BSH) of Natural and BA-Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	56	11.2	4.7

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	129.6	1	129.6	17.63265	0.003	5.317655
Within Groups	58.8	8	7.35			
Total	188.4	9				

Table A4.31: Analysis of Variance for 1hr delay time for Liquid Limit of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	234.9	46.98	3.542

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4618.201	1	4618.201	682.056	4.96E-09	5.317655
Within Groups	54.168	8	6.771			
Total	4672.369	9				

Table A4.32: Analysis of Variance for 2hrs delay time for Liquid Limit of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	243.1	48.62	0.752

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4977.361	1	4977.361	925.8484	1.48E-09	5.317655
Within Groups	43.008	8	5.376			
Total	5020.369	9				

Table A4.33: Analysis of Variance for 3hrs delay time for Liquid Limit of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	239.8	47.96	1.803

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4831.204	1	4831.204	818.64	2.41E-09	5.317655
Within Groups	47.212	8	5.9015			
Total	4878.416	9				

Table A4.34: Analysis of Variance for 1hr delay time for Plastic Limit of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	94.05	18.81	0.2755

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	548.3403	1	548.3403	106.7277	6.65E-06	5.317655
Within Groups	41.102	8	5.13775			
Total	589.4423	9				

Table A4.35: Analysis of Variance for 2hrs delay time for Plastic Limit of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	95.4	19.08	0.307

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	568.516	1	568.516	110.3165	5.88E-06	5.317655
Within Groups	41.228	8	5.1535			
Total	609.744	9				

Table A4.36: Analysis of Variance for 3hrs delay time for Plastic Limit of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	93.8	18.76	0.243

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	544.644	1	544.644	106.3446	6.74E-06	5.317655
Within Groups	40.972	8	5.1215			
Total	585.616	9				

Table A4.37: Analysis of Variance for 1hr delay time for Plasticity Index of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	140.85	28.17	4.907

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1460.472	1	1460.472	195.9445	6.58E-07	5.317655
Within Groups	59.628	8	7.4535			
Total	1520.1	9				

Table A4.38: Analysis of Variance for 2hrs delay time for Plasticity Index of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	147.7	29.54	1.708

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1630.729	1	1630.729	278.5666	1.68E-07	5.317655
Within Groups	46.832	8	5.854			
Total	1677.561	9				

Table A4.39: Analysis of Variance for 3hrs delay time for Plasticity Index of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	146	29.2	2.84

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1587.6	1	1587.6	247.2897	2.67E-07	5.317655
Within Groups	51.36	8	6.42			
Total	1638.96	9				

Table A4.40: Analysis of Variance for 1hr delay time for BSL Maximum Dry Density of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	8.155	1.631	0.00073

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	14.0304	1	14.0304	2.805876	0.13245	5.317655
Within Groups	40.00292	8	5.000365			
Total	54.03332	9				

Table A4.41: Analysis of Variance for 2hrs delay time for BSL Maximum Dry Density of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	8.269	1.6538	0.000219

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13.76164	1	13.76164	2.752267	0.135701	5.317655
Within Groups	40.00088	8	5.00011			
Total	53.76251	9				

Table A4.42: Analysis of Variance for 3hrs delay time for BSL Maximum Dry Density of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	8.245	1.649	0.000605

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13.818	1	13.818	2.763433	0.135015	5.317655
Within Groups	40.00242	8	5.000303			
Total	53.82042	9				

Table A4.43: Analysis of Variance for 1hr delay time for WAS Maximum Dry Density of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	8.259	1.6518	0.000176

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13.78511	1	13.78511	2.756973	0.135411	5.317655
Within Groups	40.0007	8	5.000088			
Total	53.78581	9				

Table A4.44: Analysis of Variance for 2hrs delay time for WAS Maximum Dry Density of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	8.91	1.782	0.002222

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12.29881	1	12.29881	2.459216	0.155474	5.317655
Within Groups	40.00889	8	5.001111			
Total	52.3077	9				

Table A4.45: Analysis of Variance for 3hrs delay time for WAS Maximum Dry Density of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	8.826	1.7652	0.000309

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12.48583	1	12.48583	2.497088	0.152712	5.317655
Within Groups	40.00123	8	5.000154			
Total	52.48706	9				

Table A4.46: Analysis of Variance for 1hr delay time for BSH Maximum Dry Density of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	8.834	1.7668	0.000167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12.46796	1	12.46796	2.493549	0.152967	5.317655
Within Groups	40.00067	8	5.000084			
Total	52.46862	9				

Table A4.47: Analysis of Variance for 2hrs delay time for BSH Maximum Dry Density of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	9.146	1.8292	2.92E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	11.78093	1	11.78093	2.356179	0.163335	5.317655
Within Groups	40.00012	8	5.000015			
Total	51.78105	9				

Table A4.48: Analysis of Variance for 3hrs delay time for BSH Maximum Dry Density of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	8.876	1.7752	0.000561

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12.37434	1	12.37434	2.474729	0.154335	5.317655
Within Groups	40.00224	8	5.000281			
Total	52.37658	9				

Table A4.49: Analysis of Variance for 1hr delay time for BSL Optimum Moisture Content of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	100	20	0.81875

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	640	1	640	118.3131	4.52E-06	5.317655
Within Groups	43.275	8	5.409375			
Total	683.275	9				

Table A4.50: Analysis of Variance for 2hrs delay time for BSL Optimum Moisture Contentof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	89.6	17.92	1.147

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	484.416	1	484.416	86.91415	1.43E-05	5.317655
Within Groups	44.588	8	5.5735			
Total	529.004	9				

Table A4.51: Analysis of Variance for 3hrs delay time for BSL Optimum Moisture Contentof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	93.6	18.72	2.117

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	541.696	1	541.696	89.41091	1.29E-05	5.317655
Within Groups	48.468	8	6.0585			
Total	590.164	9				

Table A4.52: Analysis of Variance for 1hr delay time for WAS Optimum Moisture Content of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	96.65	19.33	2.717

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	587.5223	1	587.5223	92.3995	1.14E-05	5.317655
Within Groups	50.868	8	6.3585			
Total	638.3903	9				

Table A4.53: Analysis of Variance for 2hrs delay time for WAS Optimum Moisture Contentof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	73.3	14.66	0.698

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	284.089	1	284.089	53.11067	8.49E-05	5.317655
Within Groups	42.792	8	5.349			
Total	326.881	9				

Table A4.54: Analysis of Variance for 3hrs delay time for WAS Optimum Moisture Contentof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	146	29.2	2.84

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1587.6	1	1587.6	247.2897	2.67E-07	5.317655
Within Groups	51.36	8	6.42			
Total	1638.96	9				

Table A4.55: Analysis of Variance for 1hr delay time for BSH Optimum Moisture Content of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	82.6	16.52	1.082

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	391.876	1	391.876	70.72297	3.04E-05	5.317655
Within Groups	44.328	8	5.541			
Total	436.204	9				

Table A4.56: Analysis of Variance for 2hrs delay time for BSH Optimum Moisture Contentof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	75	15	1.42

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	302.5	1	302.5	52.97723	8.56E-05	5.317655
Within Groups	45.68	8	5.71			
Total	348.18	9				

Table A4.57: Analysis of Variance for 3hrs delay time for BSH Optimum Moisture Contentof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	82.7	16.54	0.968

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	393.129	1	393.129	71.68654	2.9E-05	5.317655
Within Groups	43.872	8	5.484			
Total	437.001	9				

Table A4.58: Analysis of Variance for 1hr delay time of BSL Cohesionof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	221	44.2	10.2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4040.1	1	4040.1	400.0099	4.07E-08	5.317655
Within Groups	80.8	8	10.1			
Total	4120.9	9				

Table A4.59: Analysis of Variance for 2hrs delay time of BSL Cohesionof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	274	54.8	17.2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6451.6	1	6451.6	474.3824	2.08E-08	5.317655
Within Groups	108.8	8	13.6			
Total	6560.4	9				

Table A4.60: Analysis of Variance for 3hrs delay time of BSL Cohesionof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	197	39.4	141.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3132.9	1	3132.9	41.27668	0.000204	5.317655
Within Groups	607.2	8	75.9			
Total	3740.1	9				

Table A4.61: Analysis of Variance for 1hr delay time of WAS Cohesionof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	239	47.8	21.2

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4796.1	1	4796.1	307.4423	1.14E-07	5.317655
Within Groups	124.8	8	15.6			
Total	4920.9	9				

Table A4.62: Analysis of Variance for 2hrs delay time of WAS Cohesionof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	463	92.6	75.8

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	19624.9	1	19624.9	457.4569	2.4E-08	5.317655
Within Groups	343.2	8	42.9			
Total	19968.1	9				

Table A4.63: Analysis of Variance for 3hrs delay time of WAS Cohesionof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	220	44	179.5

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4000	1	4000	42.21636	0.000189	5.317655
Within Groups	758	8	94.75			
Total	4758	9				

Table A4.64: Analysis of Variance for 1hr delay time of BSH Cohesionof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	310	62	807.5

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	8410	1	8410	20.57492	0.001909	5.317655
Within Groups	3270	8	408.75			
Total	11680	9				

Table A4.65: Analysis of Variance for 2hrs delay time of BSH Cohesionof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	378	75.6	1024.3

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12816.4	1	12816.4	24.78275	0.001082	5.317655
Within Groups	4137.2	8	517.15			
Total	16953.6	9				

Table A4.66: Analysis of Variance for 3hrs delay time of BSH Cohesionof Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	242	48.4	438.3

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4928.4	1	4928.4	21.98706	0.001563	5.317655
Within Groups	1793.2	8	224.15			
Total	6721.6	9				

Table A4.67: Analysis of Variance for 1hr delay time of BSL Angle of Internal friction of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	37	7.4	4.425

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	28.9	1	28.9	4.006932	0.0803	5.317655
Within Groups	57.7	8	7.2125			
Total	86.6	9				

Table A4.68: Analysis of Variance for 2hrs delay time of BSL Angle of Internal friction of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	32.5	6.5	5

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	15.625	1	15.625	2.083333	0.186905	5.317655
Within Groups	60	8	7.5			
Total	75.625	9				

Table A4.69: Analysis of Variance for 3hrs delay time of BSL Angle of Internal friction of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	41	8.2	1.325

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	44.1	1	44.1	7.788079	0.023532	5.317655
Within Groups	45.3	8	5.6625			
Total	89.4	9				

Table A4.70: Analysis of Variance for 1hr delay time of WAS Angle of Internal friction of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	52	10.4	23.175

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	102.4	1	102.4	6.173323	0.037838	5.317655
Within Groups	132.7	8	16.5875			
Total	235.1	9				

Table A4.71: Analysis of Variance for 2hrs delay time of WAS Angle of Internal friction of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	42	8.4	15.675

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	48.4	1	48.4	3.770204	0.088114	5.317655
Within Groups	102.7	8	12.8375			
Total	151.1	9				

Table A4.72: Analysis of Variance for 3hrs delay time of WAS Angle of Internal friction of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	52	10.4	12.675

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	102.4	1	102.4	9.031974	0.016934	5.317655
Within Groups	90.7	8	11.3375			
Total	193.1	9				

Table A4.73: Analysis of Variance for 1hr delay time of BSH Angle of Internal friction of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	77.5	15.5	5.875

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	330.625	1	330.625	41.65354	0.000197	5.317655
Within Groups	63.5	8	7.9375			
Total	394.125	9				

Table A4.74: Analysis of Variance for 2hrs delay time of BSH Angle of Internal friction of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	65.5	13.1	6.05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	207.025	1	207.025	25.79751	0.000954	5.317655
Within Groups	64.2	8	8.025			
Total	271.225	9				

Table A4.75: Analysis of Variance for 3hrs delay time of BSH Angle of Internal friction of Natural and BA – Treated Black Cotton Soil

Groups	*Count*	*Sum*	*Average*	*Variance*
%BA	5	20	4	10
LL	5	80.5	16.1	10.05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	366.025	1	366.025	36.51122	0.000308	5.317655
Within Groups	80.2	8	10.025			
Total	446.225	9				