STABILIZATION OF BLACK COTTON SOIL TREATED WITH INDUCTION FURNACE SLAG AND SAWDUST ASH

(IN CASE OF ADDIS ABABA CMC AREA)

By: Tsion Kifle Gegu

A Thesis Submitted to The Department of Civil Engineering School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Civil Engineering (Specialization in Geotechnical Engineering)

Office of Graduate Studies

Adama Science and Technology University

July, 2021

Adama, Ethiopia

STABILIZATION OF BLACK COTTON SOIL TREATED WITH INDUCTION FURNACE SLAG AND SAWDUST ASH

(IN CASE OF ADDIS ABABA CMC AREA)

Tsion Kifle Gegu

Advisor: Tensay Gebremedhin (Ph.D.)

A Thesis Submitted to The Department of Civil EngineeringSchool of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Civil Engineering (Specialization in Geotechnical Engineering)

Office of Graduate studies

Adama Science and Technology University

July, 2021

Adama, Ethiopia

DECLARATION AND RECOMMENDATION

Declaration

I hereby declare that this Master Thesis entitled "Stabilization of Black Cotton Soil Treated with Induction Furnace Slag and Sawdust Ash (In Case of Addis Ababa CMC Area)" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

____________________ __________________ ________________

Name of the student Signature Date

Recommendation

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Stabilization of Black Cotton Soil Treated with Induction Furnace Slag and Sawdust Ash (In Case of Addis Ababa CMC Area)" prepared under my guidance by Tsion Kifle submitted in partial fulfillment of the requirements for the degree of Mater's of Science in in Civil Engineering (Specialization in Geotechnical Engineering). Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

____________________ __________________ ________________

Advisor Signature Date

APPROVAL OF BOARD OF EXAMINER

I, the advisor of the thesis entitled "Stabilization of Black Cotton Soil Treated with Induction Furnace Slag and Sawdust Ash (In Case of Addis Ababa CMC Area)" and developed by Tsion Kifle, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Tensay Gebremedhin (Ph.D.) ____________________ __________

Advisor Signature Date

We, the undersigned, members of the Board of Examiners of the thesis by Tsion Kifle have read and evaluated the thesis entitled "Stabilization of Black Cotton Soil Treated with Induction Furnace Slag and Sawdust Ash (In Case of Addis Ababa CMC Area)" and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Civil Engineering (Specialization in Geotechnical Engineering).

____________________	____________________	________________
Chairperson	Signature	Date
____________________	____________________	________________
Internal Examiner	Signature	Date
____________________	____________________	________________
External Examiner	Signature	Date

Finally, approval and acceptance of the thesis are contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the department Graduate Council (DGC) and School Graduate Committee (SGC).

____________________	____________________	________________
Department Head	Signature	Date
____________________	____________________	________________
School Dean	Signature	Date
____________________	____________________	________________
Office of Postgraduate Studies, Dean	Signature	Date

ACKNOWLEDGEMENT

First of all, I would like to thank the almighty God and his mother St. Marry for their protection and success in my life. Without them, I would not have had the wisdom and ability to do so.

I am grateful to my organization Adama Science and Technology University providing scholarship opportunities.

I would like to express my deepest gratitude to my advisor Dr. Tensay Gebremedhin for his close supervision and positive suggestion during my research work.

My special thanks also go to CORE consulting engineers PLC staffs for their support by giving material information, and Ethiopian construction design and supervision works corporation laboratory for letting me use and carry out relevant material tests in their laboratory with special supervision and guidance. My thankfulness goes to Ethiopian iron and steel factory for material support.

Finally, I would like to extend my heartfelt thanks to my father Kifle Gegu for his unlimited support and initiation for this work, and also I thank my beloved family for their help.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

AASHTO	American Association of States Highway and Transportation Officials;
ASTM	American Society of Testing and Materials;
CBR	California Bearing Ratio;
CH	In organic clay of high plasticity;
CL	In organic clay of low plasticity;
CSH	Calcium silicate;
Cu	Undrained Cohesion;
ERA	Ethiopian Road Authority
GC	Clayey gravel;
GGBS	Ground Granulated Blast Furnace Slag
GM	Silty gravel;
GP	poor graded gravel;
GW	Well graded gravel;
IFS	Induction Furnace Slag
LL	Liquid Limit;
MDD	Maximum Dry Density;
MH	In organic silts of high compressibility;
MI	In organic silts of low to medium plasticity;
ML	In organic silts of none low to plasticity;
OH	Organic clay of low to high plasticity;

OL	Organic silts of low plasticity;
OMC	Optimum Moisture Content;
PI	Plasticity Index;
PL	Plastic Limit;
SC	Clayey sand;
SDA	Sawdust Ash
SM	Silty sand;
SP	Poor graded sand;
SW	Well graded sand;
UCS	Unconfined Compressive Strength;
USCS	Unified Soil Classification System;
gm/cm^3	Gram per Centimeter Cube
%	Percent
Kpa	Kilopascal
KN/m^2	Kilo newton per Meter Square
Km	Kilo meter

ABSTRACT

This research evaluates the combined effect of sawdust ash and induction furnace slag on index and engineering properties of black cotton soils which are considered to be problematic soils for civil engineering purposes. Black cotton soils were collected from two different locations in Addis Ababa around CMC area for investigation through laboratory testing. Sawdust and indiction furnace slag were collected from philipos timber industry, Kolfe Keranio sub city and Ethiopian iron and steel factory respectively. The sawdust ash was mixed with black cotton soil in varying proportions of 4 %, 8 %, and 12 %, and the characteristics of which have been executed in the laboratory. As a result of which an optimum amount of sawdust ash was determined based on California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) values. Since the trial mixes showed that the use of 8 % sawdust ash gave better results, thus the black cotton soil treated with optimum sawdust ash content of 8 % was further stabilized with 5 %, 10 %, 15 %, and 20 % induction furnace slag. Reduction in liquid limit and plasticity index, as well as optimum increase in CBR and UCS values, which were about 178% and 157% increment in CBR values and about 40% and 26% increment in UCS values, was achieved when black cotton soils of the first and the second locations were treated with 8 % sawdust and 10 % induction furnace slag respectively. Based on the cost comparison done between the optimum mix and mass replacement method, the quantitative unit cost of black cotton soil + 8% sawdust ash + 10% induction furnace slag was 5,287,661.39 *birr/Km and the quantitative unit cost of non-expansive soil was* 4,425,051.19 *birr/Km. Stabilizing the black cotton soil found to be economical than replacing the black cotton soil with other non-expansive material with a saving cost of about 16 %. It was thus concluded that treating black cotton soil with sawdust ash and induction furnace slag enhances its strength and gives an economical way of stabilizing black cotton soil.*

Keywords: Stabilization, Furnace slag, Sawdust ash, Black cotton soil, CBR, UCS

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Infrastructure projects such as highways, railways, buildings, etc. require soil material in a very large quantity. Usually, large areas are covered with highly plastic and expansive soil, which is not suitable for such a purpose (Joseph & Sridhar, 2020). Black cotton soil is an expansive soil that has long been known to be very problematic for construction. It is not considered suitable either for the building of houses or the construction of roads. This has led to many investigations into ways of improving the subgrade by way of stabilizing it and as such improving the engineering properties of the soil (Ikeagwuani, Obeta et al., 2019).

Several attempts have been made towards stabilizing the black cotton soils. The most common and most widely used method for doing so is the addition of lime. It has been observed that the addition of lime to soil improves the engineering properties of the soil as a result of cation exchange, flocculation, and pozzolanic reaction (Ouf, 2011). In recent years the use of various waste products in civil engineering construction has gained considerable attention because of the shortage and high costs of conventional construction materials, the increasing costs of transportation, and environmental constraints. The idea of controlling the expansion of soil or improving its properties by adding solid waste is not only economical but also environmentally friendly (Joseph & Sridhar, 2020).

The waste materials available in Ethiopia include sawdust and slag. A considerable amount of research works have been done concerning the stabilization of soil with these industrial wastes (Ikeagwuani, 2016; Ikeagwuani et al., 2019; James, 2019; Jangid, Khatti et al., 2018; Joseph & Sridhar, 2020; Kale, Chaudhari et al., 2019; Mandal & J.P.Singh, 2016; Obeta, Ikeagwuani et al., 2019). It has been seen from these researches that sawdust ash and slag are pozzolanic materials with a high amount of silica and calcium oxide in proportion to other chemicals and they improved the property of the soil. However, there is no enough investigation done on these potential soil stabilizers in Ethiopia and the combinations of sawdust ash and slag in soil stabilization are limited.

In this study, the combined effect of sawdust ash and induction furnace slag on black cotton soil properties is investigated by conducting Atterberg limit, specific gravity, compaction, one point soaked CBR and UCS tests.

1.2 Statement of the Problem

Black cotton soil is an expansive soil characterized by high shrinkage and swelling properties with respect to moisture content. This expansion and shrinkage of soil cause failure of pavement, in the form of settlement, heavy depression, cracking, and unevenness. Roads laid on black cotton soil bases develop undulations at the road surface due to the loss of strength of the subgrade. In addition to this black cotton subgrade results in a larger thickness of pavement layers which increases the cost of pavement construction.

Because of increasing urbanization and modernization, many construction activities are taking place in Addis Ababa, CMC area, and problems due to expansive soils are frequently reported (Arega, 2012), which is due to soils dominated in CMC area are black cotton soils. Hence, there is a threat of damage to subgrade pavement. The cost of the normal methods of dealing with this unsuitable subgrade (excavation and carting away) would constitute a significant part of the costs of any road project in the area. As such, an economical method to stable black cotton soil is required.

Disposal of waste slag and sawdust constitutes a problem. Every day approximately1.5 - 3 tons of induction furnace slag is produced in Ethiopian iron and steel factory (Desalegn, 2020). Also huge amount of the sawdust is produced in philipos timber industry. However, sawdust and slag are not used in Ethiopia in road construction compared to other countries. The use of these easily available waste materials for black cotton soil subgrade stabilization will contribute in minimizing the construction cost of a road project and give another way to dispose sawdust and slag in an open place. This study was conducted to investigate the effects of sawdust and induction furnace slag on the properties of black cotton soil aimed to offer an economical way to mitigate the problems posed by this soil.

1.3 Objective of the Study

1.3.1 General objective

The main objective of the study is to stabilize black cotton soil by treating it with induction furnace slag and sawdust ash.

1.3.2 Specific objectives

- To determine how various proportions of induction furnace slag with fixed sawdust ash content affect index and engineering properties of black cotton soil.
- To investigate the effectiveness of sawdust ash and induction furnace slag mixture in black cotton soil.
- To determine the optimum proportion of sawdust ash with induction furnace slag mix to stabilize black cotton soil.
- To make cost comparison of the optimum mix with the replacement of existing soil with other material taking pavement section. Editted

1.4 Research Questions

1. Does the combination of sawdust ash and induction furnace slag improve the geotechnical and engineering properties of black cotton soil?
2. In which proportion of sawdust ash and induction furnace slag maximum strength is obtained?
3. Is stabilizing black cotton soil by sawdust ash and induction furnace slag effective?
4. Is stabilizing the soil economical than replacement of existing soil with other materials?

1.5 Significance of the Study

- To characterize and study the usefulness of locally available industrial wastes (sawdust ash and induction furnace slag) on the improvement of the engineering properties of problematic black cotton soil to make it suitable foundation material and to avoid mass replacement method.
- Offers another way to dispose of sawdust and slag in an open place.

1.6 Scope of the Study

This study focuses on stabilization of black cotton soils of two different locations in Addis Ababa, around CMC area with induction furnace slag and sawdust ash. It was also limited to Atterberg limit, specific gravity, compaction, one point soaked CBR and UCS test result interpretations of natural black cotton soil and black cotton soil treated with induction furnace slag and sawdust ash.

1.7 Limitation of the Study

The mineralogy of the soil samples could not be conducted due to unavailability of the XRD equipment according to the information obtained from Central Laboratory of Ministry of Mines and Energy and the chemical composition of stabilizers was not determined due to cost constraints. Due to these reasons, only the physical properties of soils and the stabilizers were determined.

1.8 Organization of the Thesis

This thesis work is organized into five chapters. The first chapter gives a brief description of the thesis background, problem statement, objectives, the significance of the thesis, scope, and limitations of the thesis, and organization of thesis work. The second chapter deals with a brief literature review comprising a study on previous similar works relevant to the present study. The third chapter discusses the description of the study area and materials and methods used in the study in detail. The fourth chapter reports the test results obtained analysis and discussion of results and also cost comparison between the replacements of black cotton soil by selected material and stabilized black cotton soil for subgrade. Finally, the fifth chapter concludes the findings of the present research work and forward recommendations. Detailed calculations of specific gravity test results, grain size and hydrometer analysis test results, Atterberg limit test results, compaction test results, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) test results of natural and stabilized soil samples are included in the appendices.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin of Black Cotton Soil

Black clays or black cottons are known to be potentially expansive soils which are "black" or "greyish black" or in their eroded phase "greyish white" heavy loam or clay (usually 50 %), with predominant clay mineral of the smectite group, rich in alkali earth elements and the horizons sometimes contain calcium carbonate or magnesium oxide concentrations (Gidigasu, 2013). Black cotton soils are susceptible to detrimental volumetric changes with moisture. The black soils are formed when volcanic rocks and some sediment are weathered under humid, alkaline conditions. Because of poor drainage, these soils are rich in soluble bases and silica (ERA, 2013b).

The parent materials of expansive soils could also be classified into two groups. The first group comprises basic igneous rocks. Here pyroxene mineral of the parent rocks decompose to form montmorillonite which is the predominant mineral of expansive soil and other secondary minerals. The second group comprises sedimentary rocks that contain montmorillonite. The expansive soils of Ethiopia are derived from both groups (Teferra & Yohannes, 1986).

2.2 Distribution of Black Cotton Soil

Black cotton soils occupy mostly the arid and semi-arid regions and also cover a very large area of the world (Ikeagwuani, 2016). In this section worldwide distribution and distribution of black cotton soil in Ethiopia are discussed.

2.2.1 Worldwide distribution of black cotton soil

Black cotton soils (vertisols) have been reported all over the world and have been found to occupy about 2 % (257 million hectares) of the total ice-free land area of the earth with 72 million hectares occurring in India, 71 million hectares in Australia and 43 million hectares are in Africa. Countries that reported having black cotton soils are Australia, Algeria, Botswana, Ethiopia, Bulgaria, Hungry, Italy, Togo, Nigeria, South Africa, Morocco, Chad, Cameroon, Kenya, Zambia, Tanzania, Sudan, India, Ghana, etc. (Gidigasu, 2013; Ikeagwuani et al., 2019).

2.2.2 Distribution of black cotton soil in Ethiopia

Black cotton soils are widely distributed in Ethiopia, especially in highlands. They are known as vertisols, they are present in the central, north-western, and eastern highlands and western lowlands. It is estimated that 7.6 million hectares of vertisol area are located in the highlands with a height of greater than 1500 m above sea level. The remaining area (over 5 million hectares) is located at elevations below 1500 m. the general slope range of the landscape on which vertisols occur is 0 - 8 %. They are more frequent in 0 % - 2 % slope range and are usually found in landscapes of restricted drainage such as seasonally inundated depressional basins, alluvial and colluvial plains, undulated plateaus, valleys, and undulating side slopes (ERA, 2013b).

In the central part of Ethiopia, in the upper valley of the Awash river which drains the northern part of the rift valley, where relatively plain to hilly, undulating and steep mountain topography prevails about 1500 m – 2500 m elevation above sea level, have reported predominantly black, highly plastic and expansive clay are found during the section from Addis Ababa to Modjo town covering an extensive area with varying thickness (Uge, 2017). Also in the capital city, Addis Ababa, considerable areas of Bole, Kotebe, CMC, and Mekanisa, are covered by black cotton soils (Arega, 2012; Tsion Argu, 2017; Uge, 2017). The soil map of Ethiopia is shown in Figure 2.1.

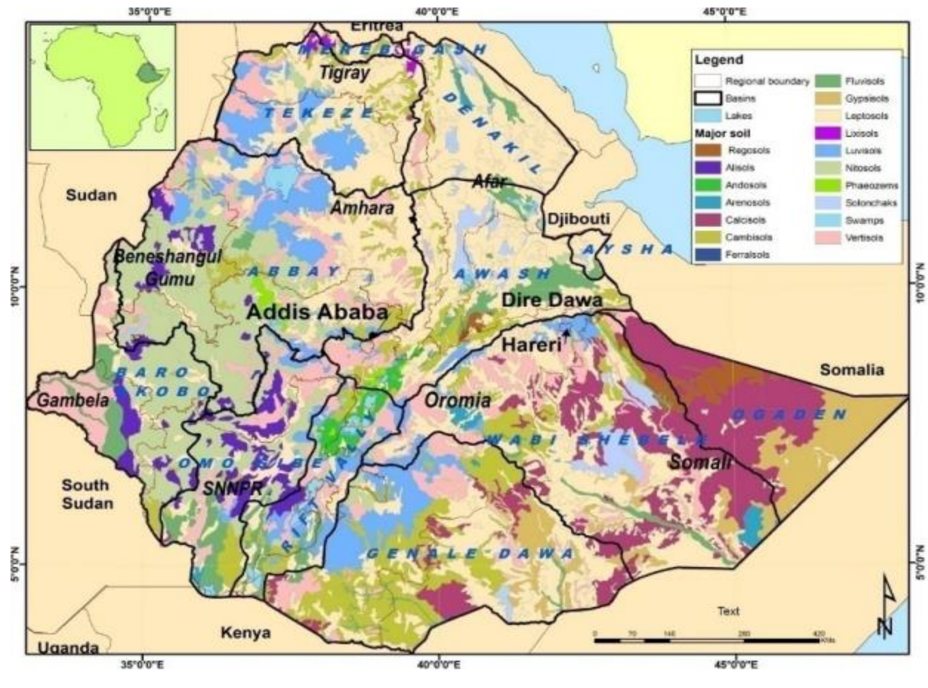

Figure 2. 1Soil map of Ethiopia (Lakew & Moog, 2016)

2.3 Clay Mineralogy

Most soil classification systems arbitrarily define clay particles as having an effective diameter of two microns (0.002 mm) or less. Particle size alone does not determine clay minerals. Probably the most important grain property of fine-grained soils is the mineralogical composition. For small size particles, the electrical forces acting on the surface of the particle are much greater than the gravitational force. These particles are said to be in the colloidal state. The colloidal particle consists primarily of clay minerals that were derived from parent rock by weathering. The three most important groups of clay minerals are montmorillonite, illite, and kaolinite, which are crystalline hydrous aluminosilicates (Chen, 1975).

a) Kaolinite group

Kaolinite is the typical two-layer mineral having a single tetrahedral sheet joined by a single octahedral sheet to form what is called a 2 to 1 lattice structureThe bonding between successive layers is by van der waals forces and hydrogen bonds. The bonding is sufficiently strong, more over water cannot easily enter between the structural units and cause expansion (Arora, 2004).

b) Illite

Illite has a similar structure to that of montmorillonite, but in the octahedral sheet there is a partial substitution of aluminum by magnesium and iron, and in the tetrahedral sheet there is a partial substitution of silicon by aluminum. The combined sheets are linked together by fairly weak bonding due to (non - exchangeable) potassium ions held between them (Chen, 1975).

c) Montmorillonite

It is a three-layer mineral having a single octahedral alumina sheet sandwiched between two silica sheets. The units are stacked one above the opposite like leaves of a book. The bonds are comparatively weak and water can enter between the sheets causing them to expand readily. When water is removed from the boundary, the sheets will contract. Thus soils containing a substantial amount of montmorillonite will exhibit high shrinkage and swelling characteristics. Experience shows that swelling problems arise when soils contain more than 20 % montmorillonite (Teferra & Yohannes, 1986).

d) Halloysite

Halloysite is a dioctahedral 1:1 clay mineral that occurs widely in soils of wet tropical and subtropical regions and weathered rocks, being formed by weathering of many types of igneous and non-igneous rocks. The structure and chemical composition of halloysite are similar to those of kaolinite but halloysite can intercalate a monolayer of water molecules giving a basal spacing near 10 Å. Halloysite (either hydrated or dehydrated) has a greater propensity for intercalating organic molecules than does kaolinite (Joussein, Petit et al., 2007).

The main clay mineral reported in black cotton soil is the smectite group of clay minerals of which montmorillonite is predominant. Accessory minerals may be kaolinite, illite, etc. (Gidigasu, 2013). Figure 2.2 shows schematic diagrams of the structure of clay minerals.

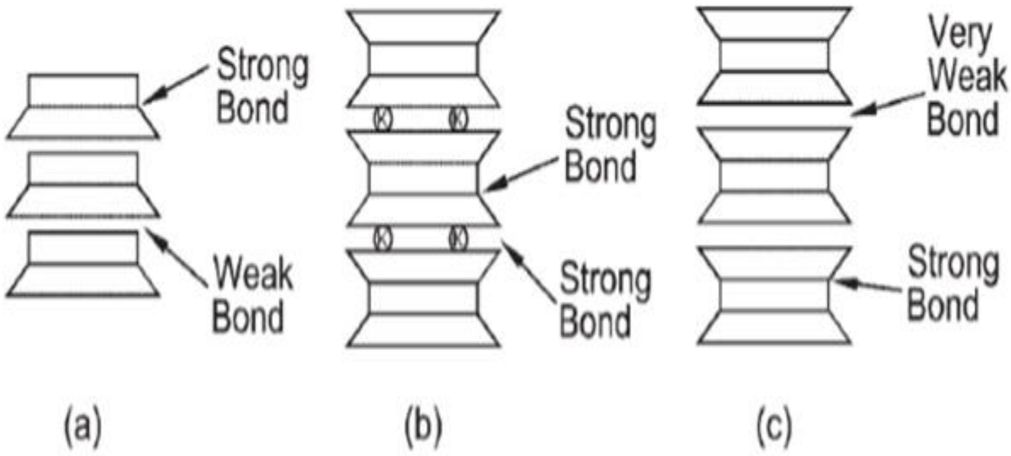

Figure 2. 2 Schematic diagrams of the structure (a) Kaolinite; (b) Illite; (c) Montmorillonite (Nelson, 2015)

2.4 Identification of Black Cotton Soil

Black cotton soils can be recognized both visually and series of laboratory test identification methods.

2.4.1 Field identification

In the field, the presence of surface desiccation cracks or fissures on clay deposits are indications of expansion. The most problematic expansive soils are typically highly plastic, stiff, fissured, over-consolidated clays. In Ethiopia, these are characteristics of the black cotton soils (ERA, 2013b). Black cotton soils can be identified visually as they are:

1. Usually have a color of black or grey.
2. Wide or deep shrinkage cracks.
3. High dry strength and low wet strength.
4. Stickiness and low traffic ability when wet.
5. Cut surfaces have a shiny appearance.
6. The appearance of cracks in nearby structures. Arid and semiarid areas are particular trouble spots because of large variations in rainfall and temperature (Chen, 1975).

2.4.2 Laboratory identification

Laboratory identification of expansive soils are often categorized into mineralogical, indirect, and direct methods

2.4.2.1 Mineralogical test

The mineralogical composition of expansive soils has a crucial pertaining to the swelling potential as explained under "clay mineralogy". The negative electric charges on the surface of the clay minerals, the strength of the interlayer bonding, and the cation exchange capacity all contribute to the swelling potential of the clay. Hence, it is claimed by the clay mineralogist that the swelling potential of any clay are often evaluated by the identification of the constituent mineral of this clay. The five techniques which may be used are as follows: (Chen, 1975)

- Differential thermal analysis.
- X-ray diffraction
- Dye adsorption.
- Chemical analysis and
- Electron microscope resolution.

Due to their property of time consumption, expensiveness, need of skilled technicians for result interpretation, these tests cannot be considered as routine tests (Chen, 1975).

2.4.2.2 Indirect Methods

These methods include simple soil property tests that a practicing engineer resort to use for identifying expansive soil. Such tests are easy and can be performed in most soil mechanics laboratories, and yield excellent indices of expansive properties. The various tests under these methods are:

Atterberg limits

In this method, measurement of the plasticity and the shrinkage characteristics of the soil are conducted for identification of all engineering soils and provide a wide acceptable means of rating. Especially once they are combined with other tests they can be used to classify expansive soils. The different types of limits under this method are liquid limit, plastic limit, and shrinkage limit.

Liquid Limit (LL):- the water content at which the soil changes from a liquid state to a plastic state. At the liquid limit, the soil starts to behave as a liquid but possesses small shear strength (Arora, 2004). The liquid limit of the black cotton soils is variable and ranges from 28 % to190 % (Gidigasu, 2013).

Plastic Limit (PL):- the water content at which the soil changes from plastic state to semi-solid state. At the plastic limit, the soil stops behaving like a plastic material and begins to crumble when rolled into a thread of soil of 3mm diameter (Arora, 2004).

Plasticity Index (PI):- the magnitude of the range of water contents over which the soil exhibits plastic properties. It is the difference between the liquid limit and plastic limit of the soil. It shows the capacity of the soil to change shape without altering its volume and indicates the amount of swelling and shrinkage that will result in the wetting and drying of the fraction tested (Arora, 2004). The plasticity index of black cotton soil ranges between 14 % and 145 % (Gidigasu, 2013). The plasticity index alone can be used as a preliminary indication of swelling characteristics of most clays (Chen, 1975). The swelling potential of clays and the plasticity index are related as shown in Table 2.1.

Table 2. 1 Relation between the swelling potential of clays and the plasticity index (Chen, 1975)

Swelling potential	Plasticity index
Low	0 – 15
Medium	10 – 35
High	20 – 55
Very high	35 and Above

Shrinkage limit: - is the water content at which the soil changes from semi-solid state to solid state. it is the water content at which the soil stops shrinking further and attain constant volume (Arora, 2004). The shrinkage limits of black cotton soils range between 7 % and 26 % (Gidigasu, 2013).

Linear Shrinkage tests

Linear Shrinkage (LS) is the change in length of a soil sample as it dries to the shrinkage limit expressed as a percentage of the original length. This test also in combination with other tests is used for the classification of expansive soil (Arora, 2004) and calculated as follows:

$$\boldsymbol{LS = \frac{(initial\ length)-(final\ length)}{initial\ length}} \quad \textbf{(2.1)}$$

Free swell

This test is a simple test conducted in the laboratory for the determination of the degree of expansiveness. Free swell tests consist of placing a known volume of dry soil in water and noting the swelled volume after the material settles, without any surcharge, to the bottom of a graduated cylinder. The difference between the final and initial volume, expressed as a percentage of the initial volume, is the free swell value. The swell test is very crude and was used in the early days when refined testing methods were not available. Experiments indicated that a good grade of high swelling commercial bentonites will have a free swell value from 1200 to 2000 percent. Soils having free swell value as low as 100 percent can cause considerable damage to lightly loaded structures, and soils having a free swell value below 50 percent seldom exhibit appreciable volume change even under very light loadings (Chen, 1975).

$$\boldsymbol{Free\ swell = \frac{(final\ volume)-(initial\ volume)}{initial\ volume}} \quad \textbf{(2.2)}$$

Colloid content

The grain size characteristics of clay appear to have a bearing on its swelling potential, particularly the colloid content. Seed, Woodward, and Lundgren (1962) believed that there is no correlation between swelling potential and the percentage of clay sizes. However, for a given clay type, the amount of swell will increase with the amount of clay (Chen, 1975).

Activity index

Atterberg limits and clay contents have been combined in a single parameter called activity ratio sometimes called activity index (A) developed by Skempton (1953). The significant change within the volume of clay soil during shrinking or swelling may be a function of the plasticity index and the quantity of colloidal clay particles present within the soil. The clay soil can be classified as inactive, normal, or active (Murthy, 2002). The activity of clay is expressed as:

$$\boldsymbol{Activity\ (A) = \frac{plasticity\ index(PL)}{Percent\ finer\ than\ 2\ micron}} \qquad \textbf{(2.3)}$$

Table 2. 2 Soil classification according to activity (Murthy, 2002)

A	Soil type
<0.75	Inactive
0.75 - 1.40	Normal
>1.40	Active

2.4.2.3 Direct Methods

These methods offer the most useful data by direct measurement, and tests are simple to perform and do not require complicated equipment. Testing should be performed on a number of samples to avoid erroneous conclusions. Direct measurement of expansive soils can be achieved by the use of a conventional one-dimensional consolidometer (Chen, 1975).

2.5 Classification of Black Cotton Soil

The classification or grouping of soils is mainly based on one or two index properties of soil which are described in detail in earlier sections. The methods that are used for classifying soils are based on one or the other of the following two broad systems:

1. A textural system which is based only on grain size distribution.
2. The systems that are based on the grain size distribution and limits of soil.

Many systems are in uses that are based on the grain size distribution and limits of soil. The systems that are quite popular amongst engineers are the American Association of State Highway and Transportation Officials (AASHTO) Soil Classification System and the Unified Soil Classification System (Murthy, 2002).

2.5.1 AASHTO Classification

This system is known as the AASHTO (American Association of State Highway and Transportation Officials) System. The revised system comprises seven groups of inorganic soils, A-l to A-7 with 12 subgroups in all. The system is based on the following three soil properties:

1. Particle-size distribution
2. Liquid Limit
3. Plasticity Index.

A group index is introduced to further differentiate soils containing appreciable fine-grained materials. The characteristics of various groups are defined in Table 2.3.

Table 2. 3 AASHTO soil classification (Murthy, 2002)

General classification	Granular materials (35 percent or less of total sample passing No. 200)							Silt-clay Materials (More than 35% percent of total sample passing No. 200)			
Group classification	A -1		A -3	A -2				A-4	A-5	A-6	A-7
	A -1-a	A -1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve analysis percent passing No. 10	50 max										
No. 40	30 max	50 max	51 min								
No. 200	15 max	25 max	10max	35 max	35 max	35 max	35 max	35 max	35 max	35 max	35 max
Characteristics of fraction passing No. 40 Liquid limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity index	6 max		N.P	10 max	10 max	11 min	11 max	10 max	10 max	11 min	11 min
Usual types of significant constituent materials	Stone fragments – gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good					Fair to poor					

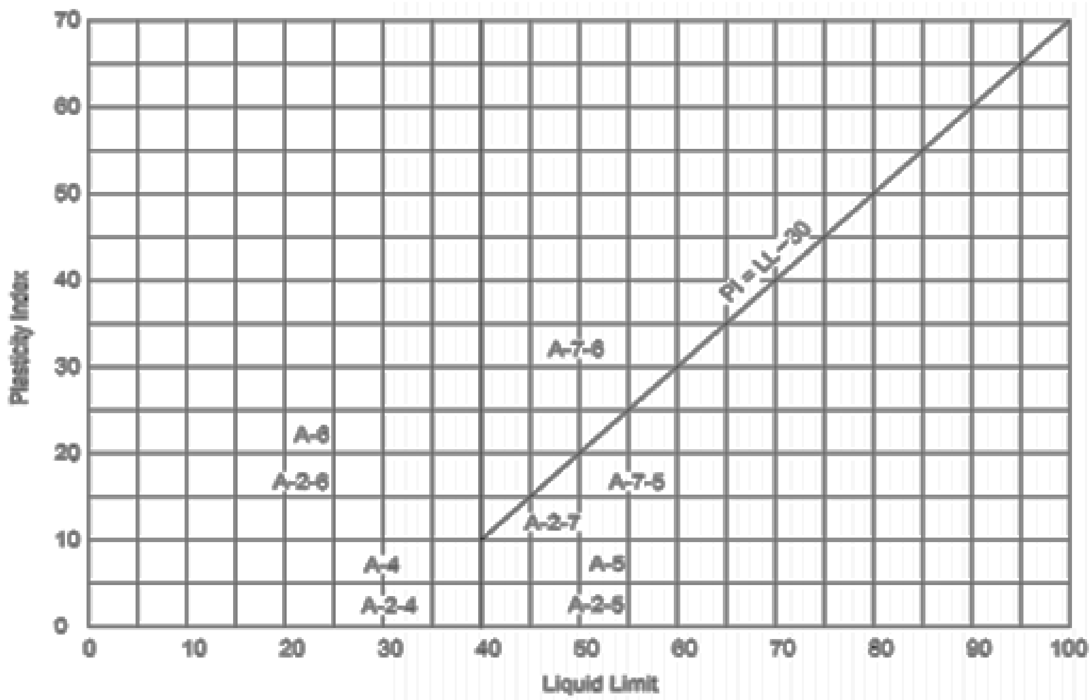

Figure 2. 3 Chart for use in AASHTO soil classification system (Murthy, 2002)

2.5.2 Unified Soil Classification Systems

Unified Soil Classification System is the most popular system for use in all types of engineering problems involving soils. The system uses both the particle size analysis and plasticity characteristics of soils (Arora, 2004).

It divides soil into three major divisions: coarse-grained soils, fine grained soils, and highly organic (peaty) soils. In the field, identification is accomplished by visual examination for the coarse-grained soils and a few simple hand tests for the fine-grained soils. In the laboratory, the grain-size curve and the Atterberg limits can be used. The peaty soils are readily identified by color, odor, spongy feel and fibrous texture. In this classification system, a correlation is made between swell potential and Unified Soil Classification as follows (Murthy, 2002).

Table 2.4 Unified soil classification

Category	Soil classification in the unified system
Little or no expansion	GW, GP, GM, SW, SP, SM
Moderate expansion	GW, SC, ML, MH
High volume change	CL, OL, CH, OH

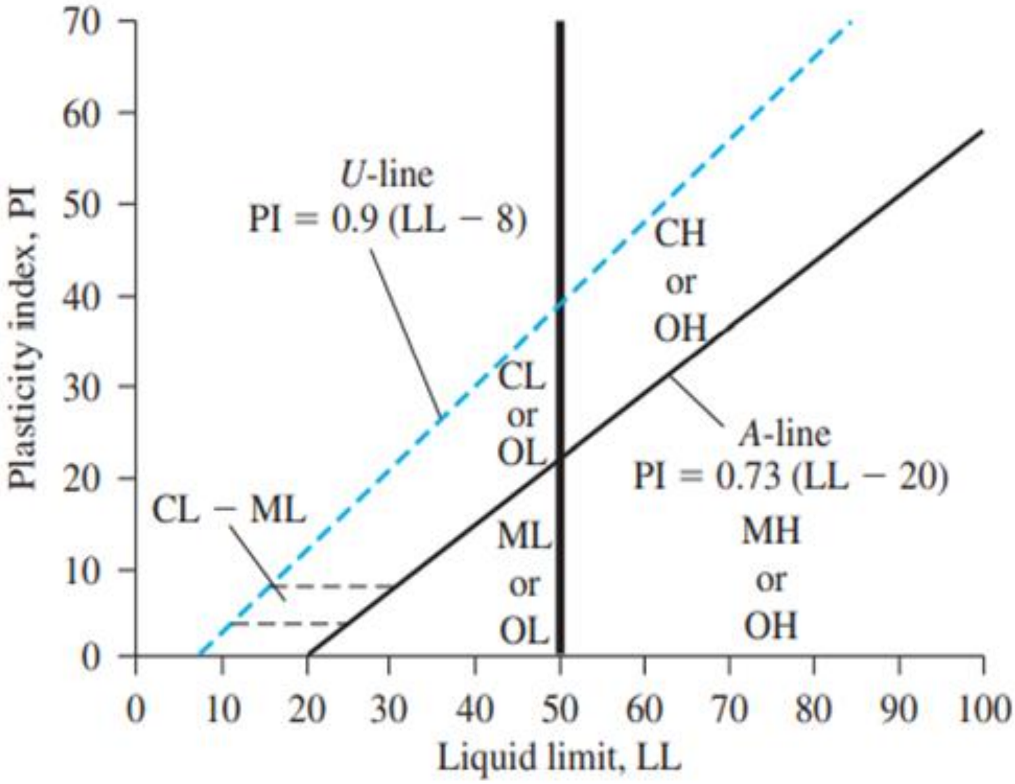

Figure 2. 4 Plasticity chart for fine-grained soils (Arora, 2004)

Most black cotton soils classify as A-7-5 and A-7-6 by the AASHTO Classification System with group index values varying from 13 - 89 and CH and CL on the Unified Soil Classification System (Gidigasu, 2013).

2.5.3 Textural classification system

By making use of the grain size limits mentioned in the table for sand, silt, and clay, a triangular classification chart has been developed as shown in Figure 2.5 for classifying mixed soils. This method of classification does not reveal any properties of the soil other than grain-size distribution. Because of its simplicity, it is widely used by workers in the field of agriculture (Murthy, 2002). The gradation of the black cotton soils varies considerably. There is little or no gravels size in most black cotton soils and those that have shown percentages of less than 8 %. The amount of sand varies between 2 % and 50 % and silt 11 % to 58 %. The clay size contents also range from 40 % to 75 %. The soils classify as clay, sandy-clay, and silty-clay on the U.S. Engineers textural classification chart (Gidigasu, 2013).

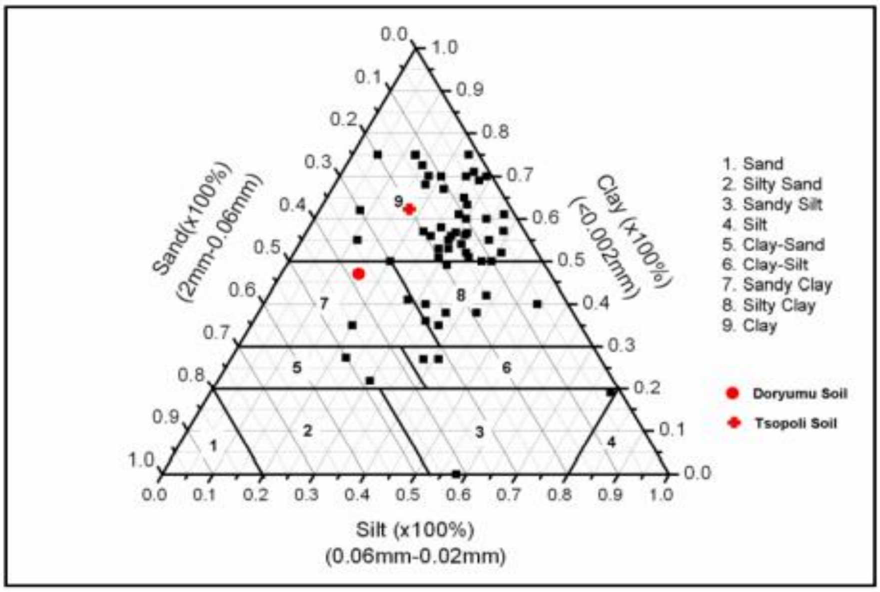

Figure 2. 5 Textural classification of black cotton soils (Gidigasu, 2013)

2.6 Damaging Effect of Black Cotton Soil

The black cotton soils are considered "problematic" and sometimes a "potential natural hazard" because they cause extensive damage to light structures founded on them due to excessive seasonal volumetric changes (swell and shrinkage). The soil deposits are usually extensive making it impossible to avoid or bypass during the construction of engineering projects. Foundations on expansive soils are prone to differential movements, such as uneven heave and settlement. Subgrade conditions for roads on expansive soils are poor, which often impair the serviceability of structures resulting in serious consequences to the construction economy. This is due to considerable differential volume change and related deformations, decrease in bearing capacity, and low shearing strength that these soils develop when wetted. Thus, the presence of expansive soils in construction sites such as road alignments is problematic, unless proper care is taken during the planning, location, design, and construction of such infrastructure (Arega, 2012).

Many roads and foundations of light buildings have been reported distressed because of the seasonal volume change (i.e. swell and shrinkage) of these soils. These soils have reportedly inflicted billions of dollars in damages and repairs annually to earth structures and facilities (Gidigasu, 2013). Table 2.5 presents some estimated costs of damages due to heaving on facilities of some countries.

Table 2. 5 Estimated cost of damages due to undesirable heave/swell of expansive soils (Gidigasu, 2013)

Country	Amount
Britain	₤3 billion (2001)
China	₮100 million
France	€3.3 billion
India	Several lakhs of rupees
Saudi Arabia	>US $300 million (1977 and 1987)
Sudan	>US $6 million (1983)
USA	US $ 2 billion annually

Appreciable parts of Ethiopia are also covered by expansive soils. Most of the roads constructed and proposed as well as a substantial amount of the newly planned railway routes in the country pass through in the heart of expansive soils. The roads on this type of soil fail before their expected design life, in some cases after few months of completion. In Ethiopia, broad range of difficulties were experienced in the road construction sector, which are challenging reminders of the requirement of careful consideration of expansive soils (Arega, 2012). Damages caused by expansive clays are particularly prevalent around Addis Ababa (ERA, 2013b). It has been reported in 2004 that Addis Ababa City Roads Authority had an annual expenditure of around 300 million Ethiopian birrs for road construction and maintenance out of which more than 30 million Ethiopian birr was expended for routine maintenances which is too big and require special attention (Uge, 2017).

As far as paved roads are concerned, differential movements and related cyclic changes in strength and stiffness of expansive soils can induce distortions and the formation of cracks onto pavement structures. Figures 2.6 & 2.7 show typical damages due to soil swelling and shrinking characteristics showing distress on lightweight and shallowly founded infrastructure.

Figure 2. 6 (A) Road surface deformation and formation of potholes, corrugation, and ruts. (B) Formation of longitudinal cracks due to the presence of expansive soils.

Figure 2. 7 (C) Roadside ditch clogging. (D) Cracks in the wall of a residential building (Arega, 2012).

In general, structural damage to roads located in areas where subgrade material is expansive; often requires extensive maintenance work that often exceeds the initial road construction costs .

2.7 Mitigating the Effects of Black Cotton Soils

Some of the mitigation methods of expansive soils are (Siddiqui, 2019):

1. Removal and replacement,
2. Moisture conditioning and compaction control,
3. Pre-wetting,
4. Using one of the various methods of soil stabilization.

2.7.1 Removal and replacement

Expansive soils are over excavated and replaced by non-expansive or treated soils. It depends on the required depth of excavation, allowable heave and location, and cost of replacement fill (Kalantari, 2012).

2.7.2 Moisture conditioning and compaction

In the case of non-availability of non-expansive fill, swelling properties of soils can be altered by moisture conditioning and compaction control. Compacting the material wet side of optimum and at a lower density but with adequate strength reduces the expansion potential (Siddiqui, 2019).

2.7.3 Pre-wetting

Increasing the water content within the expansive foundation soils will cause heave before construction, thereby reducing post-construction expansion potential. Many times it can lead to serious loss of soil strength and reduction in bearing capacity. Also, continued migration of water into lower more expansive layers can result in continued heave. Although, pre-wetting the soil is one of the most economical treatment methods, it is not completely a reliable method because of complexity of distributing the uniform moisture penetration in a reasonable time (Khadem & Budima, 2016).

2.7.4 Mechanical stabilization

Soil stabilization is a process that incorporates the various methods used for improving the strength and stability of a given soil mass as well as other engineering and physical properties. It is usually employed when the soil available for the construction work is not suitable for the intended use. Through stabilization, a better engineering performance with a reduced chance of bad engineering behavior such as washing collapse, etc. occurring by increasing the shear strength of the soil, improving the lead-bearing capacity, and controlling the shrink-swell properties. Stabilization can be used to treat a wide range of sub-grade materials varying from expansive clays to granular materials (Archibong, 2020). Soil stabilization can be accomplished by several methods. All these methods fall into two broad categories namely mechanical stabilization and chemical stabilization (Afrin, 2017).

The process of mechanical stabilization entails the mixture of at least two or more types of natural soil in an attempt to change its gradation and by so doing improve the properties of the soil. This method tries to combine the engineering properties of the constituents of the soil mixture. It is aimed at reducing the void ratio by filling up the spacing between larger granular soil properties with finer soil particles through the combination of soils possessing different granular sizes followed by thorough compaction. This method of soil stabilization can otherwise be known as granular stabilization. The compaction process ensures that the void ratio is reduced improving the soil strength parameters such as cohesion (C) and angle of internal friction (∅) (Archibong, 2020).

2.7.5 Chemical stabilization

Involves mixing or injecting the soil with chemically active admixtures such as portland cement, lime, fly ash, calcium or sodium chloride, or with bitumen materials (Barasa, 2016). Chemical stabilization is commonly regarded as the most effective method of black cotton soil or expansive soil improvement, when the right additive is used; it changes the nature of the soil, strengthens it, and removes its sensitivity both to water and subsequent stress (Batari, Chinade et al., 2017). Cementitious materials stabilize soils and modify their properties through cation exchange, flocculation and agglomeration, and pozzolanic reactions (Barasa, 2016)

a) Cation Exchange

Negatively charged clay particles adsorb cations of specific type and amount. The replacement or exchange of cations depends on several factors, primarily the valence of the cation. Higher valance cations such as the calcium ion (Ca^{++}) easily replace cations of lower valance such as sodium ions (Na^{+}). For ions of the same valance, the size of the hydrated ion becomes important; the larger the ion, the greater the replacement power. If other conditions are equal, trivalent cations are held more tightly than divalent and divalent cations are held more tightly than monovalent cations (Barasa, 2016). Below is an example of the cation exchange equation:

$$\mathbf{Ca^{2+} + Na^{+} + Clay \rightarrow Ca^{2+}\,Clay + (Na^{+})} \qquad \mathbf{(2.4)}$$

b) Flocculation and Agglomeration

Cation exchange reaction results in the flocculation and agglomeration of the soil particles with a consequent reduction in the amount of clay-sized materials and hence the soil surface area, which inevitably accounts for the reduction in plasticity. Flocculation and agglomeration change the clay texture from that of a plastic, fine-grained material to that of granular soil (Barasa, 2016).

c) Pozzolanic Reactions

Pozzolana is a siliceous material which while in itself possessing cementitious properties will in a finely divided form and the presence of water reacts with calcium hydroxide and form cementitious compounds thereby serving as an admixture. Pozzolana can be naturally occurring volcanic ash or industrial waste such as fly ash or can be produced by calcining clay (Archibong, 2020). Calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) are the two outputs in pozzolanic reactions.

$$Ca^{2+} + 2(OH)^{-} + SiO2 \text{ (Clay Silica)} \rightarrow CSH \quad \textbf{(2.5)}$$

$$Ca^{2+} + 2(OH)^{-} + Al2O3 \text{ (Clay Alumina)} \rightarrow CAH \quad \textbf{(2.6)}$$

Many researches have been done on the subject of soil stabilization using various additives; the most common methods of soil stabilization of clay soils in pavement work are cement and lime stabilization. The high strengths obtained from cement and lime stabilization may not always be required, however, there is justification for seeking cheaper additives which may be used to alter the soil properties (Afrin, 2017).

In line with this, numerous waste materials are utilized in stabilizing problematic soils. Various researchers reported that improvements in both physical and mechanical properties of black cotton soil were achieved when additives such as fly ash, slag, cement, rice husk ash, wood ash, bagasse ash, etc. have been used alone or in combination to stabilize black cotton soil (Batari et al., 2017).

2.7.6 Lime stabilization

The method of soil improvement in which lime is added to the soil to improve its properties is known as lime stabilization. When lime reacts with clay soils, there is an exchange of cations in the absorbed water layer and a decrease in the plasticity of the soil occurs resulting in more friable clay than the original clay soil thereby making it a more suitable construction material say as a subgrade or a base course for pavements (Archibong, 2020). Lime modification describes an increase in strength brought by cation exchange capacity rather than cementing effect brought by pozzolanic reaction (Afrin, 2017).

The types of lime used to the soil are hydrated high calcium lime, monohydrated dolomite lime, calcite quick lime, dolomite lime (Afrin, 2017; Archibong, 2020). The quick lime is more effective as a stabilizer than the hydrated lime, although less safe and convenient. Hydrated lime is more commonly used, better known as slaked lime with an increase in its magnesium content resulting in a decrease in its affinity for water and heat generated during the mixing (Archibong, 2020).

2.7.7 Cement stabilization

Soil cement stabilization is soil particles bonding caused by hydration of the cement particles which grow into crystals which will interlock with each other giving a high compressive strength. To achieve a successful bond, the cement particles need to coat most of the material particles. To provide good contact between soil particles and cement, and thus efficient soil cement stabilization, mixing the cement and soil with certain particle size distribution is necessary. Soil cement is a highly compacted mixture of soil/aggregate, cement, and water. Soil cement is sometimes called the cement-stabilized base, or cement-treated aggregate base. Soil-cement becomes a hard and durable material as the cement hydrates and develops strength. Cement stabilization is done when the compaction process is continuing. As the cement fills the void between the soil particles, the void ratio of soil is reduced. After this when water is added to the soil, cement reacts with water and goes hard. So, the unit weight of soil is increased. Because of the hardening of cement shear strength and bearing capacity are also increased. Cement helps decrease the liquid limit and increase the plasticity index and workability of clayey soils. Cement reaction is not dependent on soil minerals, and the key role is its reaction with water that may be available in any soil. This can be the reason why cement is used to stabilize a wide range of soils (Afrin, 2017).

2.7.8 Sawdust ash stabilization

Sawdust is a by-product waste in the form of fine granules of wood that is generated during woodworking operations like sawing, milling, planing, drilling, and sanding of timber in timber industries that process timber to be supplied for various allied manufacturing industries. This sawdust is predominantly used in particle boards, though they do have other applications like making wood pulp, mulch, charcoal briquettes, and as fuel. In sawmills, where they are generated in huge quantities, they are also used in the sawdust burners to produce heat for milling operations (James, 2019).

Sawdust ash (SDA) is a fine grey to black powdery substance produced by the burning of sawdust, which is mainly organic in nature (Ikeagwuani et al., 2019). sawdust ash has found applications in the manufacture of concrete and more recently, in soil stabilization and stabilized soil blocks (James, 2019).

The main chemical compositions of sawdust ash are SiO_2 and CaO. The chemical composition of sawdust ash is given in Table 2.6. Sawdust ash is a pozzolanic material due to its high siliceous content. Due to limited silica in clay soil, there is always free calcium from lime that is not utilized. Therefore the use of sawdust ash and slag wastes which are rich in silica enhances the pozzolanic reactions (Barasa, 2016). Its availability, affordability combined with its pozzolanic nature has made several researchers explore ways of using sawdust ash in the stabilization of different soil types. The findings have been encouraging and have necessitated the need to further harness its potential (Ikeagwuani, 2016).

Table 2. 6 Chemical composition of sawdust ash

Oxide compositions											
Reference	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	SO_3	MnO	TiO_2	P_2O_5	K_2O	LOI
(Butt, 2016)	3.6	86	2.6	10.27	1.8	0.45	0.07	-	0.43	0.11	-
(Ikeagwuani et al., 2019)	45.98	33.2	-	1.20	0.03	3.81	1.01	0.50	2.20	10.65	-
(Honest., 2014)	3.5	85	2.7	0.25	1.7	-	-	-	-	-	4.3

Several researchers have worked on the utilization of sawdust ash as a standalone stabilizer as well as in combinations with primary binders like cement and lime. The effects of sawdust ash on compaction and permeability properties of black cotton Soil has been evaluated by mixing waste sawdust ash in soil with 2 %, 4 %, and 6 % in dry weight of the soil and after conducting standard proctor compaction test and falling head permeability tests on varying percentages of waste sawdust ash. It was observed that about 5.4 % of dry density increased in addition of 2 % of sawdust ash and reduction of dry density and permeability on increasing the percentage of waste sawdust ash (Reddy, 2016).

The use of sawdust ash and lime on the compressibility characteristics of the black cotton soil has been studied by subjecting the soil to one-dimensional consolidation and conducting Atterberg's limits, specific gravity, and particle size distribution, using 0 %, 4 %, 8 %, 12 %, 16 % and 20 % sawdust ash by weight of black cotton soil as an additive and by adding 4 % lime by weight of the dry soil to all the mixed samples.

Analysis of the results obtained from the laboratory tests conducted on the soil samples and various mix proportions show that there were significant improvements in the compressibility characteristics of the black cotton soil and the optimum performance is achieved if the black cotton soil is admixed with a combination of 16 % sawdust ash and 4 % lime by weight of the black cotton soil (Ikeagwuani, 2016).

An extensive experimental study was carried out to demonstrate the soil improvement prospective of sawdust ash by performing California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests on soil samples mixed with different percentages of sawdust ash as 0, 4, 8, and 12 %. The experimental study had revealed that the addition of sawdust ash results in a significant increase in CBR and UCS with an increase in sawdust ash content, a general reduction in maximum dry unit weight was observed. The optimum moisture content (OMC) shows an increase with the increase in sawdust ash content. The CBR value increases by 103.11 % and unconfined compressive strength increase by 26.35 at 4 % sawdust ash content which is taken as optimum. Furthermore, the values of CBR obtained were within the limits recommended by the Asphalt Institute for Highway sub-base and sub-grade. Thus it is concluded that sawdust ash, an industrial waste, is a cheap satisfactory stabilizing agent for sub-base and base course in clayey fills (Butt, 2016).

A research was conducted on how black cotton soil could be stabilized and made a suitable subgrade material using sawdust ash. Sawdust ash was mixed with black cotton soil in varying proportions of 4 %, 8 %, 12 %, 16 %, and 20 %. The trial mixes showed that the use of 16 % sawdust ash gave better results, and the black cotton soil treated with optimum sawdust ash content of 16 % was further stabilized with 2 %, 4 %, 6 %, 8 %, and 10 % lime. Optimum reduction in liquid limit, differential free swell, plasticity index as well as an optimum increase in CBR and specific gravity was achieved when black cotton soil treated with 16 % sawdust ash was stabilized with 4 % lime (Ikeagwuani et al., 2019).

2.7.9 Slag stabilization

Slag is a by-product generated during the manufacturing of pig iron and steel. It is produced by the action of various fluxes upon gangue materials within the iron ore during the process of pig iron making in blast furnace and steel manufacturing in steel melting shop (Mines, 2016). Slags are compounds of oxides of metal & nonmetallic elements which form chemical compounds and solutions with each other and also contain a small volume of metals, sulfides of metal, and gases. Slags could have varied chemical and mineralogical characteristics. Differences are as a result of the differences in furnace charge, operation temperatures, grades of refractory furnace lining, and melting additives (Deshmukh & Vidhate, 2015).

Slags are named based on the furnaces from which they are generated. The main types of slags that are generated from the iron and steelmaking industries are classified as follow (Yildirim & Prezzi, 2011) :

i. Blast-furnace slag (iron making slag)
ii. Steel-furnace slag
    - Basic-Oxygen-Furnace (BOF) slag
    - Electric Furnace slag
    - Ladle slag

a) Blast-Furnace slag

Blast furnace slag is produced as a by-product during the manufacture of iron in a blast furnace. It results from the fusion of a limestone flux with ash from coke and the siliceous and aluminous residue remaining after the reduction and separation of the iron from the ore. Iron blast furnace slag consists essentially of silicates and aluminosilicates of lime and other bases. The granulated material thus produced is known as Granulated Blast Furnace Slag (GBS). GGBS is cementitious on its own (Ouf, 2011).

b) Basic-Oxygen-Furnace (BOF) slag

Basic-oxygen furnaces, which are located at integrated steel mills in association with a blast furnace, are charged with the molten iron produced in the blast furnace and steel scraps. The slag generated from a steelmaking cycle is later processed, and the final product after processing is referred to as the Basic-Oxygen-Furnace slag (BOF slag). The chemical reactions occurring during the removal of impurities determine the chemical composition of the basic oxygen-furnace slag (Yildirim & Prezzi, 2011).

c) Electric-Arc-Furnace (EAF) slag

Electric-arc furnaces (mini-mills) use high-power electric arcs, instead of gaseous fuels, to produce the heat necessary to melt recycled steel scrap and to convert it into high-quality steel. The electric-arc furnace steelmaking process is not dependent on the production from a blast furnace since the main feed for it is steel scrap with some pig iron. The EAF steelmaking process is essentially a steel scrap recycling process. Therefore, the chemical composition of EAF slag depends significantly on the properties of the recycled steel (Yildirim & Prezzi, 2011).

d) Induction Furnace slag

Induction furnace slag is a non-metallic co-product produced in the process of recycling of scrap iron in an electric induction furnace. They are air-cooled naturally and therefore crystalline. The crystallization takes place slowly and hence they are very hard (Joseph & Sridhar, 2020). The slag that formed in electrical furnace melting is the results of complex reactions between silica, iron oxide from steel scrap, other oxidation by-products from melting, and reactions with refractory linings. The resulting slag will consist of a complex liquid phase. Slag contains Al_2O_3, MgO, SiO_2, Fe_2O_3, CaO & MnO (Deshmukh & Vidhate, 2015). The chemical composition of induction furnace slag is given in Table 2.7.

Table 2. 7 Chemical composition of induction furnace slag

Oxide compositions											
Reference	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	SO_3	MnO	TiO_2	P_2O_5	K_2O	LOI
(Ahmad & Rahman, 2018)	7.12	40.59	13.54	-	20.05	-	11.8	-	-	-	-
(Joseph & Sridhar, 2020)	4.19	45.82	12.76	1.31	8.59	0.59	1.79	0.55	0.09	0.27	18.2

The additions of pozzolanic industrial products like slag bind soil particles to improve strength and decrease swelling. It also promotes the flocculation of dispersed clay particles (Sharma & Sivapullaiah, 2012). The air-cooled slag when powdered and the metal part separated, can be potentially used as a stabilizer (Joseph & Sridhar, 2020).

Series of laboratory tests have been carried out on local Indian expansive black cotton soil to improve engineering properties of the soil by using waste material Ground Granulated Blast Furnace Slag (GGBS). GGBS mixed with the expansive soil in different proportions (10 % - 90 %) with an increment of 10 %. The specimens compacted to their respective Proctor's optimum moisture content and dry densities were cured for a period of 7, 14, and 28 days and their unconfined compression strengths were determined. It is observed that the strength improvement depends on the amount of GGBS used and the effect of the curing period is less pronounced. The maximum UCS value was obtained with the addition of 10 % of GGBS further increase in GGBS content decreases the UCS value (Sharma & Sivapullaiah, 2012).

The effect of GGBS with and without lime, on the engineering behavior i.e. plasticity characteristics, compaction, Unconfined Compressive Strength (UCS), and swelling potential of clay soil had been investigated. 0 %, 4 %, 6 %, 8 %, 12 % and 14 % of GGBS by dry weight of soil was used to stabilize clay soil. The results indicated that 10 % of GGBS gives the highest strength. Finally, it was concluded the use of GGBS alone, or preferably with lime, could have a significant effect on the behavior of potentially swelling clays (Ouf, 2011).

Investigations on the behavioral aspect of soil when mixed with fix percentage of GGBS (10 %) and varying percentage of fly ash from (0 % - 25 %) with an increment of 5 % have been done. From the experimental results, it was observed that the UCS, unsoaked CBR, and soaked CBR of modified soil increased with respect to natural soil samples. The maximum strength was obtained at 10 % GGBS and 10 % fly ash. Thus, it was concluded that the properties of soil change after mixing GGBS and fly ash as a stabilizer and may be used as infrastructure development. Also, modified soil reduces the environmental degradation caused by waste materials (Mandal & J.P.Singh, 2016).

The changes in compaction and strength characteristics of the black cotton soil on the addition of two industrial solid wastes on black cotton soil had been evaluated. The virgin soil was mixed with varying percentages (5 %, 10 %, 15 % & 20 %) of the dry weight of soil with an incremental increase of 5 % of silica fume and Induction furnace slag independently and its effect on compaction characteristics was ascertained. The result showed that when induction furnace slag was used to treat the soil, Optimum Moisture Content (OMC) of the soil decreased with a percent increase in induction furnace slag and the Maximum Dry Density (MDD) increased with a percent increase in induction furnace slag. The percentage increase in strength for black cotton soil + 10 % silica fume +15 % induction furnace slag was found to be about 45 % compared to its virgin soil (Joseph & Sridhar, 2020).

2.7.9.1 Availability of induction furnace slag

According to the world steel association, global crude steel production in 2018 was approximately 1807.1 Mt and there are around 600 Mt of slags from the steel industry worldwide, of which about 58 % are blast furnace slag and 42 % are steelworks slags. In the year 2014, about 25.6 % of the world total production of steel was covered by electric furnaces, but Africa's production of steel from the electric furnaces had the lion's share, which accounted for 68.8 % of total steel production in the continent. Africa's steel production using blast furnace – basic oxygen furnace route accounted only for 31.2 % because blast furnace requires huge investment, a situation which is not convenient for developing countries. Most of the steel industries in Ethiopia are equipped with electric furnaces and the total annual production capacity of Ethiopia's steel industries was estimated to be 1.486 million tons in 2007 E.C (G/Michael, Tufa et al., 2017). About 11 to 15 Kg of slags are generated from per ton production of steel in an induction furnace (Rahman, 2018). Considering this the annual slag production in Ethiopia is estimated to be about 0.16 - 0.023 million tons. The slag produced from only Ethiopian iron and steel factory is estimated to be about 1.5 - 3 tons/day (Desalegn, 2020).

2.8 Summary of Literature Reviews and Research Gap

Black cotton soils have been reported all over the world and considerable areas of Ethiopia are also covered by these soils. The engineering and physical properties of black cotton soils can be improved by stabilizing the soil with different industrial wastes. Stabilization of black cotton soils by the addition of industrial products like fly ash, slag, sawdust ash along lime produces a high concentration of calcium ions in the double layer around the clay particles, hence decreasing the attraction of water. Also, the pozzolanic compounds bind soil particles to improve their strength and decrease swelling. It also promotes the flocculation of dispersed clay particles.

It has been seen from researches done previously that sawdust ash and slag are pozzolanic materials with a high amount of silica and calcium oxide in proportion to other chemicals and they improved the property of the soil. The results obtained showed that using sawdust ash and slag as a stand-alone as well as in combination with other materials give a significant improvement on index and engineering properties. Treating soil with sawdust ash reduces the Maximum Dry Density (MDD) rather than increasing it (Butt, 2016; Ikeagwuani, 2016; Ogundipe, Adekanmi et al., 2019) and increase Optimum Moisture Content (OMC), whereas slag stabilization leads to the reduction of

OMC and increment in the MDD of soil (Joseph & Sridhar, 2020). Both sawdust ash and induction furnace slag increase the CBR, UCS of black cotton soil. Through this research, the reduction of MDD of the soil when stabilized with sawdust ash was improved by the addition of induction furnace slag.

In Ethiopia, there is no enough investigation done on these potential soil stabilizers and the combinations of sawdust ash and slag in soil stabilization are limited in the literatures. In this study, the combined effect of sawdust ash and induction furnace slag on black cotton soil properties is investigated aimed to mitigate the problems posed by black cotton soil and offers another way to dispose the sawdust and slag.

CHAPTER THREE

MATERIALS AND METHODS

In this chapter, a description of the study area, the materials used, the methods adopted, and laboratory experiments carried out to achieve the aim of the research are presented.

3.1 Description of the Study Area

The study area is located in the North-Eastern part of Addis Ababa in Bole sub-city specifically CMC area. The geographical location of the city is approximately located at 9^o1’48N and 38^o44’24’’E (wikipedia, 2021). Addis Ababa lies at an elevation of 2355 meters above mean sea level. It lies in the temperate climatic zone locally known as Daga,

Addis Ababa is witnessing a large population growth in the past decades and rapid expansion in directions, engulfing many farmsteads and woodland into urbanized areas. Much construction activities are taking place and problems due to expansive soils are frequently reported in CMC area. A generalized soil map of the city indicates three main soil types; luvisols (grey brown podzolic soils), vertisols (black cotton soils), and nitosols (red earth) (Arega, 2012). A substantial area of the city subsoil is being occupied by black cotton soil.

The plasticity index (PI) of different area of Addis Ababa city subgrade soil is very high ranging from 11.9 to 52.5 and high liquid limit (LL) ranging from 45.5 to 97.5. The nature of the soil is highly expansive and from critical to highly critical (Tsion Argu, 2017).

Soils dominated in CMC area are dark-colored commonly known as black cotton soils which belong to vertisols family (ERA, 2013b), and grey color soils. Hence there is a threat of damage to subgrade pavement in this area. Therefore it is necessary to study the geotechnical and engineering behavior of subgrade soil.

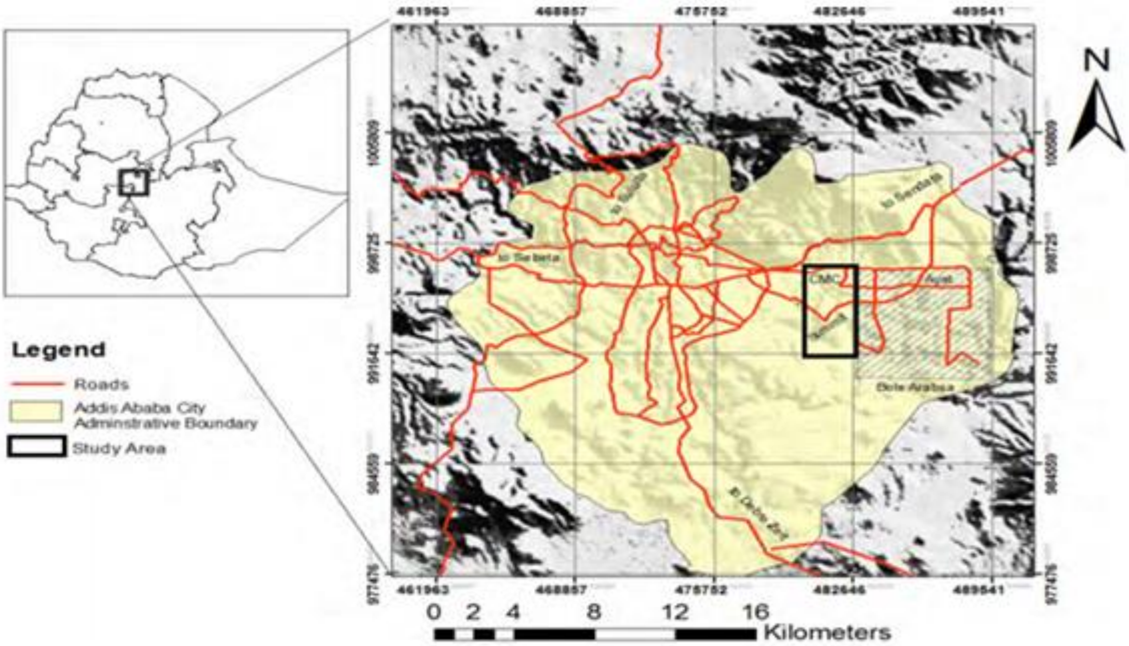

Figure 3. 1 Location map of the study area

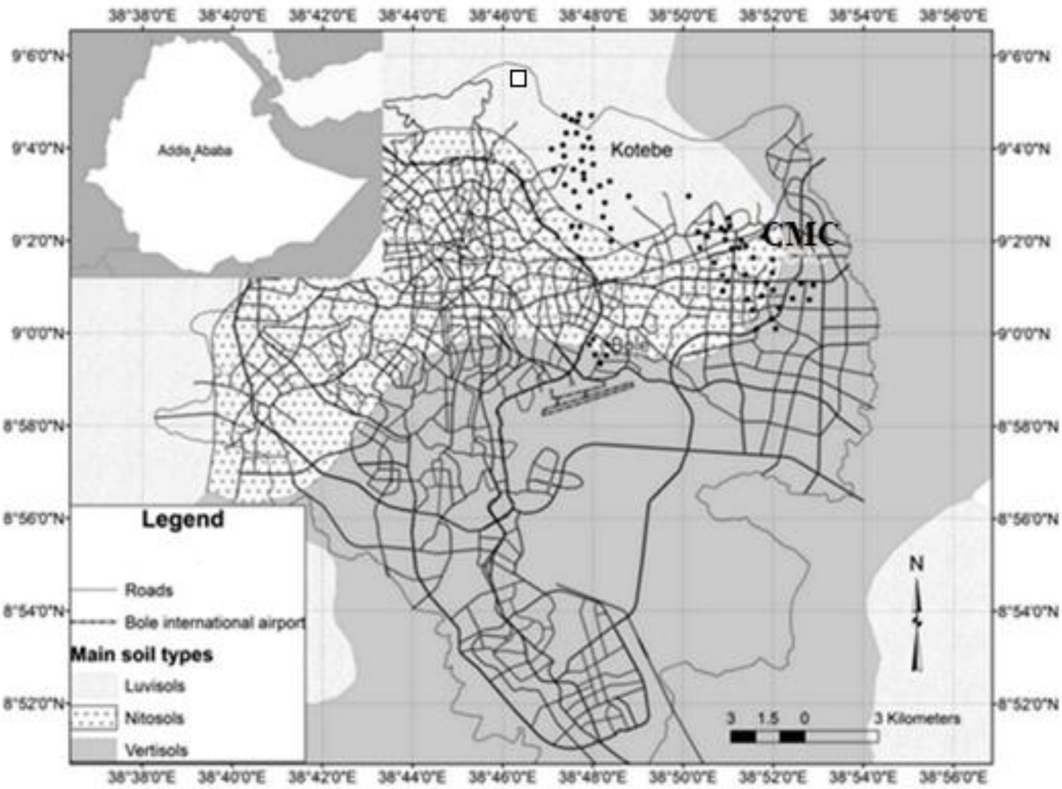

Figure 3. 2 Spatial distribution of main soil type of Addis Ababa (Arega, 2012)

3.2 Materials

3.2.1 Black cotton soil

The soil samples chosen for this investigation were black cotton soils which were collected from two different locations from CMC-Summit Medhanialem road based on the project data collected from Core consulting engineers Plc about the soil and material investigations for CMC-Summit Medhanialem road project. In order to select the sampling locations, four specific locations which are thought to be black cotton soils were selected from the previous laboratory results which were investigated in 2021 G .C. the previous results of these locations are tabulated in Table 3.1.

Table 3. 1 Previous laboratory results for CMC-Summit Medhanialem road project (Source: Core consulting engineers plc)

Location/station	CBR(3pt.)	LL	PI	Soil Classification
0+000-0+600	**1**	**88**	**43**	**A-7-5**
1+680-1+740	**3**	**52**	**21**	**A-7-5**
1+740-1+880	**2**	**87**	**39**	**A-7-5**
1+880-2+140	**4**	**52**	**20**	**A-7-5**

After that Sampling locations were selected from the lists with reference to their CBR and Plastic index value. For further investigation locations **0+000 - 0+600** and **1+740 - 1+880** were selected based on their CBR value, Plastic index values and through visual inspection and consulting the staffs on the project then soil samples were collected. The selected stations and their respective previous laboratory results are given in Table 3.2.

Table 3. 2 Laboratory test results for the selected stations for further studies (Source: Core consulting engineers plc)

Designation	Station	CBR	LL	PI	Soil Classification
TP-1	0+000 - 0+600	1	88	43	A-7-5
TP-2	1+740 - 1+880	2	87	39	A-7-5

Table 3. 3 Test pit location description for TP-1

Project	MSc. Thesis		
Location	TP-1		
Coordinate	9.007^{o} N 38.84^{o} E		
Ground Elevation	2351.1 m		
Excavation type	Open Pit		
Depth	**Sample Type**	**Sample Field Discription**	**Test Pit Photograph**
0-0.2 m		Dark gray top soil	
1.5 m	Disturbed	Dark gray clay soil	

Table 3. 4 Test pit location description for TP-2

Project	MSc. Thesis		
Location	TP-2		
Coordinate	9.018^{o} N 38.84^{o} E		
Ground Elevation	2369.9 m		
Excavation type	Open Pit		
Depth	**Sample Type**	**Sample Field Discription**	**Test Pit Photograph**
0-0.2 m		Black top soil	
1.5 m	Disturbed	black clay soil	

Disturbed soil samples were collected at a depth of 1.5 m from the natural ground surface for each location to avoid the inclusion of organic matter and transported by plastic bags to Ethiopian construction design and supervision works corporation soil laboratory where the actual experimental work on the samples was carried out. Table 3.5 shows the properties of the TP-1 and TP-2 black cotton soils.

Table 3. 5 Properties of black cotton soils

	Characteristic	**Values**	
		TP-1	**TP-2**
Particle-size Distribution	Gravel	1.10	0.76
	Sand % (4.75 to 0.075 mm)	5.03	5.06
	Silt % (0.075 to 0.002 mm)	36.29	28.16
	Clay % (<0.002 mm)	57.57	66.03
Physical Properties	Natural moisture content	12.2	11.22
	Specific gravity	2.586	2.52
	Liquid limit (%)	89.28	83.12
	Plastic limit (%)	45.89	41.51
	Plasticity index (%)	43.39	41.61
	Color	Dark gray	Black
Engineering Properties	Maximum dry density (gm/cm^3)	1.286	1.275
	Optimum moisture content (%)	26	27
	Unconfined compressive strength (KN/m^2)	276.17	333.51
	Soaked CBR (%)	0.89	1.24

3.2.2 Sawdust ash

Sawdust was collected from Addis Ababa, Kolfe Keraniyo sub-city, Philipose timber industry. The sawdust collected was air-dried to facilitate its burning and the dried sawdust was converted into ash by open-air burning as it was presented in previous studies (James, 2019; Ogundipe et al., 2019; Venkatesh & Reddy, 2016). Then it was sieved through a sieve of 75µm to get very fine ash. The properties of sawdust ash used for this research and the procedure of burning were as shown in Table 3.6 and Figure 3.3 respectively.

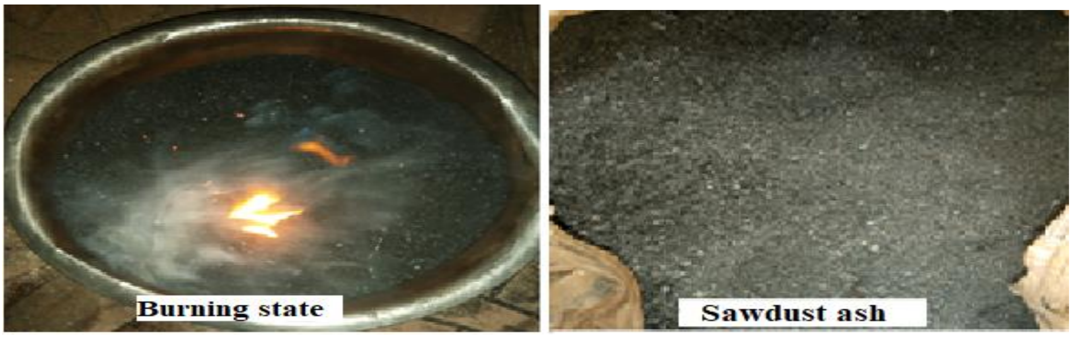

Figure 3. 3 Stages of converting sawdust ash

Table 3. 6 Properties of sawdust ash

Characteristic	Values
Natural moisture content (%)	3
Specific gravity	1.47
Plastic limit (%)	NP
Plastic index	-
Free swell	15 %
Color	Black

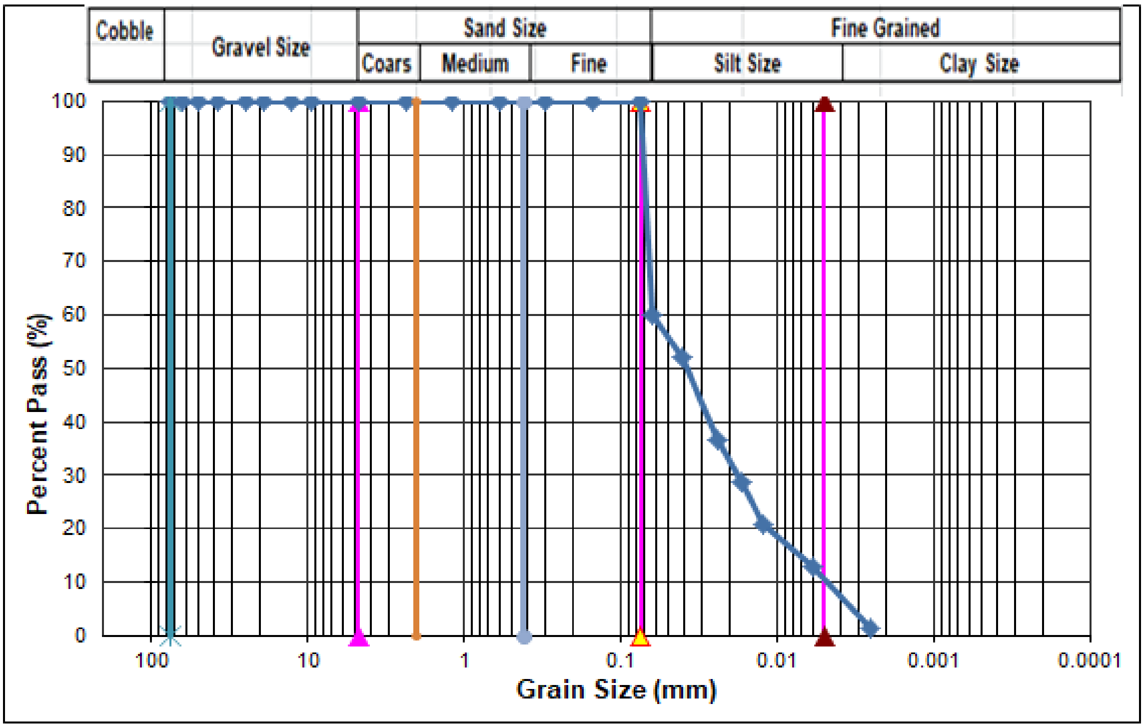

Figure 3. 4 Grain size distribution curve for sawdust ash

3.2.3 Induction furnace slag

The slag used for this study was induction furnace slag obtained from Ethiopian iron and steel factory which is found in Addis Ababa, Akaki Beseka. The slag used for this study was in powdered form. The physical properties of induction furnace slag are shown in Table 3.7.

Figure 3. 5 Induction furnace slag

Table 3. 7 Properties of induction furnace slag

Characteristic	Values
Natural moisture content (%)	0
Specific gravity	2.632
Plastic limit (%)	NP
Plasticity index (%)	-
Free swell	0

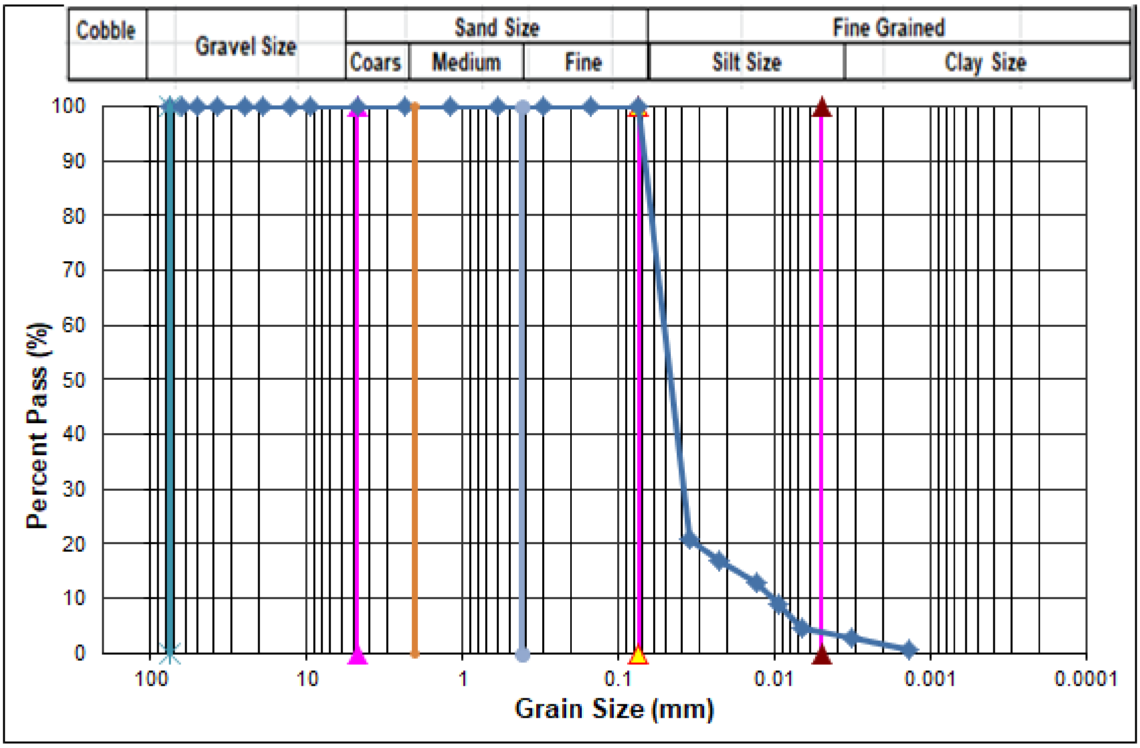

Figure 3. 6 Grain size distribution curve for induction furnace slag

3.3 Preparation and Designation of Test Samples

The soil specimens were air-dried and pulverized in the laboratory to make them good dispersion of stabilization additives and moisture. Then particle size distribution test, specific gravity, liquid limit, and plastic limit tests were done for classification and checking of the properties of the soils. Also, compaction test, unconfined compressive strength test, and California bearing ratio (CBR) test were conducted in the laboratory for both treated and untreated soil samples by using American Society of Testing Materials (ASTM) Standard Testing Methods.

Mix proportion

Based on proportions used on previous studies and their result 0 %, 4 %, 8 % and 12 % of sawdust ash (Butt, 2016; Ikeagwuani, 2016; Shawl & Er. Ved Parkash, 2007; Venkatesh & Reddy, 2016) and 5 %, 10 %, 15 % and 20 % of induction furnace slag (Joseph & Sridhar, 2020) were used for treatment.

Optimum dosage of sawdust ash and induction furnace slag:

In order to obtain the optimum dosage of sawdust ash and Induction furnace slag, first, the black cotton soil was mixed with sawdust ash alone in percentages ranging from 4 % up to 12 % of the dry weight of the soil, and the samples obtained subjected to compaction, California Bearing Ratio (CBR), and Unconfined Strength (UCS) Tests. The optimum content of sawdust ash was chosen based on the maximum CBR and UCS values. Then the soil was mixed with the chosen optimum amount of sawdust ash and 5 %, 10 %, 15 %, and 20 % of induction furnace slag and specific gravity test, Atterberg limit test, standard proctor tests, CBR, and UCS tests were carried out. Then the optimum proportion of sawdust ash and induction furnace slag was chosen based on the maximum CBR and UCS values. For different proportion of mixes, the additives were taken according to certain percentages by dry weight of soil for the ease of work and to get a precise result.

The common mix equation was used in this paper. For instance, a mix of black cotton soil, sawdust ash, induction furnace slag containing 87 % black cotton soil, 8 % sawdust ash and 5 % induction furnace slag is designated as 87 % soil + 8 % SDA+ 5 % IFS.

3.4 Test Procedures

To meet the objective of the study particle-size distribution, specific gravity test, Atterberg limit test, standard proctor tests, California Bearing Ratio test, and Unconfined Compressive Strength tests were carried out in accordance with ASTM D422, ASTM D854, ASTM D4318, ASTM D698, ASTM D1883 and ASTM D 2166-13, respectively.

3.4.1 Grain size analysis test

This test was performed using ASTM D 422 standard test method for particle – size analysis to determine the percentage of different grain sizes contained within a soil. The grain size was obtained from the wet sieve analysis and the hydrometer analysis and combined grain size distribution curve was plotted, The distribution of particle sizes larger than 75 μm (no. 200 sieve) is determined by wet sieve analysis while the distribution of particle size smaller than 75 μm determined by hydrometer analysis. For hydrometer analysis sodium hexametaphosphate ($NaPO_3$) was used as a dispersing agent. After complete particle size analysis the proportion of different size groups were determined.

3.4.2 Specific gravity test

Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of an equivalent volume of gas-free distilled water at the same temperature. The test gives an insight to how dense a soil sample is which in turn helps to distinguish between organic and inorganic soil. This test was performed for samples of induction furnace slag, sawdust ash and for both treated and untreated soil samples according to

ASTM D 854 test method. By taking a 10 gram of oven-dried soil samples and carefully put in the 100 ml pycnometer which is then half-filled with distilled water. The air entrapped in the sample is removed by heating. The bottle is then topped up with distilled water up to a calibration mark and brought up to a constant temperature after carefully wiped and dried it is weighed. The result is expressed mathematically as shown in Equation 3.1.

$$\boldsymbol{Gs} = \frac{(\boldsymbol{W2}-\boldsymbol{W1})}{[(\boldsymbol{W4}-\boldsymbol{W1})-(\boldsymbol{W3}-\boldsymbol{W2})]} \qquad \textbf{(3.1)}$$

Where: W1 = weight of density bottle, W2 = weight of bottle + soil,

W3 = weight of bottle + soil + water W4 = weight of bottle + water

3.4.3 Atterberg limit test

The test is a consistency limit identification test on the basis of moisture content. It includes the determination of the liquid limits and plastic limits for the natural soil and the soil-sawdust ash and induction furnace slag mixture. The tests were conducted in accordance with ASTM D4318 testing procedures. Soil sample used for liquid limit, plastic limit determination was oven-dried passed through No. 40 sieve (425μm) pass. about 100 gm of soil was mixed with distilled water into a uniform paste and placed on Casagrande's cup and leveled by standard grooving tool the soil sample was cut at the center, the handle was next turned at a rate of about two revolutions per second then the number of blows counted between 10 to 40 blows to close the groove and the water content near the closed groove is found out up to four trials the procedure was continued. Then after the graph of water content versus no of blows was plotted, the water content corresponding to 25 blows determined as a liquid limit. The same procedure is also carried out for the soil treated with varied contents of induction furnace slag and sawdust ash. And the plastic limit was determined by mixing the soil with water and rolling the soil up to 3 mm diameter; the procedure of mixing and rolling is repeated till the soil signs of crumbling when the diameter is 3 mm and the average water content of the crumbled portion of the thread was determined.

Figure 3. 7 Photographic views of plastic limit and liquid limit test

3.4.4 Compaction test

This test is aimed at determining the relationship between moisture content and dry density of soil for a specified compactive effort. Gradual increase in the volume of water added to any given soil at a specified compactive effort tends to remove the voids present in the soil sample there by increasing its dry density. This phenomenon continues and the density will attain its maximum value at particular water content before it starts to decrease with a further increase of the water content. That density and the corresponding moisture content are called Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). To evaluate these compaction characteristics, the soil samples in natural and treated states were compacted in accordance ASTM-D 698 compaction characteristics of soil using standard effort. All samples used for this study were air-dried passed through sieve number 4 (4.75 mm) sieve and mixed with a measured quantity of water and was compacted in the mold in three equal layer and each layer was compacted in 25 blows and the representative soil sample was taken to determine its water content. After the compaction process was completed the MDD and OMC were obtained from the dry density versus water content graph.

3.4.5 California Bearing Ratio (CBR) test

This test is an indirect way of measuring the shear strength of soil for use as subgrade or base material in flexible pavement construction. It involves measuring the resistance offered by the soil under controlled moisture content and density conditions to the penetration of a cylindrical plunger. The test was done for treated and untreated soil samples according to ASTM D1883.

Soil samples were compacted in the mold in three approximately equal layers and each layer subjected to 56 uniformly distributed blows at Maximum Dry Density (MDD) in accordance with ASTM D1883 and soaked for 4 days (96 hours). After 4 days of soaking, the samples were removed from the soaking tank, poured the water off the top, and allowed to drain downward for 15 minutes. The CBR mold along with the soaked soil sample was brought to a loading frame for testing. Then using the CBR test machine the load readings at penetrations of 0.64 mm, 1.27 mm, 1.91mm, 2.54 mm, 3.81mm, 5.08 mm, and 7.62 mm were taken.

Figure 3. 8 CBR samples in a soaking condition

Calculations

Stress-penetration curve: calculate the penetration stress (dividing the load by the plunger area) and plot the stress penetration curve.

Bearing ratio: the bearing ratio can be obtained using stress values taken from the stress penetration curve for 2.54 mm and 5.08 mm penetration. The bearing ratio is calculated by dividing the corrected stress values at 2.54 mm and 5.08 mm by the standard stresses of 13.2 MPa and 20 MPa respectively and multiplying by 100. But the CBR is selected at 2.54 mm penetration. If the ratio at 5.08 mm penetration is greater, rerun the test. If the check test gives a similar result, the ratio at 5.08 mm is used. Then the CBR value calculated as shown in Equation 3.2.

$$CBR\ (\%) = (Test\ load/Standard\ load) \times 100 \qquad (3.2)$$

3.4.6 Unconfined Compressive Strength (UCS) test

The test is used to determine the compressive strength of soil in an unconfined state which in turn is used to calculate the unconsolidated undrained shear strength of cohesive soil. The unconfined compressive strength (qu) of a soil specimen is the ratio of failure load to the cross-sectional area of the specimen at failure when it is not subjected to any confining pressure.

Unconfined compressive strength (UCS) tests were carried out for both treated and untreated soil samples in accordance with ASTM D2166. All samples used for this test were prepared passing through 4.75 mm sieve and remolded by compacting them in three approximately equal layers and each layer subjected to 5 blows at maximum dry density.

Figure 3. 9 UCS specimens after testing until failure

CHAPTER FOUR
RESULTS AND DISCUSSIONS

In this chapter, the result of laboratory tests conducted to evaluate the effects of sawdust ash and induction furnace slag on the specific gravity, liquid limit, plastic limit, Optimum Moisture Content (OMC), Maximum Dry Density (MDD), California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) of black cotton soils collected from both locations i.e. Test pit 1(TP-1) and Test pit 2 (TP-2) are discussed briefly and the results of natural soil samples are compared with the results of the mixture of soil, sawdust ash, and induction furnace slag. Tabular and graphical analyses were adopted to determine whether stabilization has an effect on these properties of the samples. With refined samples used in the laboratory, clear effects are identified. The graphical and tabular interpretations were performed by means of Originpro software and the numerical analysis of cost comparisons was performed using Microsoft Excel software.

4.1 Grain Size Analysis Test Results

The grain size analysis test was performed in accordance to ASTM D 422 standard test method. Table 4.1 shows the proportion of different size groups and grain size distribution curve of TP-1 and TP-2soil samples that were determined from this test. The detailed laboratory test analyses are given in Appendix A.

Table 4.1 Particle size proportion of TP-1 and TP-2 soils

Particle size	TP-1	TP-2
Clay	59.76	66.03
Silt	34.1	28.16
Sand	5.03	5.06
Gravel	1.10	0.76

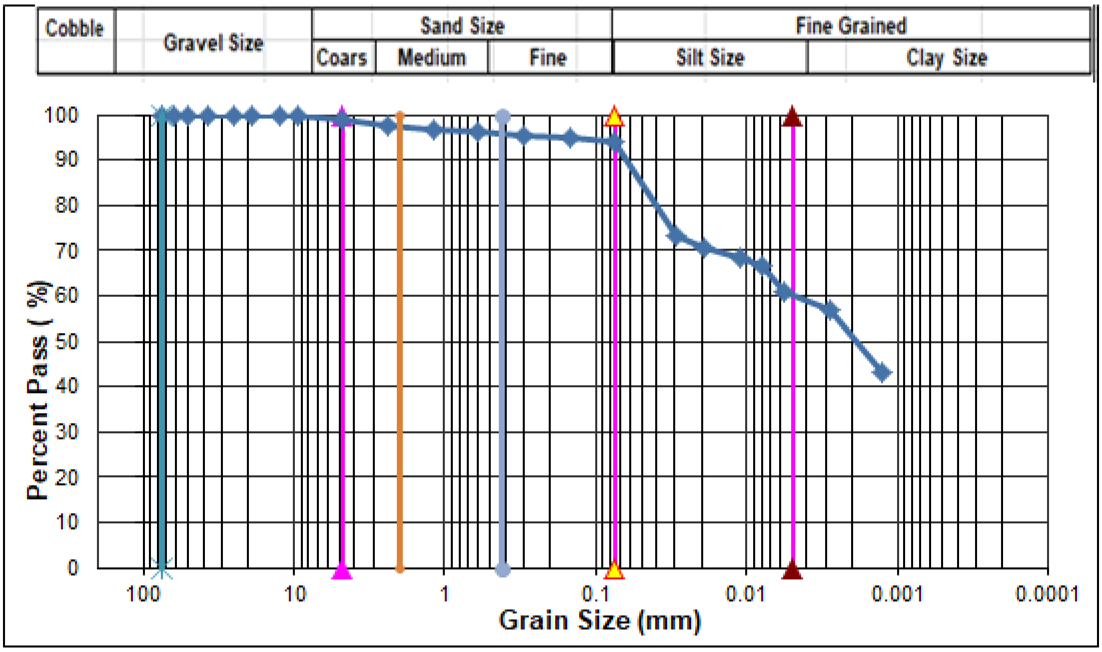

Figure 4. 1 Particle size distribution curve for TP-1

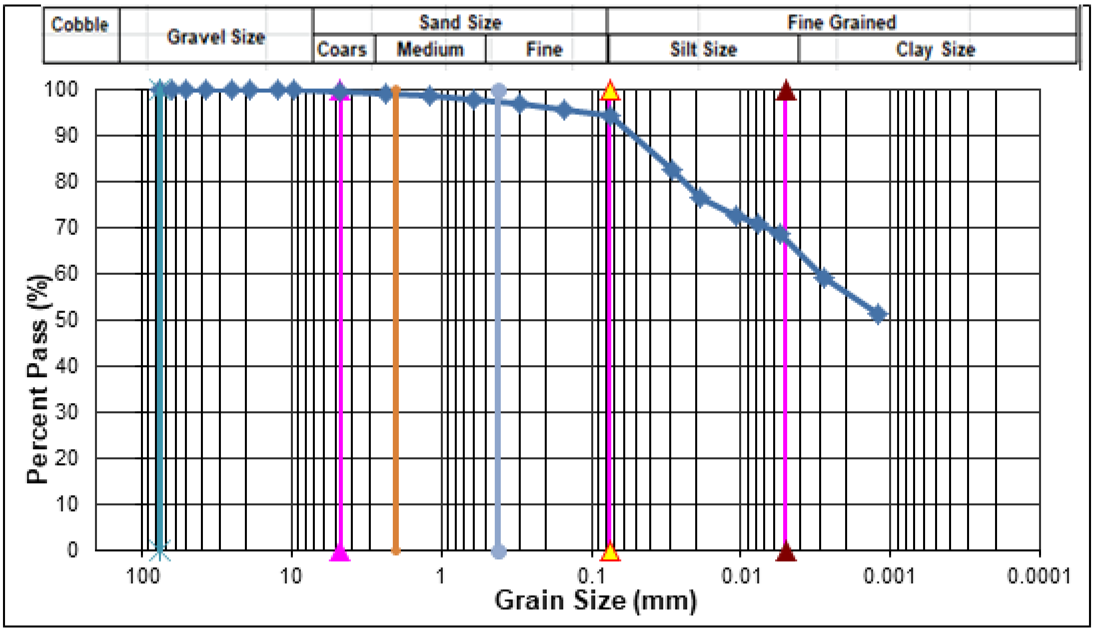

Figure 4. 2 Particle size distribution curve for TP-2

Particle size distribution test on natural samples revealed that for ,Test pit 1 (TP-1) and , Test pit 2 (TP-2) contain clay content 59.79 % and 66.03 %, silt fraction 34.1 % and 28.16 %, sand fraction 5.03 % and 5.06 % and gravel 1.10 % and 0.76 % respectively. The combined wet sieve and hydrometer test curve indicates both soil samples contain more than 50 % clay soil fractions. The curve and the amount of clay contents satisfy the requirement for fine-grained soils according to both ASHTO and USC systems for fine particle specifications.

4.2 Optimum Sawdust Ash Content

The results of the tests carried out on the soil samples mixed with different proportions of sawdust ash are given in Table 4.2 The addition of sawdust ash in percentages ranging from 4 % to 12 % decrease the maximum dry density from 1.286 to 1.22 for TP-1 and from 1.275 to 1.19 for TP-2. The addition of 8 % sawdust ash resulted in an increase in the CBR value from 0.89 % to 1.52 % for TP-1 and from 1.24 to 2.13 for TP-2. Also, increase the UCS value from 276.17 to 286.93 and 333.51 to 359.09 for TP1- and TP-2 respectively. However, a further increase in sawdust ash content to 12 % resulted in a reduction of the UCS and CBR values. Therefore 8 % of sawdust ash content by dry weight of the soil was taken as an optimum amount. Detailed discussions of the results are made in sections 4.5.2, 4.6.2, and 4.7.2.

Table 4.2 Summary of soil properties as a result of sawdust ash addition

Soil + Sawdust ash (SDA) Mix						
TP-1						
Samples	**OMC**	**MDD**	**CBR**	**CBR Swell**	**UCS**	**Remark**
100 % soil + 0 % SDA	26	1.286	0.89	7.09	276.17	
96 % soil + 4 % SDA	27.1	1.27	1.06	6.98	286.93	
92 % soil + 8 % SDA	29	1.26	1.52	6.05	306.61	Optimum
88% soil + 12 % SDA	33	1.22	1.42	6.06	290.03	
TP-2						
Samples	**OMC**	**MDD**	**CBR**	**CBR Swell**	**UCS**	**Remark**
100 % soil + 0 % SDA	27	1.275	1.24	6.18	333.51	
96 % soil + 4 % SDA	33.5	1.258	1.77	6.09	340.73	
92 % soil + 8 % SDA	34.5	1.245	2.13	5.83	359.09	Optimum
88 % soil + 12 % SDA	38	1.19	1.42	5.96	198.83	

4.3 Specific Gravity Test Results

The specific gravity of the solid matter in a soil particle may be defined as the ratio of the unit weight of solid matter to the unit weight of water. The specific gravity was determined in the laboratory for natural black cotton soil and treated black cotton soil with optimum sawdust ash content and different contents of induction furnace slag according to ASTM D 854. The results obtained for both natural soil and soil treated with sawdust ash and induction furnace slag are presented and discussed in the following sections. The detailed laboratory test analyses are given in Appendix B.

4.3.1 Specific gravity results for natural black cotton soils

The specific gravity of the natural black cotton soils was found to be 2.586 and 2.521 for Test pit 1 (TP-1) and Test pit 2 (TP-2) respectively as shown in Table 4.3.

4.3.2 Specific gravity results for black cotton soils treated with sawdust ash and induction furnace slag

Variation of specific gravity of TP-1 and TP-2 soils with the addition of optimum of 8 % sawdust ash and varying amounts of induction furnace slag ranging from 5% to 20 % are illustrated in Figure 4.3.

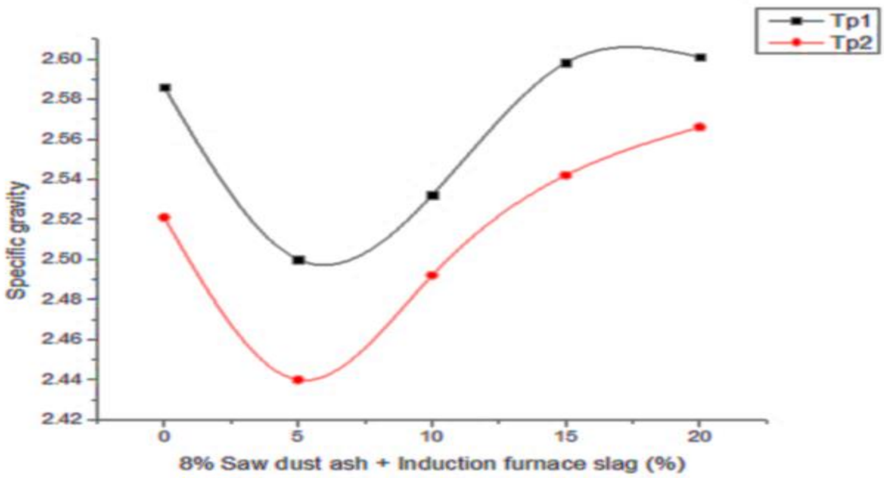

Figure 4. 3 Variation of specific gravity with 8 % sawdust ash and varying induction furnace slag contents for TP-1 and TP-2 sample

As shown in Figure 4.3 the specific gravity of both TP-1 and TP-2 soils decreased with the addition of 5 % induction furnace slag and 8 % sawdust ash then it starts to increase with the addition of 10 % induction furnace slag and 8 % sawdust ash and continued to peak values of 2.601 and 2.566 for both TP-1 and TP-2 soil samples respectively at 20 % induction furnace slag addition.

Table 4.3 Summary of specific gravity results

Sample designations	TP-1	TP-2
	Specific gravity	Specific gravity
100 % Soil	2.586	2.521
87 % Soil + 8 % SDA + 5 % IFS	2.5	2.44
82 % Soil + 8 % SDA + 10 % IFS	2.532	2.492
77 % Soil + 8 % SDA + 15 % IFS	2.598	2.542
72 % Soil + 8 % SDA + 20 % IFS	2.601	2.566

4.4 Atterberg Limit Test Results

The Atterberg limits are basic measures of the critical water contents of fine-grained soil. Plastic limits, liquid limits, and plastic index of soil samples of Test pit 1 (TP-1) and Test pit 2 (TP-2) were determined in accordance with ASTM D4318. The results obtained for both natural soil and soil treated with sawdust ash and induction furnace slag are presented and discussed below. The summary of the test results is shown in Table 4.4 and the detailed laboratory test analyses are given in Appendix C.

4.4.1 Atterberg limit results for natural black cotton soils

The liquid limit, Plastic limit, and plastic index of natural soil samples are found to be 89.28 %, 45.89 %, and 43.39 % respectively for Test pit 1 (TP-1) and 83.12 %, 41.51 %, and 41.61 % respectively for Test pit 2 (TP-2). The plastic limit values of 45.89 % and 41.51 % are evidence of the high plasticity of the soils. Both soil samples fail under the A-7-5 soil class based on the AASHTO soil classification system which has poor subgrade material property.

4.4.2 Atterberg limit results for black cotton soils treated with sawdust ash and induction furnace slag

Liquid limit, plastic limit, and plastic index results for Test pit 1 (TP-1) and Test pit 2 (TP-2) black cotton soils treated with 8 % sawdust ash and varying percentages of induction furnace slag are shown below in Figures 4.4 and 4.5.

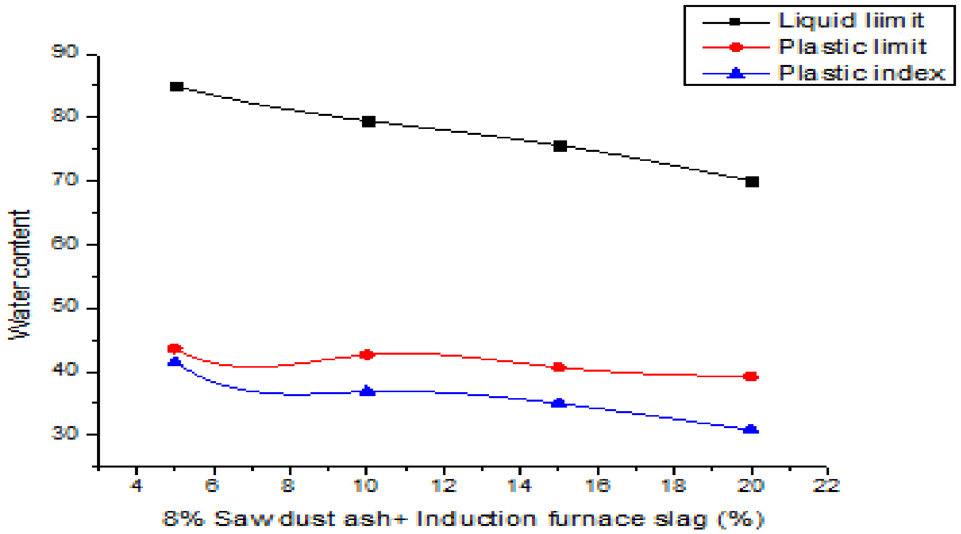

Figure 4. 4 Atterberg limit results for TP-1 black cotton soil stabilized with 8 % sawdust ash and varying percentages of induction furnace slag

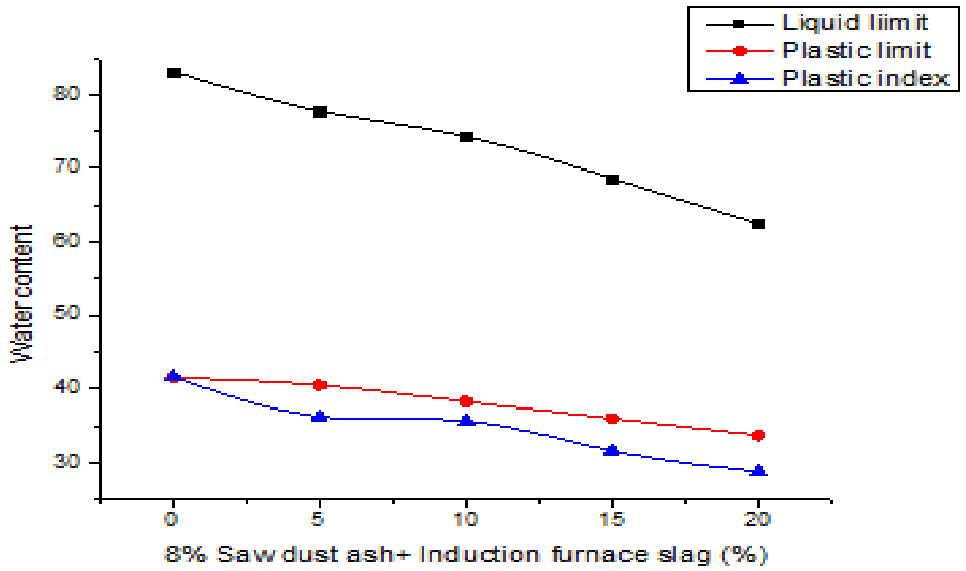

Figure 4. 5 Atterberg limit results for TP-2 black cotton soil stabilized with 8 % sawdust ash and varying percentages of induction furnace slag

As shown in the above figures the reduction in LL, PL, and PI value is directly proportional to the quantity of sawdust ash and induction furnace slag increment. The highest reduction in PI value is attained when the black cotton soil is treated with 8 % sawdust ash and 20 % induction furnace slag which is about 29 % and 31 % reduction when compared to the untreated soil for TP-1 and TP-2 soil samples respectively. The decline in percentage may be due to the non-plastic properties of sawdust ash and induction furnace slag.

Table 4.4 Summary of Atterberg limit results

Sample	TP-1			TP-2		
	LL	PL	PI	LL	PL	PI
100 % Soil	89.28	45.89	43.39	83.12	41.51	41.61
87 % Soil + 8 % SDA + 5 % IFS	84.97	43.57	41.4	7.77	40.47	36.3
82 % Soil + 8 % SDA + 10 % IFS	79.47	42.65	36.82	74.28	38.27	36.01
77 % Soil + 8 % SDA + 15 % IFS	75.61	40.65	34.96	68.63	36.02	32.61
72 % Soil + 8 % SDA + 20 % IFS	70.03	39.21	30.81	62.52	33.73	28.79

4.5 Compaction Test Results

Compaction properties i.e. maximum dry density (MDD) and optimum moisture content (OMC) were determined in the laboratory of all trial mixtures in accordance with ASTM-D 698. The summary of the test results are given in Table 4.5 and detailed laboratory test analyses are given in Appendix D.

4.5.1 Compaction results for natural black cotton soils

The compaction results for 100 % black cotton soil shown in Figure 4.6 indicate that the optimum moisture content of TP-1 black cotton soil was 26 % and the maximum dry density was 1.286 g/cm^3 while the optimum moisture content of TP-2 black cotton soil was 27 % with a maximum dry density (MDD) of 1.275 g/ cm^3.

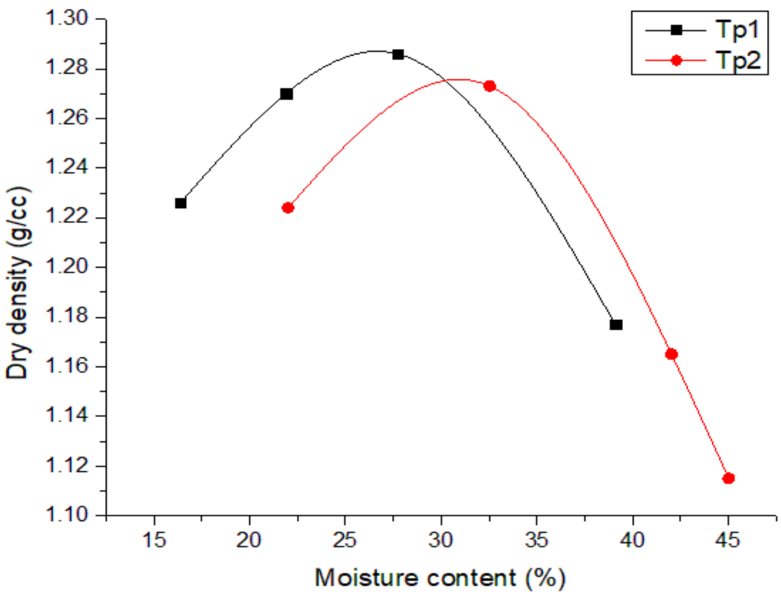

Figure 4. 6 compaction curves for TP-1 and TP-2

4.5.2 Compaction results for black cotton soils treated with sawdust ash

The compaction curves obtained from the addition of varying percentages of sawdust ash for both test pits are shown in Figures 4.7 and 4.8.

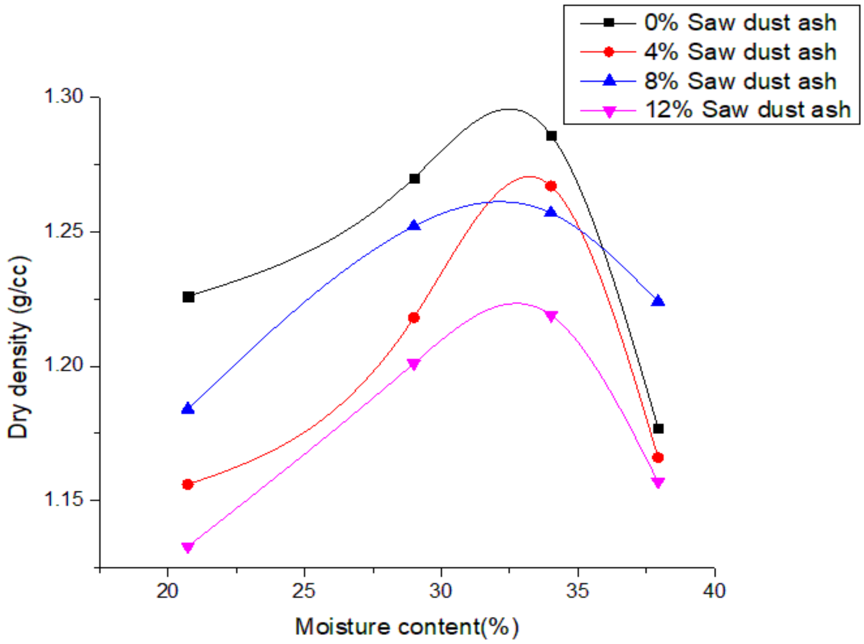

Figure 4. 7 Variation of MDD and OMC for TP-1 black cotton soil treated with varying percentages of sawdust ash

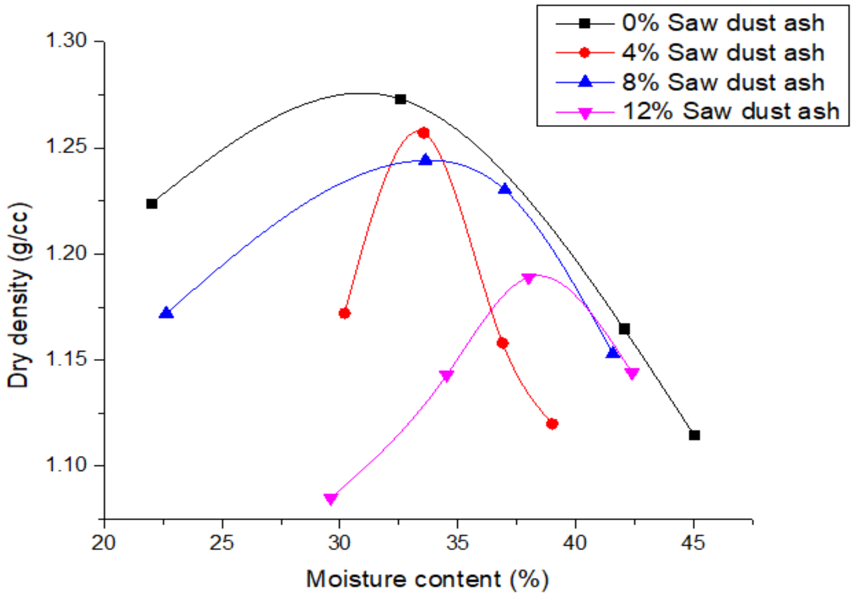

Figure 4. 8 Variation of MDD and OMC for TP-2 black cotton soil treated with varying percentages of sawdust ash

The curves show that Optimum Moisture Content (OMC) increased with the increment of sawdust ash content whereas the Maximum Dry Density (MDD) decreases with an increase in sawdust ash content. A similar trend was observed by (Butt, 2016; Ikeagwuani, 2016). A decrease in the dry unit weight may be due to the lower specific gravity of the sawdust ash, while an increase in the optimum moisture content may be as a result of water needed to be hydrated.

4.5.3 Compaction results for black cotton soils treated with sawdust ash and induction furnace slag

The combined effect of sawdust ash and induction furnace slag on the maximum dry density of both samples calculated by taking the optimum percentage of sawdust ash i.e. 8 % and blending it with different percentages of induction furnace slag from (5 % - 20 %). The compaction curves obtained from the addition of 8 % sawdust ash and varying percentages of induction furnace slag for both test pits are shown in Figures 4.9 and 4.10.

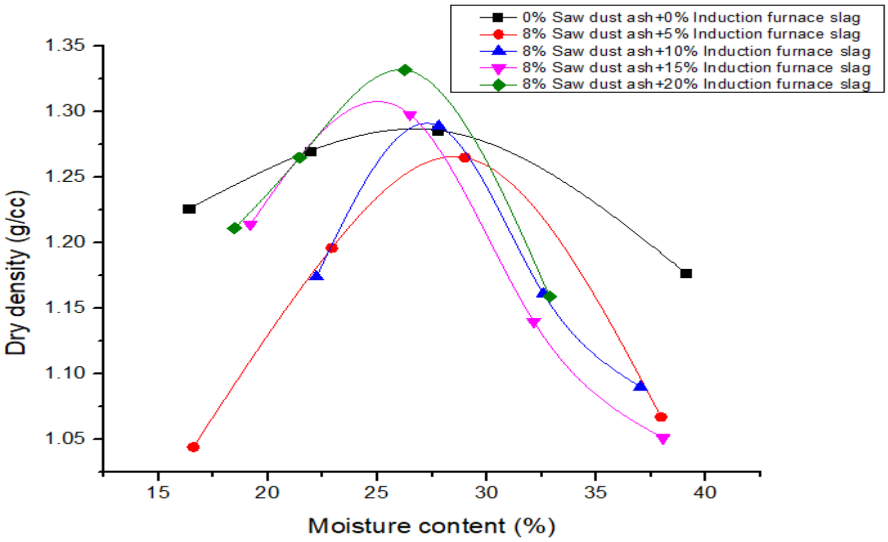

Figure 4. 9 Variation of MDD and OMC for TP-1 black cotton soil treated with 8 % sawdust ash and varying percentages of induction furnace slag

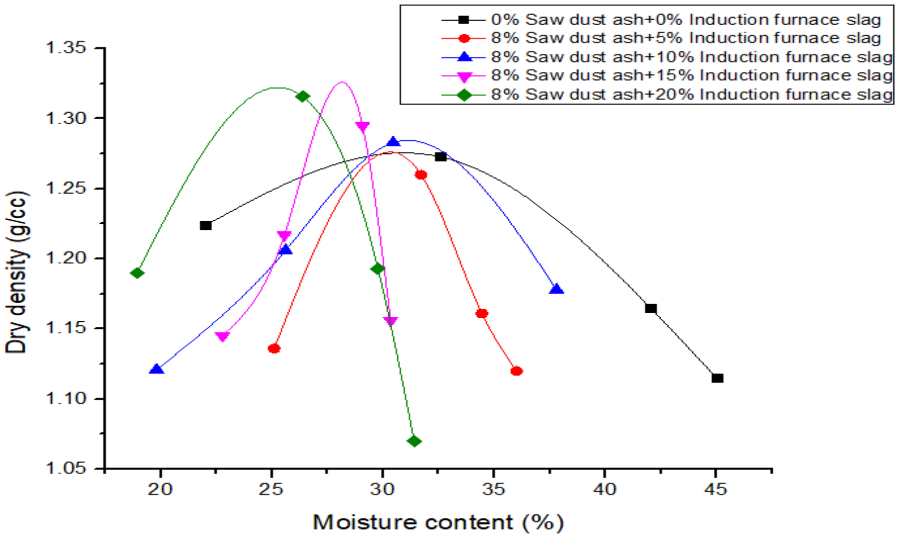

Figure 4. 10 Variation of MDD and OMC for TP-1 black cotton soil treated with 8 % sawdust ash and varying percentages of induction furnace slag

The compaction curves in the above figures show that MDD decrease up to the addition of 8 % sawdust ash and 5 % induction furnace slag then increases with the addition of 10 % induction furnace slag and continued to increase to peak values of 1.335 g/cm^3 and 1.315g/cm^3 for TP-1 and TP-2 respectively at 8 % sawdust ash and 20 % induction furnace slag addition. The reduction in MDD may be due to the effect of lightweight behavior of sawdust ash overtaking when the addition of 8 % sawdust ash and 5 % induction furnace slag and the increment after addition of 10 % induction furnace slag is due to increment of slag content which has relatively higher specific gravity and decreases in clay content of the soil with increased additions of induction furnace slag.

Table 4.5 Compaction test results summary

Percentage	TP-1		TP-2	
	OMC	MDD	OMC	MDD
100 % soil	26	1.286	27	1.275
96 % soil + 4 % SDA	27.1	1.27	33.5	1.258
92 % soil + 8 % SDA	29	1.26	34.5	1.245
88 % soil + 12 % SDA	33	1.22	38	1.19
87 % Soil + 8 % SDA + 5 % IFS	28	1.27	31.7	1.26
82 % Soil + 8 % SDA + 10 % IFS	27.81	1.29	30	1.284
77 % Soil + 8 % SDA + 15 % IFS	26.4	1.299	29	1.299
72 % Soil + 8 % SDA + 20 % IFS	25.5	1.335	26.5	1.315

4.6 California Bearing Ratio (CBR) Test Results

CBR test has been done for all samples to determine the strength character of the treated and untreated black cotton soils. The summary of the test result is tabulated below in Table 4.6 and the laboratory test analyses are given in Appendix E

4.6.1 CBR results for natural black cotton soils

Figure 4.11 shows CBR test results of natural black cotton soils. The soaked CBR values of natural soils were 0.89 % and 1.24 % for TP-1 and TP-2 soil samples respectively. According to (ERA, 2013a) the minimum recommended CBR value for sub-grade material is 2 %. This implies that unless they are treated both soil samples cannot be used as subgrade materials since their CBR value is less than the minimum requirement.

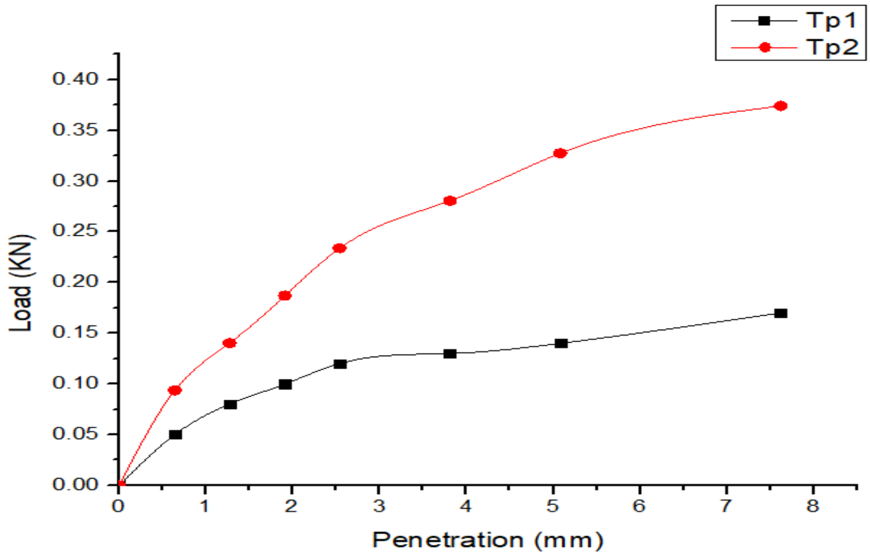

Figure 4. 11 CBR test results for TP-1 and TP-2 natural black cotton soils

4.6.2 CBR results for black cotton soils treated with sawdust ash

The soaked California Bearing Ratio (CBR) test results of soil samples treated with varying percentages of sawdust ash are shown in Figures 4.12 and 4.13 for both soil samples collected from TP-1 and TP-2 respectively and also the variations of CBR values with different percentage of soil and sawdust ash combinations are shown in Figure 4.14.

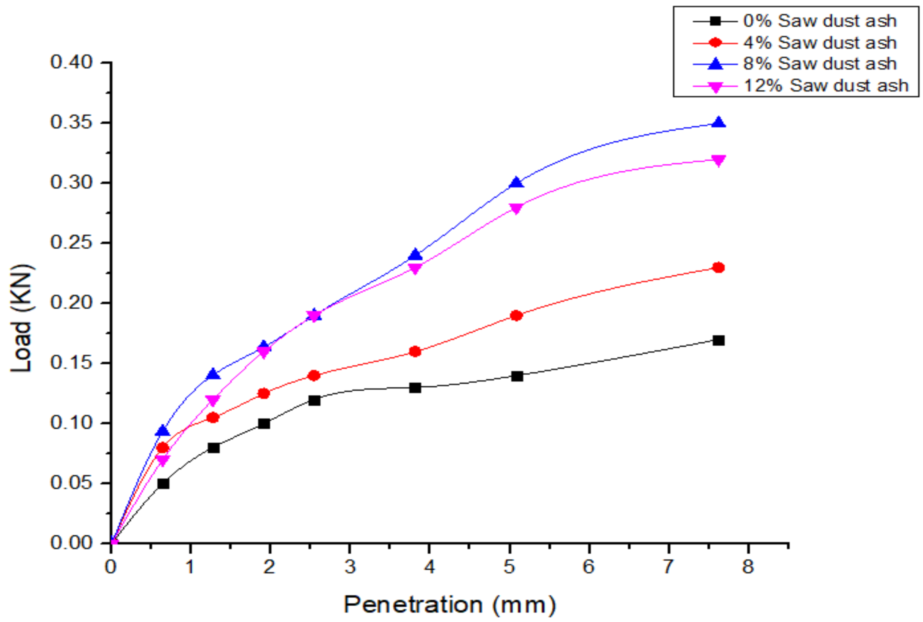

Figure 4. 12 CBR test results for TP-1 black cotton soil treated with varying percentages of sawdust ash

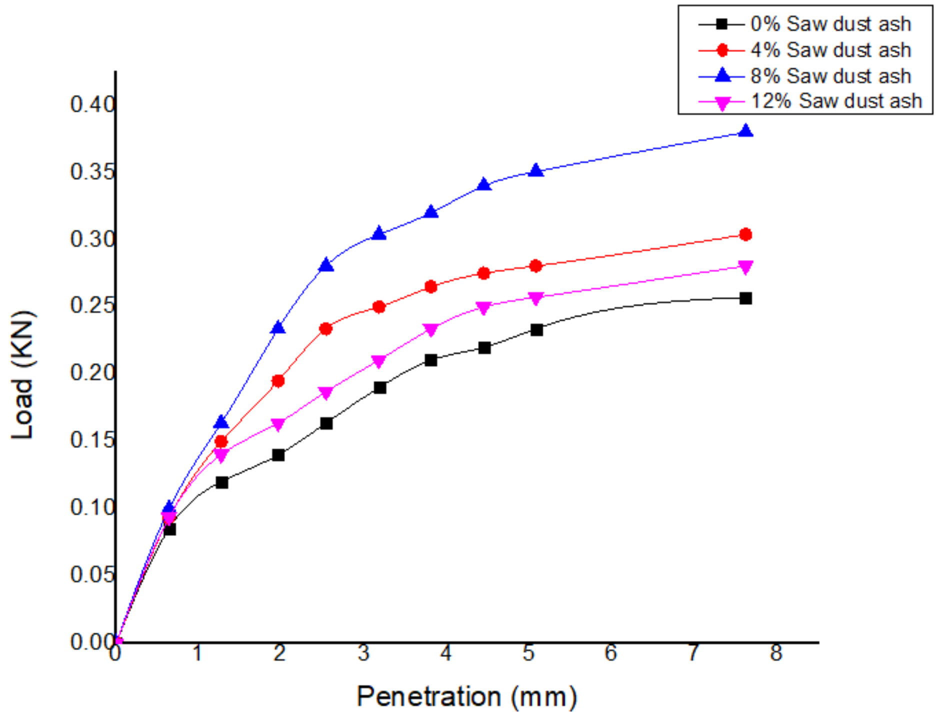

Figure 4. 13 CBR test results for TP-2 black cotton soil treated with varying percentages of sawdust ash

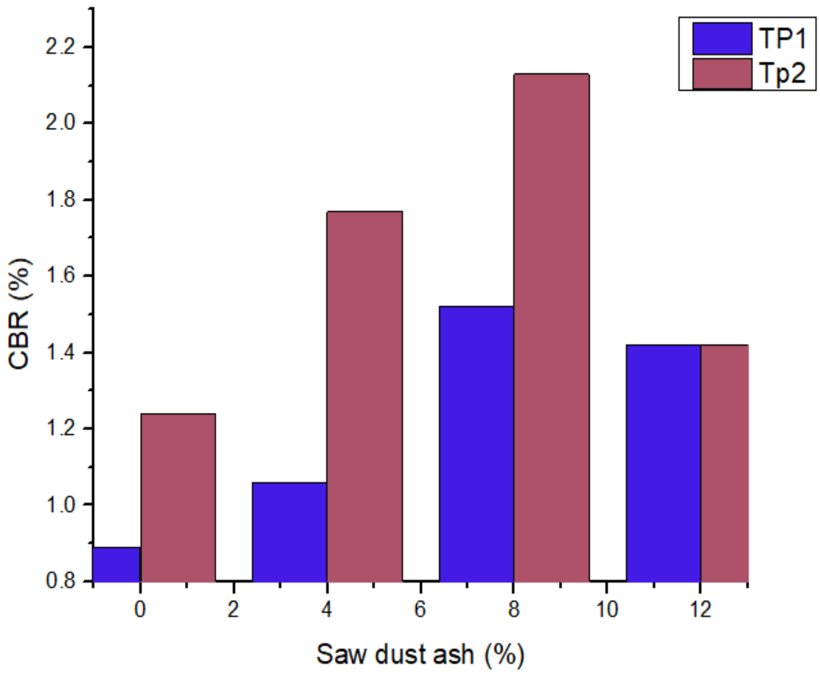

Figure 4. 14 Variation of CBR value with sawdust ash content

As shown in Figure 4.14 increment in CBR value was observed with the addition of sawdust ash content up to 8 % then it became decrease. The peak values were 1.52 % and 2.13 % CBR values at 8 % sawdust ash content for TP-1 and TP-2 respectively.

4.6.3 CBR results for black cotton soils treated with sawdust ash and induction furnace slag

The California Bearing Ratio (CBR) tests were done by the addition of different percentage of induction furnace slag on soils treated with 8 % sawdust ash. The test results are shown in Figures 4.15 and 4.16 for both soil samples collected from TP-1 and TP-2 respectively. The variations of CBR values with the addition of different percentage of induction furnace slag on soil and sawdust ash combination is shown in Figure 4.17.

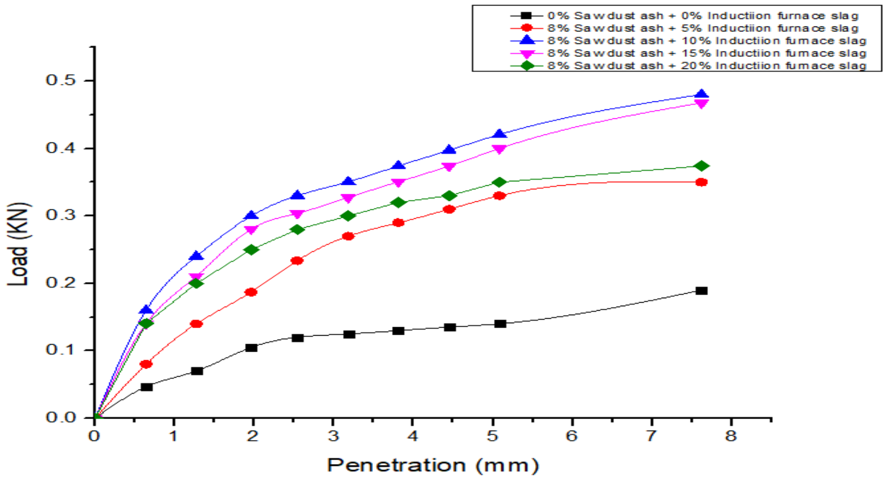

Figure 4. 15 CBR result for TP-1 black cotton soil treated with optimum sawdust ash and varying percentages of induction furnace slag

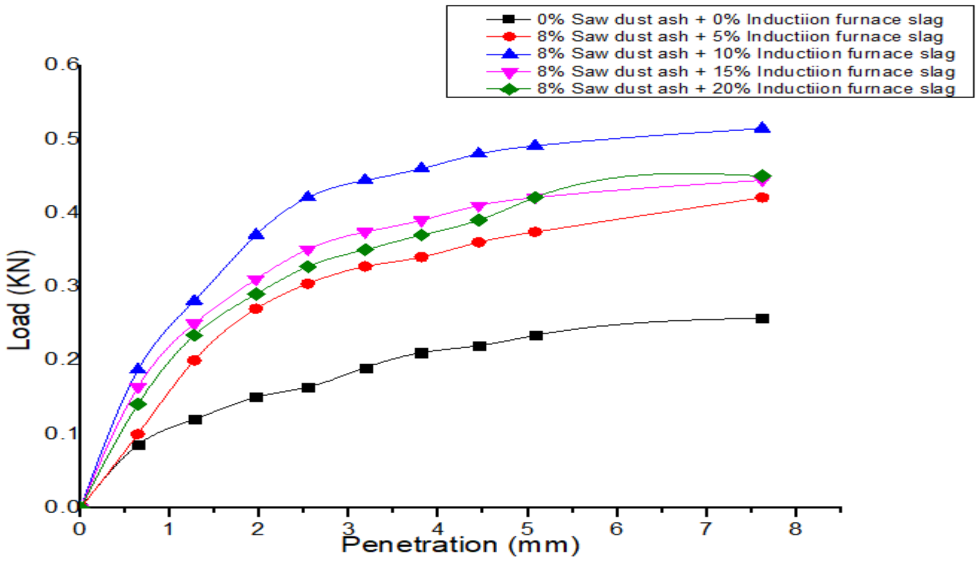

Figure 4. 16 CBR result for TP-2 black cotton soil treated with optimum sawdust ash and varying percentages of induction furnace slag

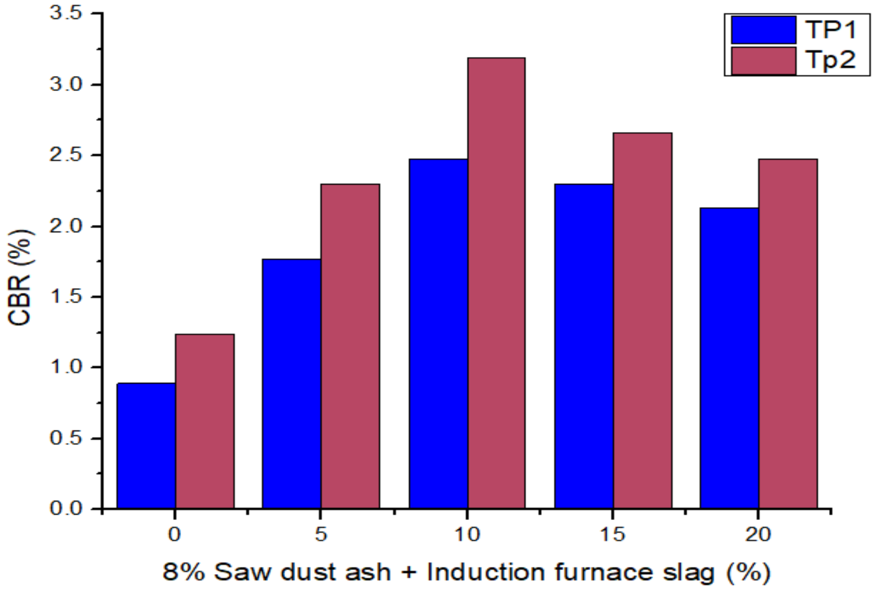

Figure 4. 17 Variations of CBR values with the addition of different percentage of induction furnace slag on soil and saw a dust ash combination

Similar trends were noted in the results for both soil samples. It is clear from the test result that the CBR value of soil increases as the induction furnace slag content increases up to 10 % after that it starts decreasing. The addition of 10 % induction furnace slag to the sawdust ash- black cotton soil mixture resulted in a higher CBR value than that obtained from the combination of sawdust ash and black cotton soil only. The resultant increases in CBR from natural soil are 178.7 % and 157.3 % for TP-1 and TP-2 soil samples respectively. The increment in CBR can be attributed to the pozzolanic effect of induction furnace slag and sawdust. The gradual decrease in CBR after 10 % induction furnace slag may be due to excess induction furnace slag which consequently occupies space within the sample and reduce the bond in soil-sawdust ash and induction furnace slag mix.

Table 4.6 CBR test result summaries

Percentage	TP-1		TP-2	
	CBR	**CBR swell**	**CBR**	**CBR swell**
100 % soil	0.89	7.09	1.24	6.18
96 % soil + 4 % SDA	1.06	6.98	1.77	6.09
92 % soil + 8 % SDA	1.52	6.05	2.13	5.83
88 % soil + 12 % SDA	1.42	6.06	1.42	5.96
87 % Soil + 8 % SDA + 5 % IFS	1.77	5.92	2.3	5.66
82 % Soil + 8 % SDA + 10 % IFS	2.48	5.73	3.19	5.39
77 % Soil + 8 % SDA + 15 % IFS	2.3	5.57	2.66	4.94
72 % Soil + 8 % SDA + 20 % IFS	2.13	5.46	2.48	4.79

4.7 Unconfined Compression Strength (UCS) Test Results

Unconfined Compression Strength (UCS) is taken as the maximum load attained per unit area during loading. The shear strength was calculated to be half of the compressive stress at failure. The UCS tests were performed according to ASTM Standard D2166 on both un-stabilized and stabilized soil materials which are blended at different ratios. The summary of the UCS test result is tabulated in Table 4.7 and the laboratory test analyses are given in Appendix F.

4.7.1 UCS results for natural black cotton soils

Unconfined compressive strength (UCS) test results for natural black cotton soil are shown in Figure 4.18. This figure illustrates the stress-strain behaviors of untreated soil samples. The UCS values of natural soil samples were found to be 276.17 KN/m^2 with a cohesion of 138.085 KN/m^2 and 333.51 KN/m^2 with the cohesion of 166.755 KN/m^2 for TP-1 and TP-2 respectively. Therefore according to (Arora, 2004), both soils are very stiff clays.

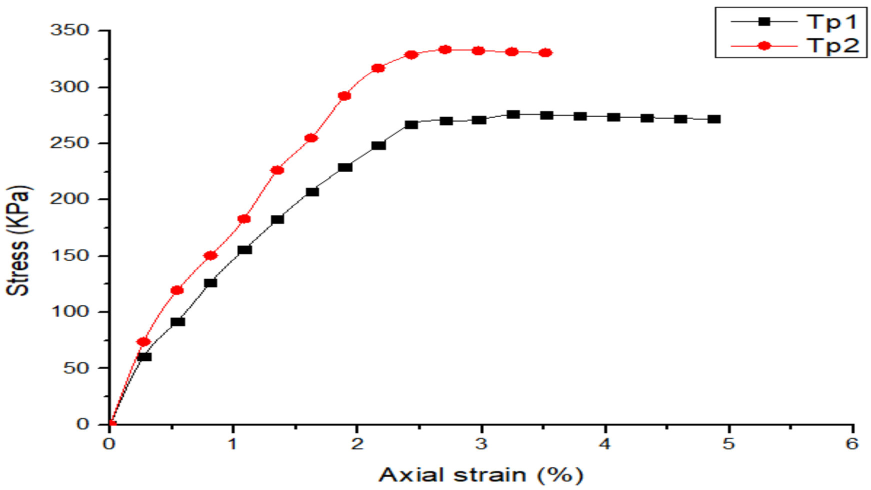

Figure 4. 18 UCS stress-strain curve for TP-1 and TP-2 natural black cotton soil

4.7.2 UCS results for black cotton soils treated with sawdust ash

The stress-strain behavior of sawdust ash treated soils of TP-1 and TP-2 are illustrated in Figures 4.19 and 4.20. The maximum UCS value of 306.61 KN/m^2 and 359.09 KN/m^2 for TP-1 and TP-2 soil samples respectively is found to occur with the combination of 8 % sawdust ash contents.

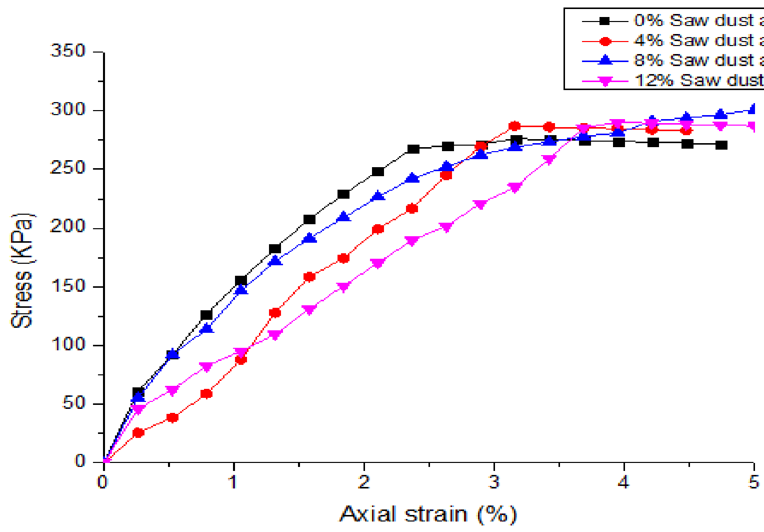

Figure 4. 19 UCS stress-strain curve for TP-1 black cotton soil treated with varying percentages of sawdust ash

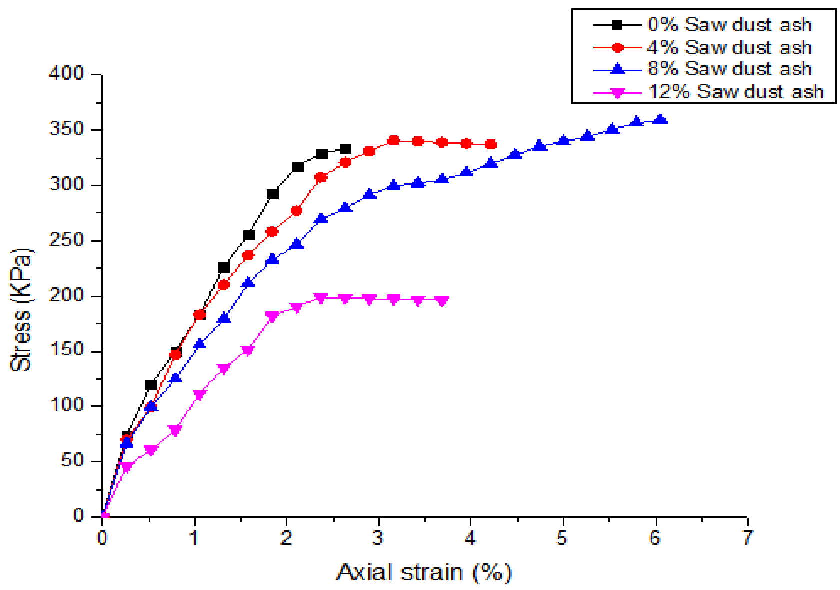

Figure 4. 20 UCS stress-strain curve for TP-2 black cotton soil treated with varying percentages of sawdust ash

4.7.3 UCS results for black cotton soils treated with sawdust and induction furnace slag

Figures 4.21 and 4.22 show the stress-strain behavior of TP-1 and TP-2 black cotton soils after stabilizing with the optimum of 8 % sawdust ash and various percentages of induction furnace slag ranging from 5 % to 20 % respectively. The variation of Unconfined Compression Strength (UCS) for soil at different percentages of induction furnace slag and 8 % sawdust ash is also shown in Figure 4.23.

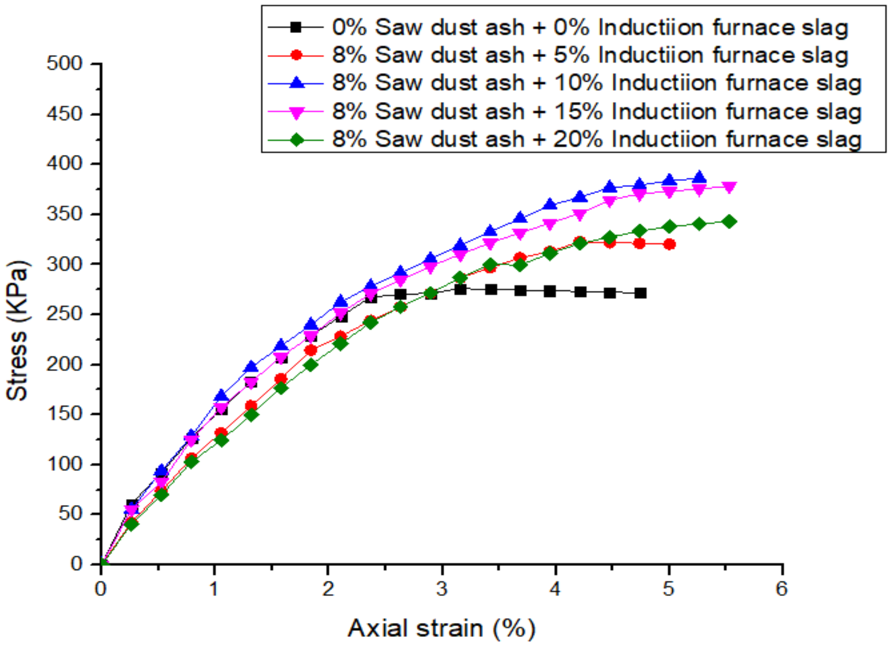

Figure 4. 21 UCS stress-strain curve for TP-1 black cotton soil stabilized with 8 % sawdust ash and varying percentages of induction furnace slag

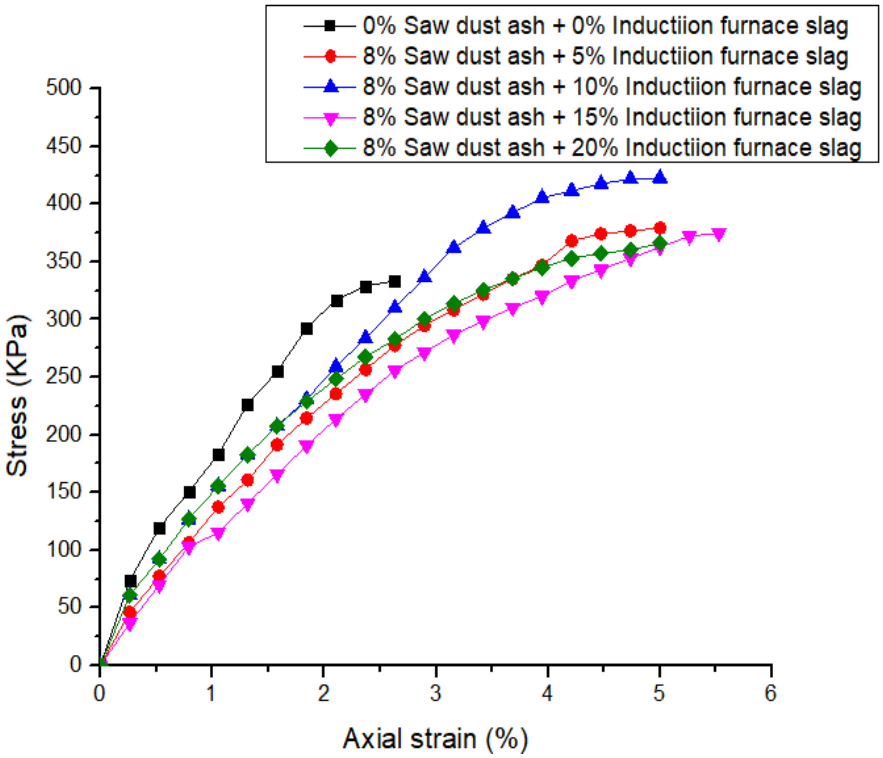

Figure 4. 22 UCS stress-strain curve for TP-2 black cotton soil stabilized with 8 % sawdust ash and varying percentages of induction furnace slag

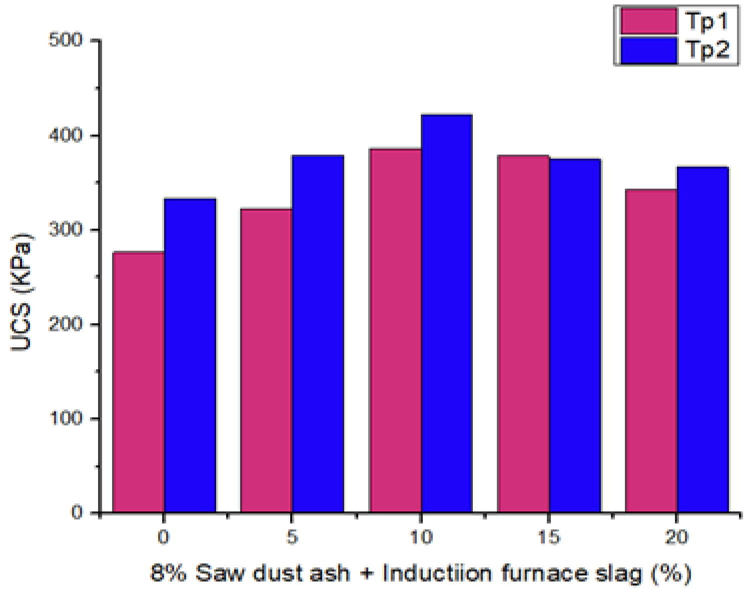

Figure 4. 23 Variation of UCS with 8 % sawdust ash and induction furnace slag content for TP-1 and TP-2

There was a sharp increase in the UCS with the addition of induction furnace slag when compared to the UCS of natural soil. The UCS value further increased with the addition of induction furnace slag into soil - sawdust ash mix to its maximum at 10 % and it drops. The resultant increase in UCS value at 10 % is 40 % and 26.7 % for TP-1 and TP-2 respectively and would be more if cured.

Based on the UCS values, the consistency of a clayey soil can be determined as follows : 0–25 KN/m^2 indicates very soft, 25–50 KN/m^2 is soft, 50–100 KN/m^2 is medium soft, 100–200 KN/m^2 is stiff, 200–400 KN/m^2 is very stiff and greater than 400 KN/m^2 indicates hard clay (Arora, 2004; Butt, 2016). All treated samples fall under very stiff clay except TP-2 soil treated with 8 % sawdust ash and 10 % induction furnace slag which fall under hard clay.

Table 4.7 UCS test result summaries

Percentage	**TP-1**		**TP-2**	
	UCS (KN/m^2)	**Cu (KN/m^2)**	**UCS (KN/m^2)**	**Cu (KN/m^2)**
100 % soil	276.17	138.085	333.51	166.755
96 % soil + 4 % SDA	286.93	143.465	340.73	170.365
92 % soil + 8 % SDA	306.61	153.305	359.09	179.545
88 % soil + 12 % SDA	290.03	145.015	198.83	99.415
87 % Soil + 8 % SDA + 5 % IFS	323	161.5	379.41	189.705
82 % Soil + 8 % SDA + 5 % IFS	386.44	193.22	422.65	211.325
77 % Soil + 8 % SDA + 10 % IFS	378.44	189.22	374.94	187.47
72 % Soil + 8 % SDA + 15 % IFS	343.40	171.70	366.3	183.15

4.8 Comparative Analysis of the Properties of Unstabilized and Stabilized Black Cotton Soil

The Atterberg limits test result shows that liquid limit and plastic limit of TP-1 and TP-2 natural soil samples are found to be 89.28 %, 45.89 %, and 83.12 %, 41.51 % respectively. The test results show that the soils of the study area are highly plastic with plasticity indexes of 43.39 % and 41.61 % for TP-1 and TP-2 respectively.

The results of black cotton soils stabilized with 8 % sawdust ash and black cotton soil stabilized with the combination of optimum 8 % sawdust ash and 10 % induction furnace slag are discussed in the previous section. As shown from these results the liquid limit of the black cotton soils decreased from 89.28 % to 70.03 % and from 83.12 % to 62.52 % for TP-1 and TP-2 black cotton soils respectively with the addition of 8 % sawdust ash and 20 % induction furnace slag, which is a reduction of about 22 % and 25 % respectively.

The plastic limit decreased by 14.55 % and 18.74 % when 8 % sawdust ash and 20 % induction furnace slag were added. This is due to the non-plastic properties of sawdust ash and induction furnace slag and the number of fine particles present in clay soil decreased by the addition of sawdust ash and induction furnace slag. Similarly, the plasticity index of both test pits decreased from 43.39 % to 36.82 % and from 41.61 % to 36 % on the addition of 8 % sawdust ash and 10 % induction furnace slag and further decreased to 30.81 % and 28 % when additional 10 % induction furnace slag was added.

The specific gravity, which was determined using the pycnometer method, drops from an initial value of 2.586 and 2.521 in the TP-1 and TP-2 natural black cotton soil to a value of 2.532 and 2.492 respectively when 8 % sawdust ash and 10 % induction furnace slag were added but it improved to 2.601 and 2.566 for TP-1 and TP-2 respectively when 10 % induction furnace slag was further added to the sample. This may be due to relatively higher unit weight of induction furnace slag.

The Optimum Moisture Content (OMC) for the TP-1 100 % black cotton soil was found to be 26 % but this increased to 29 % when 8 % sawdust ash was added and decreased to 27.81 % with the further addition of 10 % induction furnace slag to the sample. The OMC for TP-2 was initially 27 % for the 100 % black cotton soil, but this increased to 34

% with the addition of 8 % sawdust ash and reduced to 26.5 % when further 10 % induction furnace slag was added.

The Maximum Dry Density (MDD) was found to be 1.286 g/cc and 1.275 g/cc for TP-1 and TP-2 respectively in the 100 % black cotton soil. The result in the case of TP1 is that MDD decreased by 2 % and then increased by 0.31 % with the addition of 8 % sawdust ash and 8 % sawdust ash + 10 % induction furnace slag, respectively. In the case of TP-2 soil, which had a value of 1.275 g/cc, MDD decreased by 2.35 % when 8 % sawdust ash was added then increased by 0.7 % when further 10 % induction furnace slag was added, and also increased further by 3.04 % when 8 % sawdust ash and 20 % induction furnace slag was added.

The Soaked California Bearing Ratio(CBR) for TP-1 black cotton soil, which was obtained after 96 hr. of soaking, increased from 0.89 % to 1.52 % which is about 71 % increment when 8 % sawdust ash was added, and upon further addition of 10 % induction furnace, it increased from 0.89 % to 2.48 % (about 178.7 % increase). In the case of TP-2 black cotton soil, the CBR increased by 72 % when 8 % sawdust ash was added and further increased by 157.3 % when 10 % induction furnace slag was added.

The UCS for TP-1 black cotton soil was increased from 276.17 KN/m^2 to 306.61 KN/m^2 when 8 % sawdust ash was added, and upon the further addition of 10 % induction furnace, it increased to the highest value 389.44 KN/m^2. In the case of TP-2 black cotton soil, the UCS increased from 333.51 KN/m^2 to 359.09 KN/m^2 when 8 % sawdust ash was added and further increased to the highest value 422.65 KN/m^2 when 10 % induction furnace slag added.

4.9 Cost Comparison

In this section comparison made between the cost of constructing roads using removal and replacement method and constructing by stabilizing the black cotton soil using sawdust ash and induction furnace slag is discussed.

When the cost comparison is made the following basic common assumptions were taken to make the comparisons on a similar podium. And based on the following assumptions cost comparison is shown in Table 4.10.

- The location of selected materials is the same for the study area.
- The material cost above the subgrade layer is the same in both cases, only the subgrade cost is analyzed for comparison since the remaining layers base layer and asphalt are the same in both cases therefore, the surfacing layer cost is not considered during the comparison.
- Road width of 10 meters and 1-kilometer length road is used for the quantity tabulation. The poor soil is removed to a depth of 1.3 meters after removing the top surface of soil 0.2 meters below the natural ground level.
- A combination of 8 % sawdust ash and 10 % induction furnace content by weight of soil was used to stabilize the subgrade soil since the optimum CBR and UCS were obtained in this combination.

4.9.1 Cost analysis for replacing

Following the above examined data and assumptions, an excel plate is developed to analyze the cost of replacing the existing expansive soil with selected materials. The details of cost breakdown analyses for quantitative parameters are given on Annex G1. The result of quantitative cost analysis is tabulated in Table 4.8.

Table 4.8 Summary of quantitative unit cost for replacing

Item No.	Work Item	Unit	Unit rate (birr)	Unit rate (birr/km)
	I. Road Prism/Road Section			
1	Clearing and Grubbing within Road Prism	m^2	4.88	48,854.26
2	Under Cut Excavation	m^3	34.4	447,214.5
3	Disposal of Under Cut Excavation	m^3	60.40	785,230.30
	II. preparation of borrow material production			
4	Clearing and Grubbing for Borrow Production	m^2	4.88	48,854.26
5	Excavation of Overburden	m^3	63.19	821,521.35
	III. Borrow Material Production			
6	Select/Borrow Product	m^3	49.71	646,256.8
7	Transportation of Borrow material	m^3	70.29	913,777.21
	IV. Placing of Borrow Material			
8	Road bed preparation & Placing of Borrow Material	m^3	71.571	930,433
	V. Reinstatement of Borrow areas			
9	Reinstating of Borrow Pit	m^3	49.65	645,519.71
	Total		**408.97**	**5,287,661.39**

4.9.2 Cost analysis for stabilizing

The amount of stabilizers needed for the existing black cotton soil in kilogram was calculated and following the above assumptions, an excel plate is developed to analyze the cost of stabilizing the soil. The summary of cost analysis for quantitative parameters is tabulated in Table 4.9 and the details of cost breakdown analyses for quantitative parameters are given in Annex G2.

For 100 Kg of sample 8 % sawdust ash and 10 %, induction furnace slag are needed to stabilize 82 % of black cotton soil.

Therefore, for 100 Kg of sawdust ash-induction furnace slag-soil mix material, we need 8 Kg of sawdust ash and 10 Kg of induction furnace slag for stabilization of 82 Kg of black cotton soil.

Specific gravity of soil $= \frac{\text{Unit weight of soil}}{\text{unit weight of water}}$

Unit weight of soil = Specific gravity of soil * Unit weight of water

Specific gravity of soil = 2.521, Unit weight of water = 1000 Kg/ m^3

Unit weight of soil = 2.521 X 1000 Kg/ m^3 = 2,521 Kg/ m^3

Therefore, the mass of soil in Kg per m^3 soil will be,

1 m^3 of Soil = 2,521 Kg of soil

(x) m^3 of Soil = 1Kg of soil

x = 0.0004 m^3 of soil

But, for 82 Kg of soil, we need 8Kg of sawdust ash and 10Kg of induction furnace slag.

1 Kg of soil = 0.0004 m^3

82 Kg of soil = (x) m^3 of soil

x = 0.033 m^3 of soil

- ✓ This implies that for 0.033 m^3 of soil the amount of sawdust ash required will be 8 Kg.

Therefore, 0.033 m^3 of soil = 8 Kg of sawdust ash

1 m^3 of soil = (y) Kg of sawdust ash

y = 242.42 Kg of sawdust ash and

0.033 m^3 of soil = 10 Kg of induction furnace slag.

1 m^3 of soil = (z) Kg of induction furnace slag.

z = 303 Kg of induction furnace slag.

Hence, from the results obtained, 242.42 Kg of sawdust ash and 303 Kg of induction furnace slag is found to be used as a stabilizing agent for 1m^3 of black cotton soil.

Table 4.9 Summary of quantitative unit cost for soil + 8% SDA +10% IFS

Item No.	Work Item	Unit	Unit rate (birr)	Unit rate (birr/km)
	I. Road prism/Road section			
1	Clearing and grubbing within road prism	m^2	4.88	48,854.26
2	Under cut excavation	m^3	34.4	447,214.5
3	Mixing of stabilizer	m^3	47.73	620,429.06
4	Placing of stabilizer and compaction		54.50	708,553.37
	Purchase cost of stabilizers			
5	Cost of sawdust for 1m^3 of black cotton soil including preparation	m^3	150	1,950,000
6	Cost of induction furnace slag preparation	m^3	50	650,000
	Total			4,425,051.19

4.9.3 Result comparison of cost analysis

The quantitative cost result comparison of replacing and stabilizing with sawdust ash and induction furnace slag on the above cost analysis is shown in Table 4.10.

Table 4.10 Comparison of a quantitative cost analysis of replacing versus stabilizing

S/N	Description	Unit cost (birr/Km)	% Saving
1	Total cost of replacing the existing black cotton soil with locally available suitable material	5,287,661.39	16.3 %
2	Total cost of stabilizing the existing black cotton soil with 8% sawdust ash and 10% induction furnace slag	4,425,051.19	
	Difference	862,610.2	

It can be seen from the above Table 4.10 that the unit cost for stabilizing the existing black cotton soil with sawdust ash and induction furnace slag is found to be lower than that of replacing the existing black cotton soil with locally available suitable material. The analysis shows that there is about 16 % saving cost by using sawdust ash and induction furnace slag stabilization over cost of replacing.

5. CONCLUSIONS AND RECOMMENDATIONS

This chapter includes conclusions drawn from the laboratory test results discussed in the previous chapter and provides recommendations for future researches.

5.1 Conclusions

Based on the test results obtained from the investigation of the selected soils treated with sawdust ash and induction furnace slag the following conclusions are drawn.

- ✓ The liquid limit and plasticity index showed a reduction with increasing percentages of sawdust ash and induction furnace slag.
- ✓ The specific gravity decreased for the combination of 8 % sawdust ash and induction furnace slag up to 10 % but it increased beyond 8 % sawdust ash and 10 % induction furnace slag.
- ✓ The MDD reduced with the addition of sawdust ash alone and increases with the further addition of induction furnace slag whereas OMC decreased with the increase in the percentage of induction furnace slag.
- ✓ A combination of 8 % sawdust ash and 10 % induction furnace slag by dry weight of a soil results in the maximum CBR as well as UCS values, thus it was taken to be optimum stabilizer content.
- ✓ The CBR value of the soils treated with the optimum amount of stabilizers (8 % sawdust ash and 10 % induction furnace slag) were within the limits recommended by Ethiopian Road Authority for subgrade soils and fall under subgrade class 2.
- ✓ From the quantitative cost analysis, stabilizing the existing black cotton soil with 8 % sawdust ash and 10 % induction furnace slag was found to be economical than replacing it with a saving cost of about 16 %. Thus it is concluded that a combination of sawdust ash and induction furnace slag can be used as a stabilizing agents for sub-grade construction.

5.2 Recommendations

The present work has attempted to investigate the combined effect of sawdust ash and induction furnace slag on black cotton soil samples collected from a certain portions of Addis Ababa sub city around CMC area. However, due to financial constraints and time limitations, the present research work did not cover the whole aspects of black cotton soil treatment with sawdust ash and induction furnace slag. Therefore, findings should be considered indicative rather than definitive for filed applications. In view of this, it would be desirable to consider the following recommendations for better use of sawdust ash and induction furnace slag as a stabilizing agent for black cotton soils.

1. There is no enough investigation done on sawdust ash and slag as soil stabilizers in Ethiopia. So it is recommended that extensive researches on soil samples taken from different places in Ethiopia with different samples of sawdust ash and induction furnace slag should be done.
2. All test results conducted in this thesis study were without curing the samples to a certain period of time except for that of CBR test. Hence, anyone who has the interest to study on sawdust ash and induction furnace slag as stabilizing agents to black cotton soil shall conduct by including the cured case.

SPECIAL ACKNOWLEDGEMENT

This research project is funded by Adama Science and Technology University under the grant number:

ASTU/ SM-R/ 244 / 21

Adama, Ethiopia

REFERENCES

Afrin, Habiba. (2017). A Review on Different Types Soil Stabilization Techniques. *International Journal of Transportation Engineering and Technology, 3*, 19-24. doi:10.11648/j.ijtet.20170302.12

Ahmad, Syed Ishtiaq, & Md Shafiqur Rahman. (2018). Mechanical and Durability Properties of Induction-Furnace-Slag-Incorporated Recycled Aggregate Concrete. *Advances in Civil Engineering, 2018*, 1-11. doi:10.1155/2018/3297342

Archibong, G. A., Sunday, E. U., Akudike, J. C., Okeke, O. C. and Amadi, C. (2020). A Review of the principles and methods of soil stabilization. *International Journal of Advanced Academic Research | Sciences, Technology and Engineering, 6*(3).

Arega, Fekerte. (2012). *Remot sensing and geotechnical investigation of expansive soil.* (Doctor Dissertation), University of Twente, (201)

Arora, K. R. (2004). *Soil Mechanics and Foundation Engineering*. Delhi: A. K. Jain.

Barasa, Patrick Khaoya. (2016). *Stabilization of Expansive Clay Soil Using Bagasse Ash and Lime.* (Master of Science), Jomo Kenyatta University of Agriculture and Technology,

Batari, Ahmad, et al. (2017). Effect of Bagasse Ash on the Properties of Cement Stabilized Black Cotton Soil. *International Journal of Transportation Engineering and Technology, 3*, 67-73. doi:10.11648/j.ijtet.20170304.14

Butt, Wajid Ali, Gupta, Karan Jha, J. N. (2016). Strength behavior of clayey soil stabilized with saw dust ash. *International Journal of Geo-Engineering, 7*(1). doi:10.1186/s40703-016-0032-9

Chen, Fu Hua. (1975). *Foundations On Expanive Soils*. Amsterdam - Oxford -New York: Elsevier Scientific Publishing Company.

Desalegn, Henok. (2020). *Evaluation of Hot-Mix Asphalt Mixtures Containing Steel Slag.* (A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the Road and Transport Engineering), Bahir Dar University,

Deshmukh, M. V., & N. R. Vidhate. (2015). Analysis of Induction Furnace Slag of Ferrous Foundry. *IJSRD - International Journal for Scientific Research & Development, 2*(11).

ERA, Ethiopian Roads Authority. (2013a). *Flexible Pavements* (Vol. I).

ERA, Ethiopian Roads Authority. (2013b). *Site Investigation Manual* (Vol. 1).

G/Michael, Tesfaye, et al. (2017). *Development of Ethiopian Steel Industries: Challenges, Prospects, and Policy Options (2015 –2025)*. Addis Ababa, Ethiopia: FDRE, Policy Study and Research Center - PSRC and Adama Science and Technology University, ASTU.

Gidigasu, S. S. R, Gawu S. K.Y. (2013). The Mode of Formation, Nature and Geotechnical characteristics of Black Cotton Soils. *Standard Scientific Research and Essays, 14*, 377-390.

Honest., George Rowland Otoko & Braide K. (2014). Stabilization of Nigerian Deltaic Laterites with Saw Dust Ash. *International Journal of scientific research and management (IJSRM), 2*(8), 1287-1292.

Ikeagwuani, C. C. (2016). Compressibility Characteristics of Black Cotton Soil Admixed with Sawdust Ash and Lime. *Nigerian Journal of Technology, 35*(4). doi:10.4314/njt.v35i4.5

Ikeagwuani, C.C., et al. (2019). Stabilization of black cotton soil subgrade using sawdust ash and lime. *ScienceDirect, 59*(1), 162-175. doi:10.1016/j.sandf.2018.10.004

James, Jijo. (2019). Strength benefit of sawdust/wood ash amendment in cement stabilization of an expansive soil. *Revista Facultad de Ingeniería, 28*(50), 44-61. doi:10.19053/01211129.v28.n50.2019.8790

Jangid, Amit Kumar, et al. (2018). Stabilization of Black cotton soil by 15% Kota stone slurry wiyh wooden saw dust. *International Journal of Advance Research in Sciences and Engineering, 7*(02).

Joseph, Winny, & R. Sridhar. (2020). Effect of silica fume and induction furnace slag in the compaction and strength characteristics of black cotton soil. *IOP Conference Series: Materials Science and Engineering, 872*. doi:10.1088/1757-899x/872/1/012114

Joussein, Emmanuel, et al. (2007). Behavior of halloysite clay under formamide treatment. *Applied Clay Science, 35*(1-2), 17-24. doi:10.1016/j.clay.2006.07.002

Kalantari, Behzad. (2012). Foundations on Expansive Soils. *Research Journal of Applied Sciences, Engineering and Technology*.

Kale, R.Y., et al. (2019). Effect of saw dust ash and lime on expansive soil (Black cotton soil). *International Research Journal of Engineering and Technology (IRJET), 6*(04).

Khadem, Faezehossadat, & Jeff Budima. (2016). Expansive Soil Causes and Treatments. *i-manager's Journal on Civil Engineering, 6*.

Lakew, Aschalew, & Otto Moog. (2016). *Top-down operative stream classification system (typology) for Ethiopian highlands*.

Mandal, Sougat, & J.P.Singh. (2016). Stabilization of Soil using Ground Granulated Blast Furnace Slag and Fly Ash. *International Journal of Innovative Research in Science, Engineering and Technology, 5*(12). doi:10.15680/IJIRSET.2016.0512038

Mines, Government of India Minstry of Mines Indian Bureau of. (2016). *Slag-Iron and Steel* (54 ed.).

Murthy, V. N. S. (2002). *Principles and Practices of Soil Mechanics and Foundation Engineering*. New York.

Nelson, John D., Kuo Chieh Chao,Daniel D.Overton. (2015). *Foundation Engineering for Expansive Sois*.

Obeta, I. N., et al. (2019). Stability and durability of sawdust ash-lime stabilised black cotton soil. *Nigerian Journal of Technology, 38*(1). doi:10.4314/njt.v38i1.10

Ogundipe, Olumide Moses, et al. (2019). Effect of Compactive Efforts on Strength of Laterites Stabilized with Sawdust Ash. *Civil Engineering Journal, 5*(11), 2502-2514. doi:10.28991/cej-2019-03091428

Ouf, Mohamed EL-Sadek Abdel rahman. (2011). *Stabilization of clay subgrade soils using Ground Granulated Blastfurnace Slag.* (requirements for the degree of Doctor of Philosophy), University of Leeds,

Rahman, Syed Ishtiaq Ahmad and Md. Shafiqur. (2018). Mechanical and Durability Properties of Induction-Furnace-Slag-Incorporated Recycled Aggregate Concrete. *Hindawi Advances in Civil Engineering*. doi:10.1155/2018/3297342

Reddy, A. Venkatesh and Dr. G. Sreenivasa. (2016). Effect Of Waste Saw Dust Ash On Compaction And Permeability Properties Of Black Cotton Soil. *International Journal of Civil Engineering Research*.

Sharma, Anil Kumar, & P.V. Sivapullaiah. (2012). *Improvement of Strength of Expansive soil with waste Granulated Blast Furnace Slag*. Paper presented at the GeoCongress.

Shawl, Zuhaib Zahoor, & Er. Vishal Kumar Er. Ved Parkash. (2007). Use of Lime and Saw Dust Ash in Soil Stablization. *International Journal of Innovative Research in Science, Engineering and Technology, 6*(2). doi:10.15680/IJIRSET.2017.0602037

Siddiqui, Trudeep N. Dave and Arshad K. (2019). *A Review of Expansive Soil -Effects and Mitigation Techniqu*. https://www.researchgate.net/publication/334881375

Teferra, Alemayehu, & Solomon Yohannes. (1986). Investigation on the Expansive soils of Addis Ababa. *Journal of EAEA, 7*.

Tsion Argu. (2017). *Subgrade Soil Stabilization Practice of AACRA.* Addis Ababa Science and Technology University,

Uge, Bantayehu Uba. (2017). Performance, Problems and Remedial Measures for Roads Constructed on Expansive Soil in Ethiopia. *Civil and Environmental Research, 9*.

Venkatesh, A., & Dr. G. Sreenivasa Reddy. (2016). Effect Of Waste Saw Dust Ash On Compaction And Permeability Properties Of Black Cotton Soil. *International Journal of Civil Engineering Research, 7*, 27-32.

wikipedia. (2021). Addis Ababa.

Yildirim, Irem Zeynep, & Monica Prezzi. (2011). Chemical, Mineralogical, and orphological Properties of Steel Slag. *Advances in Civil Engineering*. doi:10.1155/2011/463638

APPENDICES

Appendix A - Grain Size and Hydrometer Analysis Test Results

The grain analysis test was performed for only natural black cotton soils of TP-1 and TP-2. The detailed test results for both samples are given in this section;

Table A- 1 Grain size analysis test result (TP-1)

Sieve size		Retained for 1st Sieving		Percent Passing
	(mm)	Weight	% Rtd.	(%)
3/8"	9.5	0.00	0.00	100.00
N^o 4	4.75	2.50	1.10	98.90
N^o 10	2	2.40	1.06	97.84
N^o 16	1.18	2.20	0.97	96.87
N^o 30	0.6	1.60	0.71	96.16
N^o 50	0.3	1.50	0.66	95.50
N^o 100	0.15	1.70	0.75	94.75
N^o 200	0.075	2.00	0.88	93.86
Pan		212.60	93.86	
Total		227	100	

Table A- 2 Hydrometer analysis test result (TP-1)

Elapsed Time, t,min	Actual Hydrometer Reading Ra	Temp (^oC)	Effective Depth, L (mm)	K From Table	Temprature Correction Factor Ct	Modified Hydrometer Reading R= Ra -Cz+Ct	Particle DiameterD (mm)	Percentage Pass (%)	Corrected Percentage Pass (%)
0									
2	43.5	21	8.95	0.01324	0.18	37.856	0.0280	74.77	70.19
5	42	21	9.20	0.01324	0.18	36.356	0.0180	71.81	67.40
15	41	21	9.37	0.01324	0.18	35.356	0.0105	69.84	65.55
30	40	21	9.53	0.01324	0.18	34.356	0.0075	67.86	63.70
60	37	21	10.03	0.01324	0.18	31.356	0.0054	61.94	58.13
250	34	23	10.52	0.01293	0.66	29.324	0.0027	57.92	54.37
1440	28	21	11.51	0.01324	0.18	22.356	0.0012	44.16	41.45

Specific gravity of soil = 2.586

TP 1	
CLAY	59.76
SILT	34.10
SAND	5.03
Gravel	1.10

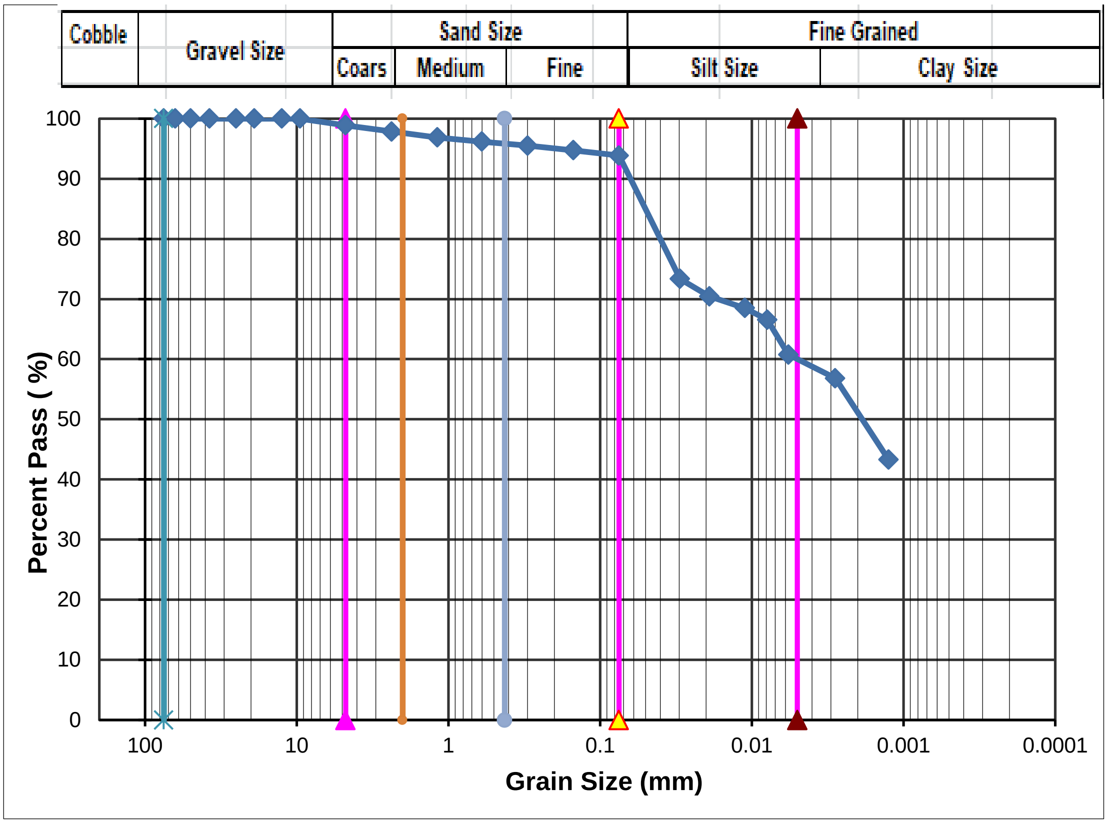

Figure A- 1 Particle size distribution curve for TP-1

Table A- 3 Grain size analysis test result (TP-2)

Sieve size		Retained for 1st Sieving		Percent Passing
	(mm)	Weight	% Rtd.	(%)
3/8"	9.5	0.00	0.00	100.00
N° 4	4.75	1.90	0.76	99.24
N° 10	2	0.90	0.36	98.88
N° 16	1.18	1.30	0.52	98.35
N° 30	0.6	2.00	0.80	97.55
N° 50	0.3	2.30	0.92	96.63
N° 100	0.15	3.00	1.20	95.43
N° 200	0.075	3.10	1.24	94.18
Pan		234.70	94.18	
Total		249	100	

Table A- 4 Hydrometer analysis test result (TP-2)

Elapsed Time, t,min	Actual Hydrometer Reading Ra	Temp (°C)	Effective Depth, L (mm)	K From Table	Temprature Correction Factor Ct	Modified Hydrometer Reading R= Ra -Cz+Ct	Particle DiameterD (mm)	Percentage Pass (%)	Corrected Percentage Pass (%)
0									
2	48	21	8.21	0.0137	0.18	42.356	0.0278	85.86	80.86
5	45	21	8.71	0.0137	0.18	39.356	0.0181	79.77	75.13
15	43	21	9.04	0.0137	0.18	37.356	0.0106	75.72	71.31
30	42	21	9.20	0.0137	0.18	36.356	0.0076	73.69	69.41
60	41	21	9.37	0.0137	0.18	35.356	0.0054	71.67	67.50
250	35	23	10.36	0.0133	0.66	30.324	0.0027	61.47	57.89
1440	32	21	10.85	0.0137	0.18	26.356	0.0012	53.42	50.32

Specific gravity of soil = 2.52

TP 2	
CLAY	66.03
SILT	28.16
SAND	5.06
Gravel	0.76

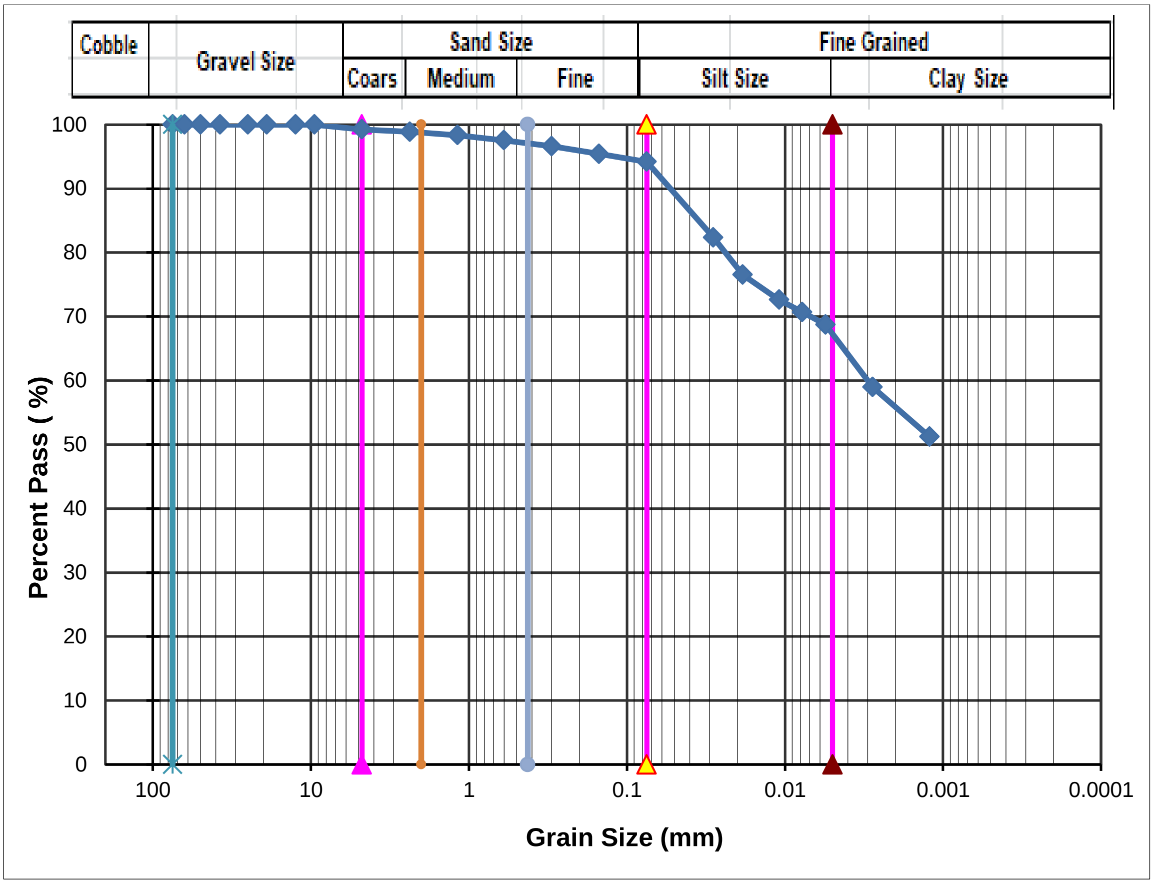

Figure A- 2 Particle size distribution curve for TP-2

Table A- 5 Hydrometer analysis test result for sawdust ash

Date	Time	Elapsed Time, t,min	Actual Hydrometer Reading Ra	Temp (^oC)	Effective Depth, L (mm)	K From Table	Temprature Correction Factor Ct	Modified Hydrometer Reading R= Ra - Cz+Ct	Particle Diameter D (mm)	Percentage Pass (%)	Corrected Percentage Pass (%)
		0									
		2	16.000	21	13.49	0.01353	0.18	10.356	0.0351	20.80	20.80
		5	14.000	21	13.82	0.01353	0.18	8.356	0.0225	16.78	16.78
		15	12.000	21	14.15	0.01353	0.18	6.356	0.0131	12.76	12.76
		30	10.000	21	14.48	0.01353	0.18	4.356	0.0094	8.75	8.75
		60	8.000	21	14.81	0.01353	0.18	2.356	0.0067	4.73	4.73
		250	6.000	23	15.14	0.01322	0.66	1.324	0.0033	2.66	2.66
		1440	6.000	21	15.14	0.01353	0.18	0.356	0.0014	0.71	0.71

Table A- 6 Hydrometer analysis test result for induction furnace slag

Date	Time	Elapsed Time, t,min	Actual Hydrometer Reading Ra	Temp (^oC)	Effective Depth, L (mm)	K From Table	Temprature Correction Factor Ct	Modified Hydrometer Reading R= Ra - Cz+Ct	Particle Diameter D (mm)	Percentage Pass (%)	Corrected Percentage Pass (%)
		0									
		2	21.000	21	12.67	0.02522	0.18	15.356	0.0635	59.81	59.81
		5	19.000	21	13.00	0.02522	0.18	13.356	0.0407	52.02	52.02
		15	15.000	21	13.66	0.02522	0.18	9.356	0.0241	36.44	36.44
		30	13.000	21	13.99	0.02522	0.18	7.356	0.0172	28.65	28.65
		60	11.000	21	14.32	0.02522	0.18	5.356	0.0123	20.86	20.86
		250	8.000	23	14.81	0.02463	0.66	3.324	0.0060	12.95	12.95
		1440	6.000	21	15.14	0.02522	0.18	0.356	0.0026	1.39	1.39

Appendix B - Specific Gravity Test Results

The specific gravity was determined in the laboratory for natural black cotton soil and treated black cotton soil with optimum sawdust ash content and different contents of induction furnace slag according to ASTM D 854. The results obtained for both natural soil and treated soil are given below;

Table B- 1 Specific gravity test result for natural black cotton soil

Sample ID		TP-1		TP-2	
Determination No		133	139	135	128
Wt. Bottle + water + soil	g	168.5	168.1	166	166.7
Wt. Bottle + water	g	159.3	158.9	156.9	157.7
Wt. Bottle Dry soil	g	66.4	66	64.4	67
Wt. Bottle	g	51.4	54.4	49.4	52
Wt. soil	g	15	15	15	15
Specific gravity (GS)		2.586	2.586	2.542	2.500
Average Specific gravity (GS)		2.586		2.521	

Table B- 2 Specific gravity test result for TP-1 black cotton soil with Sawdust Ash (SDA) and Induction Furnace Slag (IFS)

TP-1					
Sample ID		**5 %IFS+8 %SDA+87 % black cotton soil**		**10 %IFS+8 %SDA+82 % black cotton soil**	
Determination No		P7	P18	P8	P3
Wt. Bottle + water + soil	g	91.2	90.6	91.7	90.8
Wt. Bottle + water	g	85.2	84.6	85.6	84.8
Wt. Bottle Dry soil	g	42.6	42.6	44.2	42.8
Wt. Bottle	g	32.4	32.6	34.2	32.6
Wt. soil	g	10	10	10	10
Specific gravity(GS)		2.500	2.500	2.564	2.50
Average Specific gravity(GS)		2.500		2.532	

Sample ID	**15 %IFS+8 %SDA+87 % black cotton soil**		**20 %IFS+8 %SDA+82 % black cotton soil**	
Determination No	P5	P15	31	P14
Wt. Bottle + water + soil g	90.2	90	90.3	90.8
Wt. Bottle + water g	84.1	83.8	84	84.8
Wt. Bottle Dry soil g	42	42	41	42.4
Wt. Bottle g	31.8	32	31	32
Wt soil g	10	10	10	10
Specific gravity(GS)	2.564	2.632	2.703	2.500
Average Specific gravity(GS)	2.598		2.601	

Table B- 3 Specific gravity test result for TP-2 black cotton soil with Sawdust Ash (SDA) and Induction Furnace Slag (IFS)

TP-2				
Sample ID	**5 %IFS+8 %SDA+87 % black cotton soil**		**10 %IFS+8 %SDA+82 % black cotton soil**	
Determination No	P4	37	P20	P19
Wt. Bottle + water + soil g	90.4	89.6	89.7	90.9
Wt. Bottle + water g	84.4	83.8	84.4	84.4
Wt. Bottle Dry soil g	42.8	41	41.4	41.6
Wt. Bottle g	32.8	31	31.2	31.6
Wt soil g	10	10	10	10
Specific gravity(GS)	2.500	2.381	2.128	2.857
Average Specific gravity(GS)	2.440		2.492	
Sample ID	**15 %IFS+8 %SDA+87 % black cotton soil**		**10 %IFS+8 %SDA+82 % black cotton soil**	
Determination No	P9	P16	P10	P12
Wt. Bottle + water + soil g	89.6	88.3	89.4	90.8
Wt. Bottle + water g	83.8	82	83.2	84.8
Wt. Bottle Dry soil g	41	39	40.8	42.4
Wt. Bottle g	31	29.2	30.8	32.4
Wt soil g	10	10	10	10
Specific gravity(GS)	2.381	2.703	2.632	2.500
Average Specific gravity(GS)	2.542		2.566	

Table B- 4 Specific gravity test result of sawdust ash and induction furnace slag

Sample ID	**Sawdust ash**		**Induction furnace slag**	
Determination No	10	20	126	124
Wt. Bottle + water + soil g	159.4	159.2	164	166.2
Wt. Bottle + water g	155	154	154.8	156.8
Wt. Bottle Dry soil g	66.6	68.8	65.2	67
Wt. Bottle g	51.6	53.8	50.2	52
Wt. soil g	15	15	15	15
Specific gravity(GS)	1.415	1.531	2.586	2.679
Average Specific gravity(GS)	1.473		2.632	

Appendix C - Atterberg Limits Test Results

The Plastic limits, liquid limits and plastic index of soil samples of Test pit 1 (TP-1) and Test pit 2 (TP-2) were determined in accordance with ASTM D4318. Detailed laboratory test analyses are given in this section.

Table C-1 Atterberg limit for TP-1 natural black cotton soil

Type of test	**Liquid limit**				**Plastic limit**	
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2
No. of Blows N	36	29	23	15	-	-
Mass of moist Sample + Can M_1	30.39	31.71	33.57	37.68	28.47	28.84
Mass of Dried Sample + Can M_2	23.27	23.73	24.13	26.70	24.12	24.34
Mass of Can M_c	14.89	14.82	13.78	14.79	14.71	14.46
Mass of Moist $M_m=M_1-M_2$	7.12	7.98	9.44	10.98	4.35	4.50
Mass of Dried Sample $M_d=M_2-M_c$	8.38	8.91	10.35	11.91	9.41	9.88
Moisture Content = M_m / M_d x 100	84.96	89.56	91.21	92.19	46.23	45.55

LL = 89.28 % PL = 45.89 % PI = 43.39 %

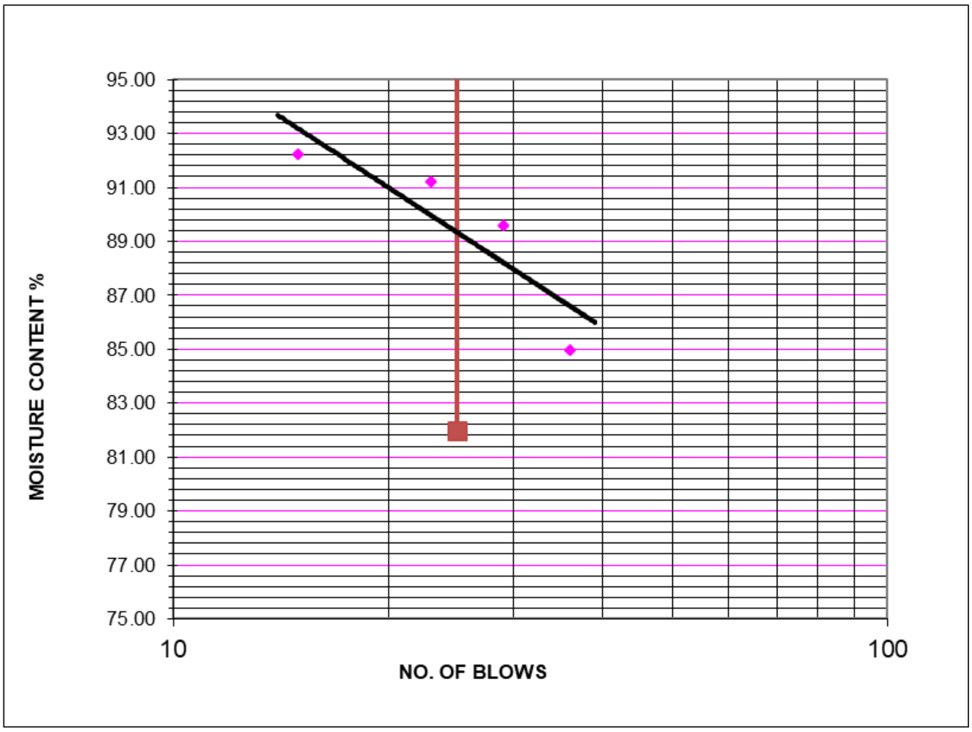

Figure C- 1 flow curve for TP-1 natural black cotton soil

Table C-2 Atterberg limit for TP-1 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Type of test	**Liquid limit**				**Plastic limit**	
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2
No. of Blows N	36	30	23	17	-	-
Mass of moist Sample + Can M_1	29.29	30.32	33.46	34.87	26.97	27.29
Mass of Dried Sample + Can M_2	23.13	23.49	24.86	24.99	23.25	23.50
Mass of Can M_c	15.03	14.88	14.89	14.95	14.82	14.69
Mass of Moist $M_m=M_1-M_2$	6.16	6.83	8.60	9.88	3.72	3.79
Mass of Dried Sample $M_d=M_2-M_c$	8.10	8.61	9.97	10.04	8.43	8.81
Moisture Content = M_m / M_d x 100	76.05	79.33	86.26	98.41	44.13	43.02

LL = 84.97 % PL = 43.57 % PI = 41.40 %

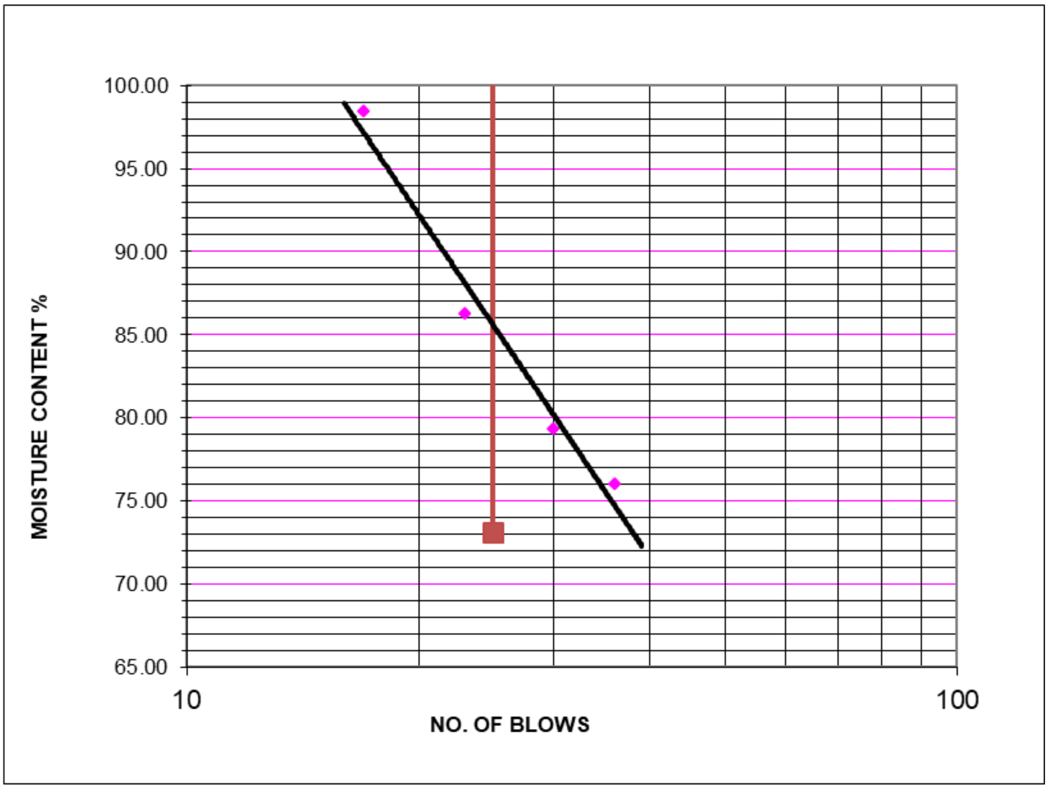

Figure C- 2 flow curve for TP-1 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Table C-3 Atterberg limit for TP-1 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Type of test	Liquid limit				Plastic limit	
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2
No. of Blows N	34	28	21	12	-	-
Mass of moist Sample + Can M_1	42.96	42.60	44.96	41.73	28.85	28.94
Mass of Dried Sample + Can M_2	30.96	30.06	31.22	29.65	24.69	24.75
Mass of Can M_c	14.94	14.70	14.82	14.77	14.94	14.92
Mass of Moist $M_m=M_1-M_2$	12.00	12.54	13.74	12.08	4.16	4.19
Mass of Dried Sample $M_d=M_2-M_c$	16.02	15.36	16.40	14.88	9.75	9.83
Moisture Content = M_m / M_d x 100	74.91	81.64	83.78	81.18	42.67	42.62

LL = 79.47 % PL = 42.65 % PI = 36.82 %

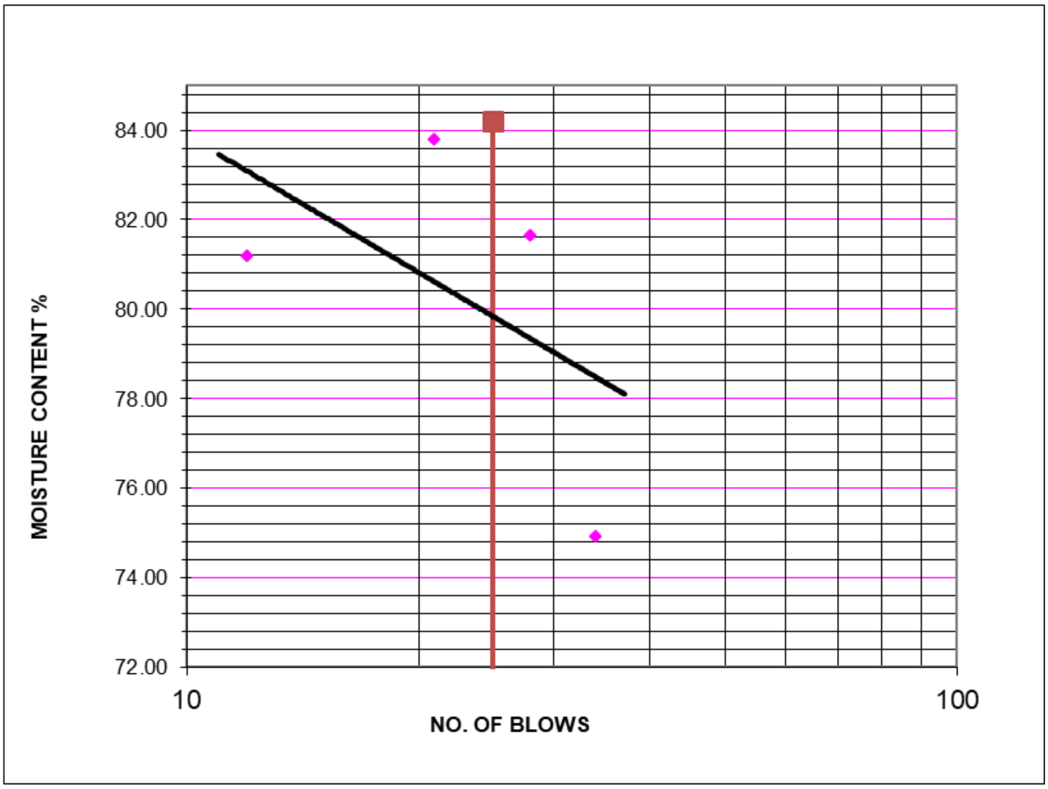

Figure C- 3 flow curve for TP-1 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Table C-4 Atterberg limit for TP-1 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Type of test	**Liquid limit**				**Plastic limit**	
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2
No. of Blows N	36	29	23	18	-	-
Mass of moist Sample + Can M_1	26.53	29.57	30.46	32.05	26.71	26.14
Mass of Dried Sample + Can M_2	21.91	23.42	23.40	23.96	23.25	22.93
Mass of Can M_c	14.59	14.91	14.63	14.62	14.72	15.05
Mass of Moist $M_m=M_1-M_2$	4.62	6.15	7.06	8.09	3.46	3.21
Mass of Dried Sample $M_d=M_2-M_c$	7.32	8.51	8.77	9.34	8.53	7.88
Moisture Content = M_m / M_d x 100	63.11	72.27	80.50	86.62	40.56	40.74

LL = 75.61 % PL = 40.65 % PI = 34.96 %

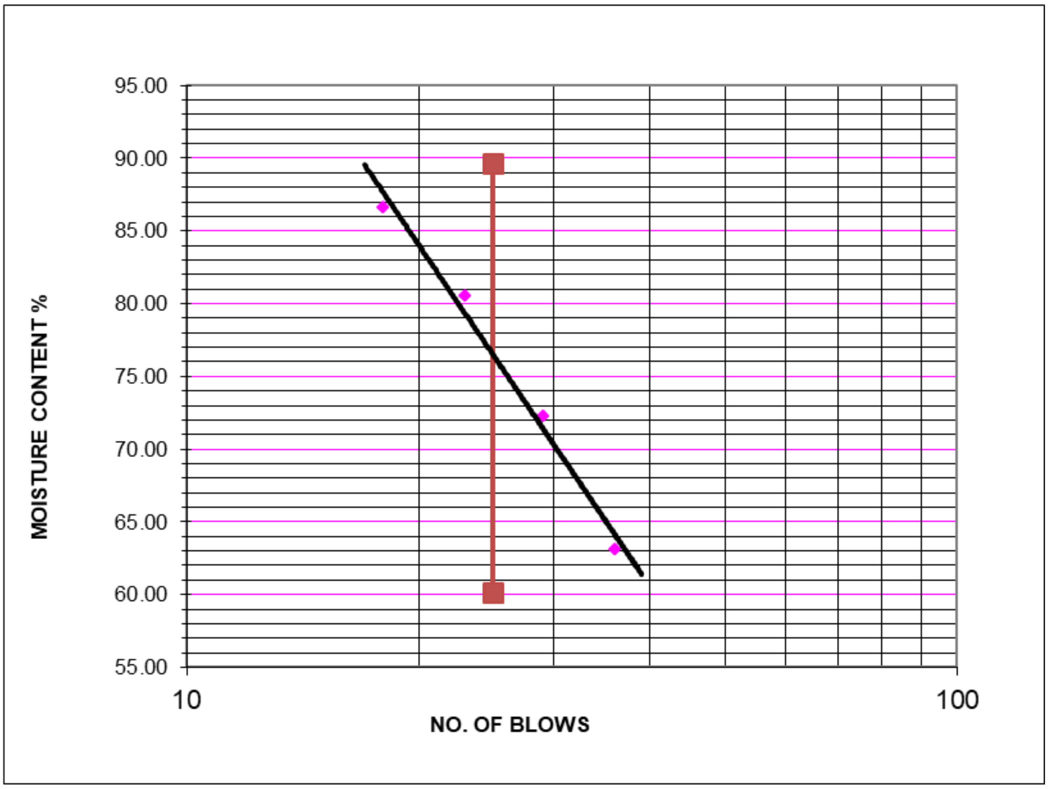

Figure C- 4 flow curve for TP-1 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Table C-5 Atterberg limit for TP-1 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Type of test	**Liquid limit**				**Plastic limit**	
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2
No. of Blows N	35	30	22	15	-	-
Mass of moist Sample + Can M_1	29.06	32.43	33.49	34.68	27.08	27.12
Mass of Dried Sample + Can M_2	23.66	25.19	25.91	25.48	23.71	23.65
Mass of Can M_c	14.81	14.67	14.77	14.50	14.86	15.05
Mass of Moist $M_m=M_1-M_2$	5.40	7.24	7.58	9.20	3.37	3.47
Mass of Dried Sample $M_d=M_2-M_c$	8.85	10.52	11.14	10.98	8.85	8.60
Moisture Content = M_m / M_d x 100	61.02	68.82	68.04	83.79	38.08	40.35

LL = 70.03 %   PL = 39.21 %   PI = 30.81 %

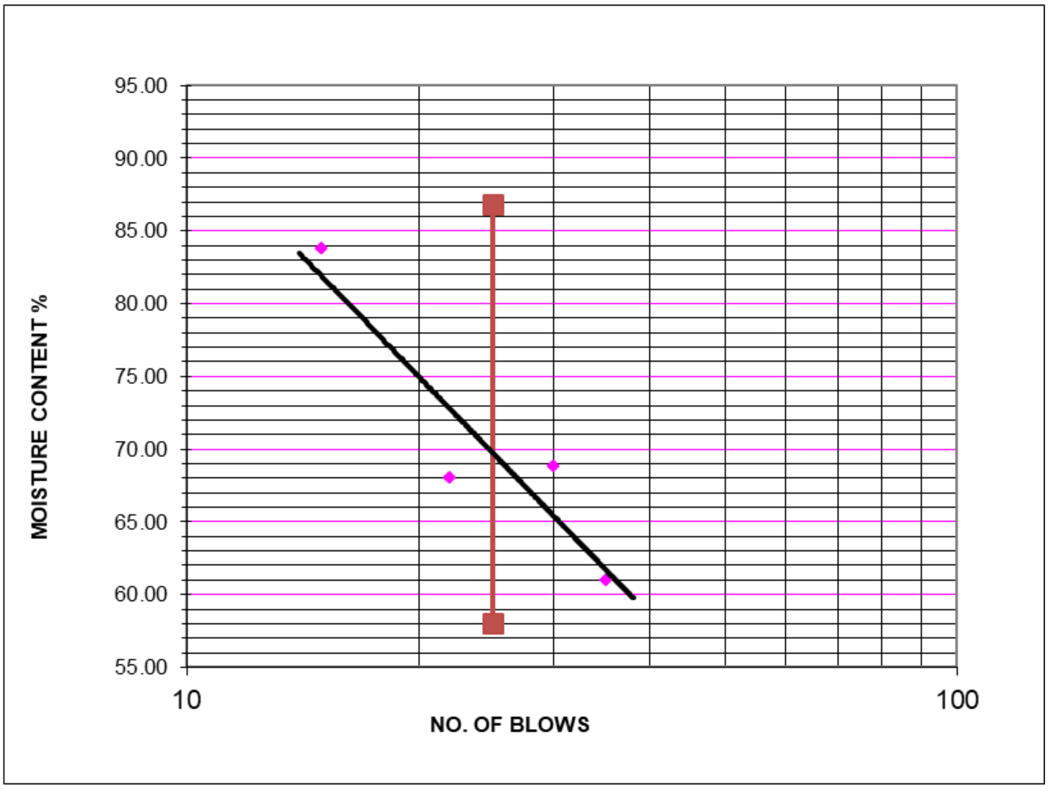

Figure C- 5 flow curve for TP-1 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Table C-6 Atterberg limit for TP-2 natural black cotton soil

Type of test	Liquid limit				Plastic limit	
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2
No. of Blows N	36	29	22	18	-	-
Mass of moist Sample + Can M_1	26.32	29.43	31.76	32.50	27.75	27.58
Mass of Dried Sample + Can M_2	21.27	22.90	24.08	24.23	23.82	23.80
Mass of Can M_c	14.88	15.00	14.90	14.71	14.46	14.59
Mass of Moist $M_m=M_1-M_2$	5.05	6.53	7.68	8.27	3.93	3.78
Mass of Dried Sample $M_d=M_2-M_c$	6.39	7.90	9.18	9.52	9.36	9.21
Moisture Content = M_m / M_d x 100	79.03	82.66	83.66	86.87	41.99	41.04

LL = 83.12 % PL = 41.51 % PI = 41.61 %

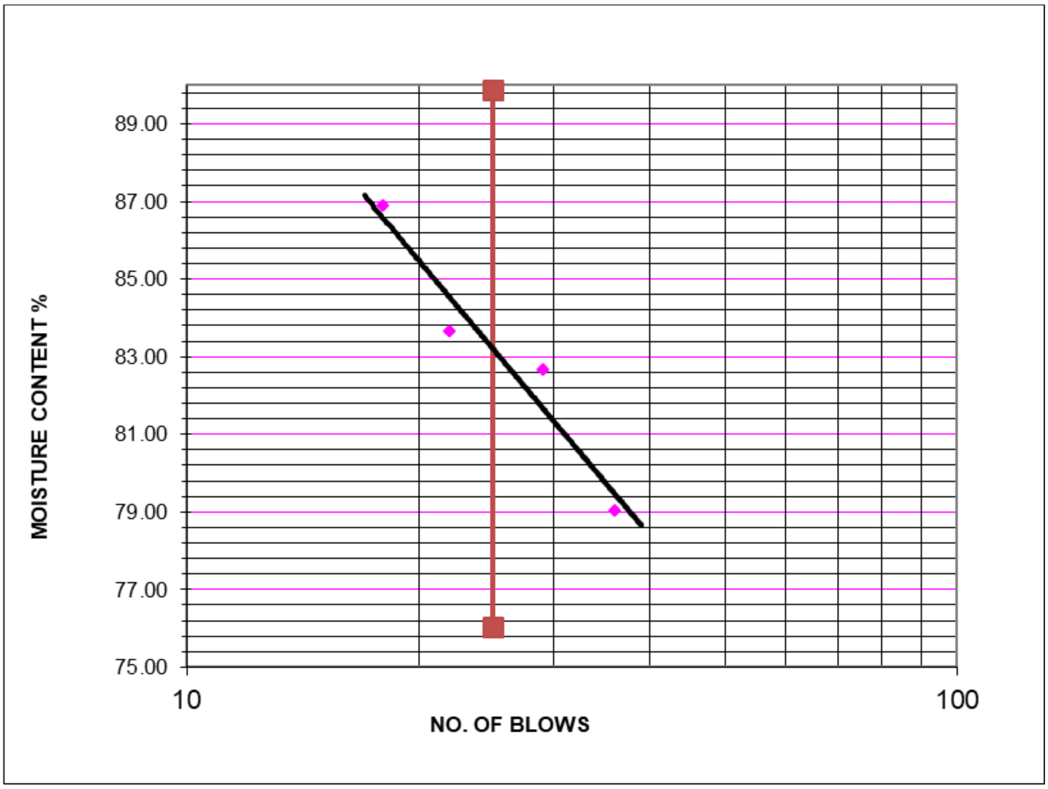

Figure C- 6 flow curve for TP-2 natural black cotton soil

Table C-7 Atterberg limit for TP2 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Type of test	**Liquid limit**				**Plastic limit**	
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2
No. of Blows N	37	27	23	16	-	-
Mass of moist Sample + Can M_1	29.84	32.08	34.05	39.01	26.54	26.99
Mass of Dried Sample + Can M_2	23.91	24.07	25.59	27.87	23.10	23.44
Mass of Can M_c	15.26	13.71	14.82	14.54	14.48	14.79
Mass of Moist $M_m=M_1-M_2$	5.93	8.01	8.46	11.14	3.44	3.55
Mass of Dried Sample $M_d=M_2-M_c$	8.65	10.36	10.77	13.33	8.62	8.65
Moisture Content = M_m / M_d x 100	68.55	77.32	78.55	83.57	39.91	41.04

LL = 76.77 % PL = 40.47 % PI = 36.30 %

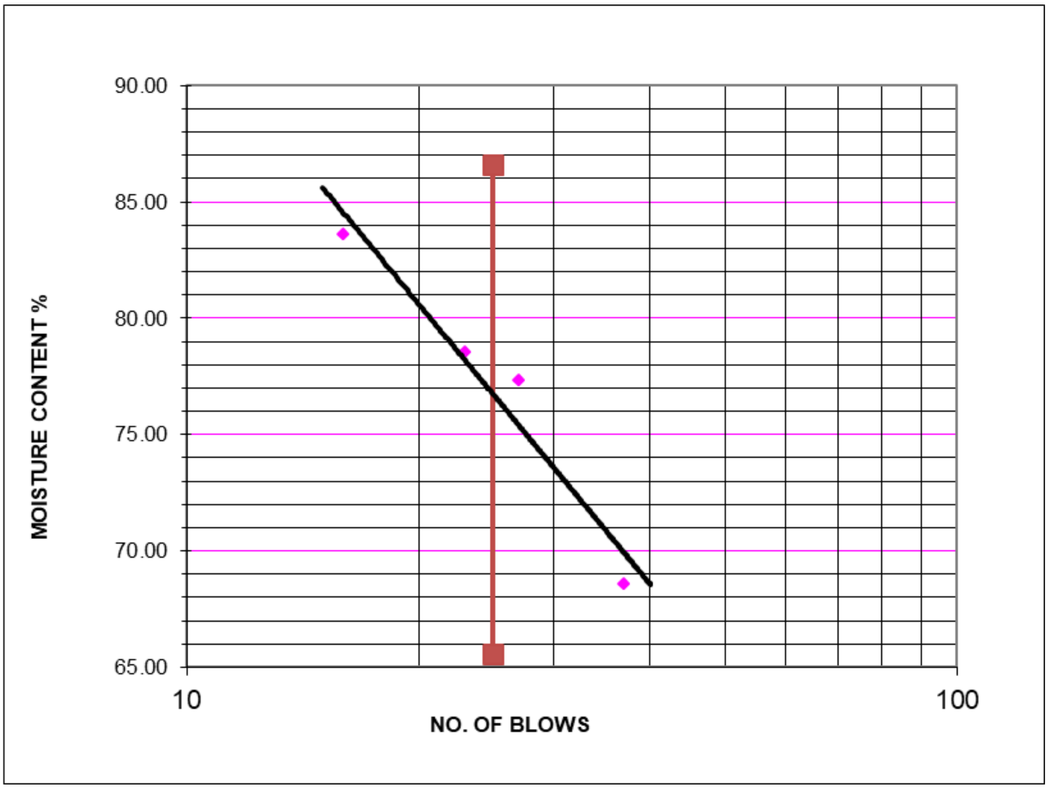

Figure C- 7 flow curve for TP-2 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Table C-8 Atterberg limit for TP-2 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Type of test	**Liquid limit**				**Plastic limit**	
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2
No. of Blows N	35	29	21	15	-	-
Mass of moist Sample + Can M_1	36.99	49.08	53.12	50.76	27.61	27.42
Mass of Dried Sample + Can M_2	28.03	34.55	36.33	34.96	24.22	23.91
Mass of Can M_c	14.59	15.10	14.96	14.94	15.38	14.72
Mass of Moist $M_m=M_1-M_2$	8.96	14.53	16.79	15.80	3.39	3.51
Mass of Dried Sample $M_d=M_2-M_c$	13.44	19.45	21.37	20.02	8.84	9.19
Moisture Content = M_m / M_d x 100	66.67	74.70	78.57	78.92	38.35	38.19

LL = 74.28 % PL = 38.27 % PI = 36.01 %

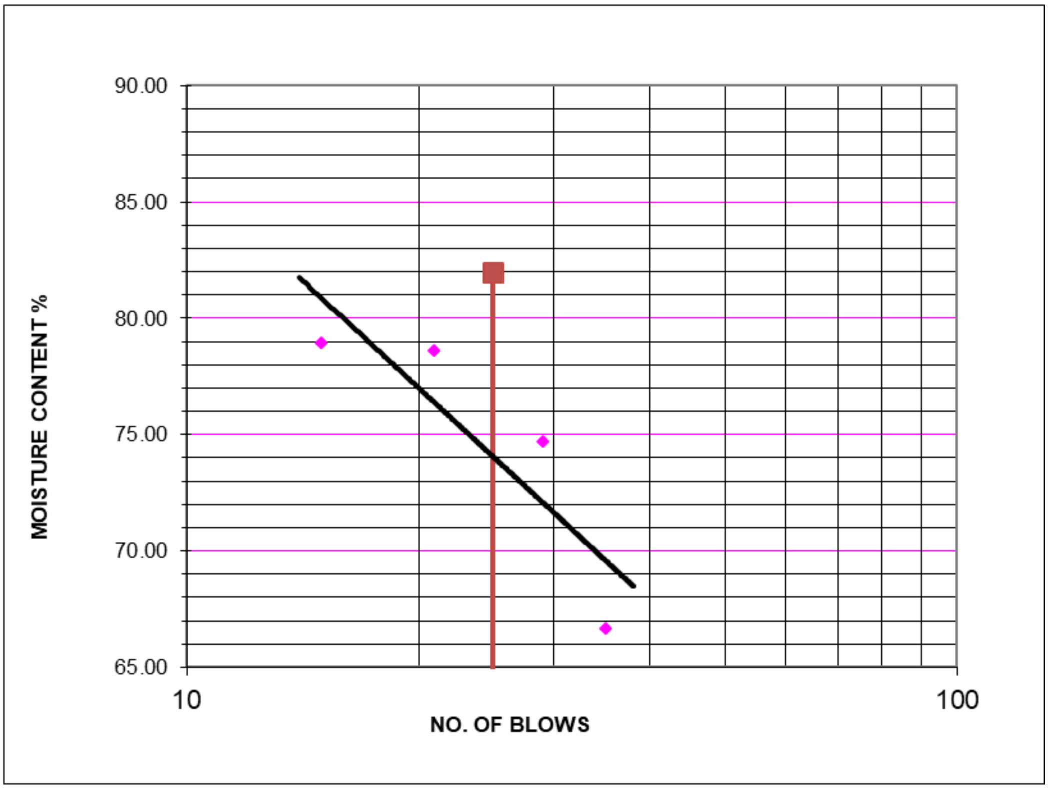

Figure C- 8 flow curve for TP-2 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Table C-9 Atterberg limit for TP-2 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Type of test	**Liquid limit**				**Plastic limit**	
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2
No. of Blows N	36	28	22	14	-	-
Mass of moist Sample + Can M_1	43.84	41.97	44.47	40.52	29.22	29.08
Mass of Dried Sample + Can M_2	32.54	30.89	31.98	29.86	25.38	25.36
Mass of Can M_c	14.72	14.71	14.64	15.12	14.67	15.08
Mass of Moist $M_m=M_1-M_2$	11.30	11.08	12.49	10.66	3.84	3.72
Mass of Dried Sample $M_d=M_2-M_c$	17.82	16.18	17.34	14.74	10.71	10.28
Moisture Content = M_m / M_d x 100	63.41	68.48	72.03	72.32	35.85	36.19

LL = 68.63 % **PL= 36.02** **PI= 32.61**

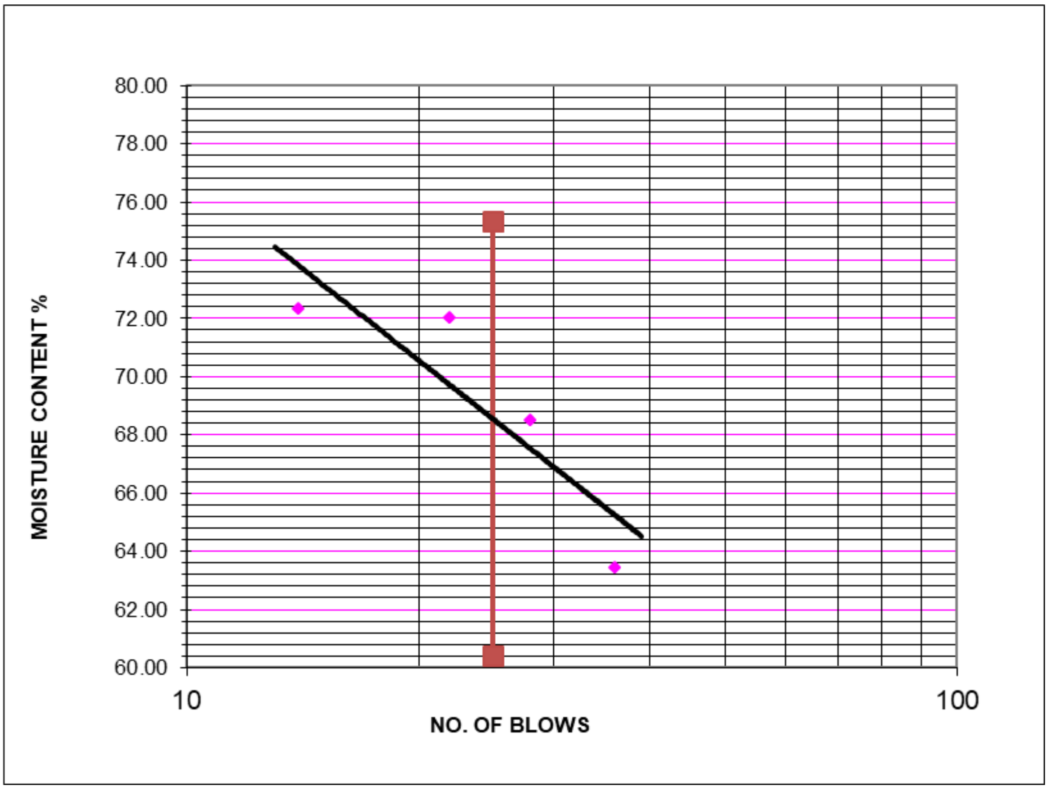

Figure C- 9 flow curve for TP-2 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Table C-10 Atterberg limit for TP-2 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Type of test	**Liquid limit**				**Plastic limit**	
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 1	Trial 2
No. of Blows N	36	26	23	15	-	-
Mass of moist Sample + Can M_1	32.26	37.22	41.32	40.70	27.35	27.78
Mass of Dried Sample + Can M_2	26.90	28.00	31.26	29.38	23.90	24.72
Mass of Can M_c	14.84	14.62	15.21	14.54	14.06	15.23
Mass of Moist $M_m=M_1-M_2$	5.36	9.22	10.06	11.32	3.45	3.06
Mass of Dried Sample $M_d=M_2-M_c$	12.06	13.38	16.05	14.84	9.84	9.49
Moisture Content = M_m / M_d x 100	44.44	68.91	62.68	76.28	35.06	32.24

LL = 62.52 % PL = 33.65 % PI = 28.87 %

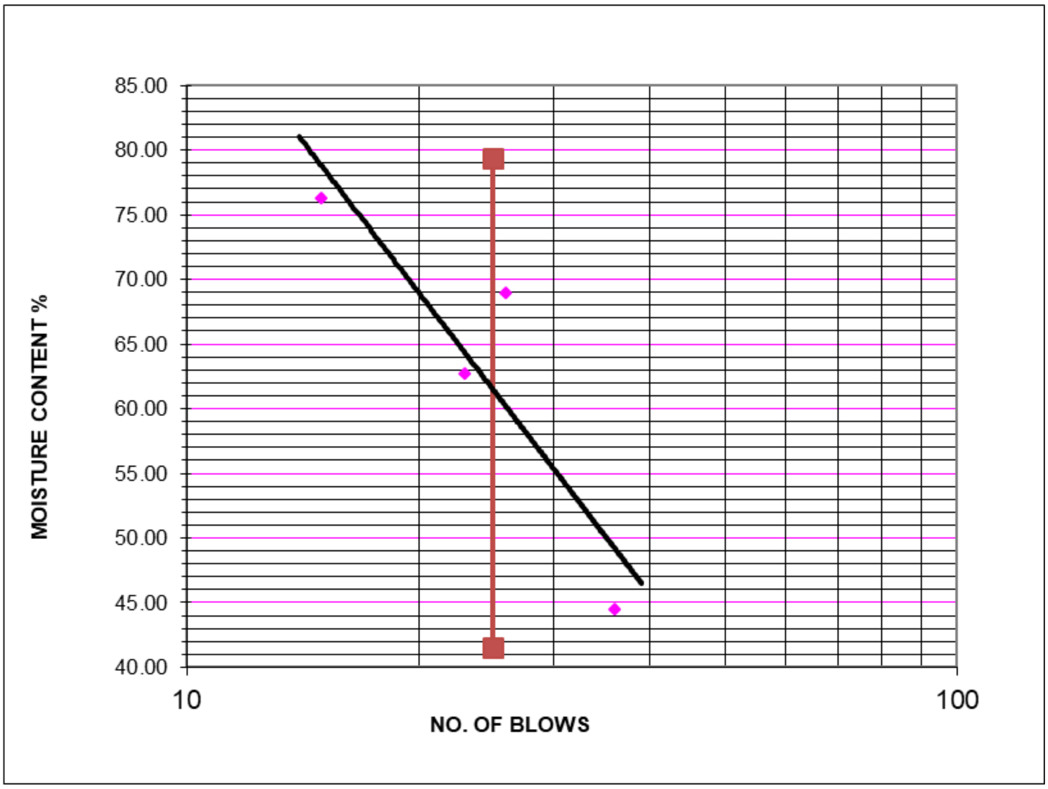

Figure C- 10 flow curve for TP-2 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Appendix D - Compaction Test Results

Compaction properties i.e. maximum dry density (MDD) and optimum moisture content (OMC) were determined in the laboratory of all trial mixture in accordance with ASTM-D 698. Detailed laboratory test analyses are given in this section.

Table D- 1 Compaction test result for TP-1

Trial	1	2	3	4
Wt. of mould + Wet sample(g)	4901	5023.5	5105.5	5100
Wt. of mould (g)	3554.5	3554.5	3554.5	3554.5
Wt. of wet soil(g)	1346.5	1469.0	1551.0	1545.5
Volume of mould cm^3	944	944	944	944
Wet Density gm/cm^3	1.43	1.56	1.64	1.64
Moisture content				
Wet soil + tin (g)	106.60	99.5	103.9	102.3
Dry soil + tin (g)	94.00	84.6	84.8	78.1
Wt. of tin (g)	17.1	16.6	15.9	16.2
Wt. of Water (g)	12.60	14.90	19.10	24.20
Wt. of Dry soil (g)	76.9	68	68.9	61.9
Moisture content %	16.38	21.91	27.72	39.10
Dry Density gm/cm^3	1.226	1.276	1.286	1.177

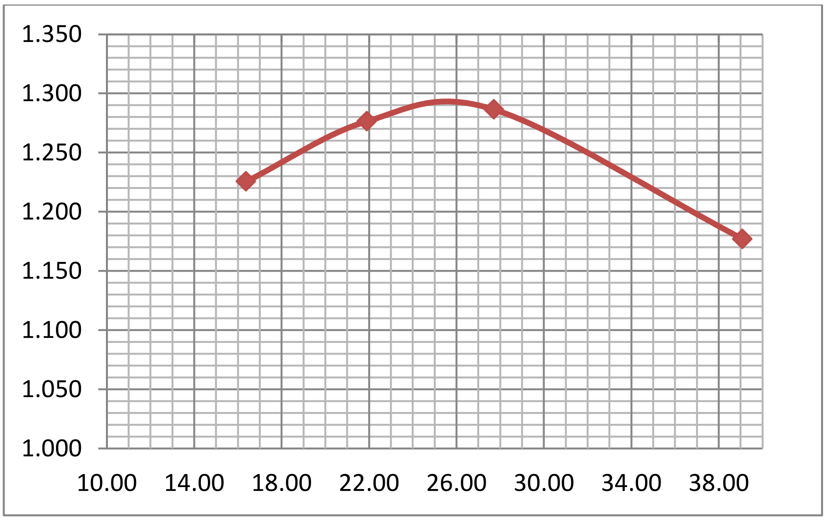

Figure D- 1 Compaction curve for TP-1

Table D- 2 Compaction test result for TP-1 black cotton soil + 4 % sawdust ash

Trial	1	2	3	4
Wt. of mould + Wet sample(g)	4885.7	4992	5081.5	5084.7
Wt. of mould (g)	3554.5	3554.5	3554.5	3554.5
Wt. of wet soil(g)	1331.2	1437.5	1527.0	1530.2
Volume of mould cm^3	944	944	944	944
Wet Density gm /cm^3	1.41	1.52	1.62	1.62
Moisture content				
Wet soil + tin (g)	88.80	88.3	101.1	127.5
Dry soil + tin (g)	75.70	72.5	81.4	96.4
Wt. of tin (g)	16	9.3	10.1	16.6
Wt. of Water (g)	13.10	15.80	19.70	31.10
Wt. of Dry soil (g)	59.7	63.2	71.3	79.8
Moisture content %	21.94	25.00	27.63	38.97
Dry Density gm /cm^3	1.156	1.218	1.267	1.166

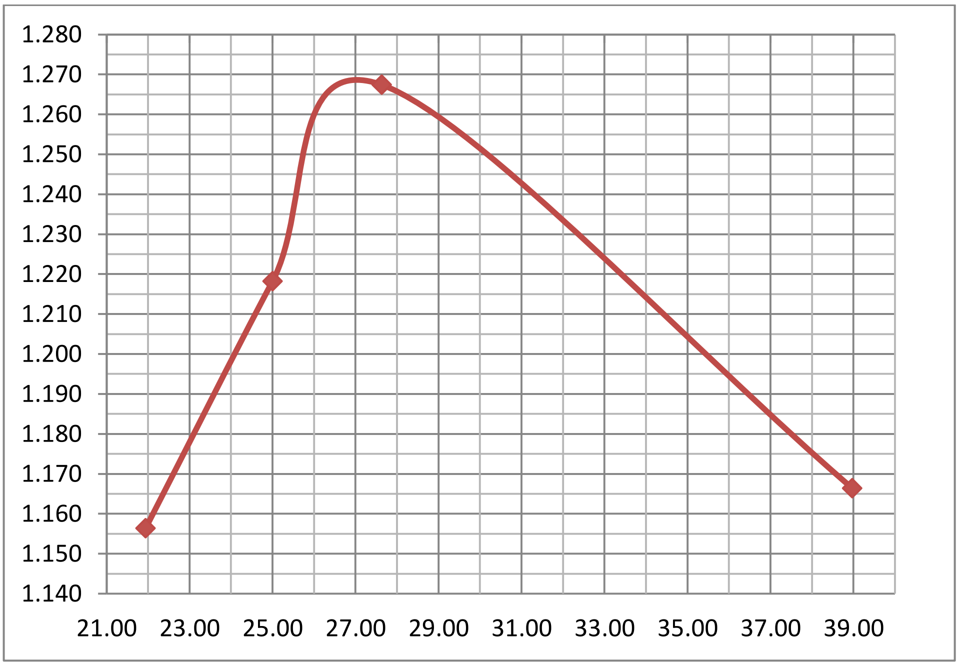

Figure D- 2 Compaction curve for TP-1 black cotton soil + 4 % sawdust ash

Table D- 3 Compaction test result for TP-1 black cotton soil + 8 % sawdust ash

Trial	1	2	3	4
Wt. of mould + Wet sample(g)	4736.9	4860.8	4906.7	4924.0
Wt. of mould (g)	3354.5	3354.5	3354.5	3354.5
Wt. of wet soil(g)	1382.4	1506.3	1552.2	1569.5
Volume of mould cm^3	944	944	944	944
Wet Density gm /cm^3	1.46	1.60	1.64	1.66
Moisture content				
Wet soil + tin (g)	84.70	88.8	119.4	158.5
Dry soil + tin (g)	71.60	71.8	93.6	120.9
Wt. of tin (g)	16.3	9.8	9.9	16.0
Wt. of Water (g)	13.10	17.00	25.80	37.60
Wt. of Dry soil (g)	55.3	62	83.7	104.9
Moisture content %	23.69	27.42	30.82	35.84
Dry Density gm /cm^3	1.184	1.252	1.257	1.224

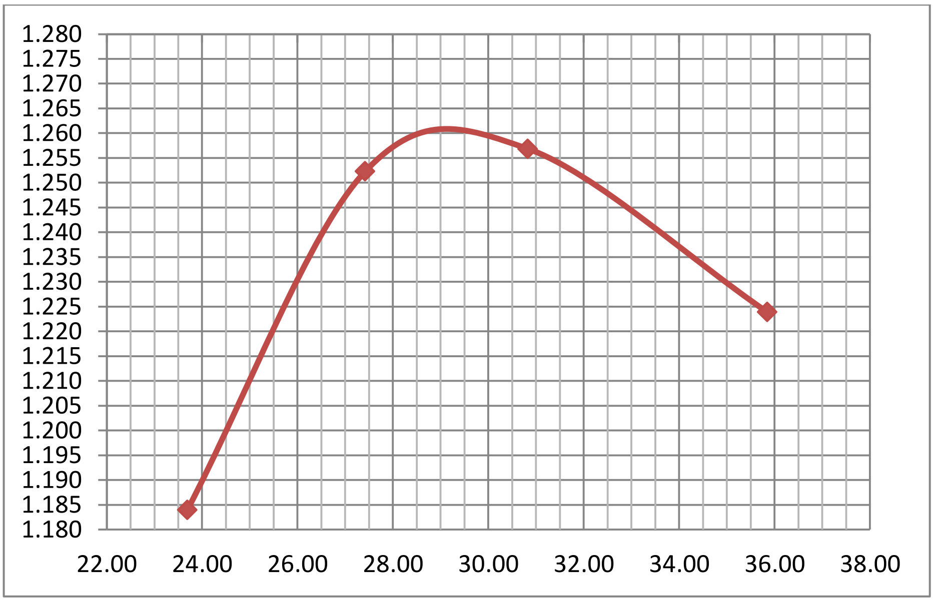

Figure D- 3 Compaction curve for TP-1 black cotton soil + 8 % sawdust ash

Table D- 4 Compaction test result for TP-1 black cotton soil + 12 % sawdust ash

Trial	1	2	3	4
Wt. of mould + Wet sample(g)	4645.7	4817.4	4896.7	4860.4
Wt. of mould (g)	3354.0	3354.0	3354.0	3354.0
Wt. of wet soil(g)	1291.7	1463.4	1542.7	1506.4
Volume of mould cm3	944	944	944	944
Wet Density gm /cm3	1.37	1.55	1.63	1.60
Moisture content				
Wet soil + tin (g)	62.30	91	108.7	108.8
Dry soil + tin (g)	54.40	74.3	85.4	83.5
Wt. of tin (g)	16.3	16.7	16.9	16.8
Wt. of Water (g)	7.90	16.70	23.30	25.30
Wt. of Dry soil (g)	38.1	57.6	68.5	66.7
Moisture content %	20.73	28.99	34.01	37.93
Dry Density gm /cm^3	1.133	1.202	1.219	1.157

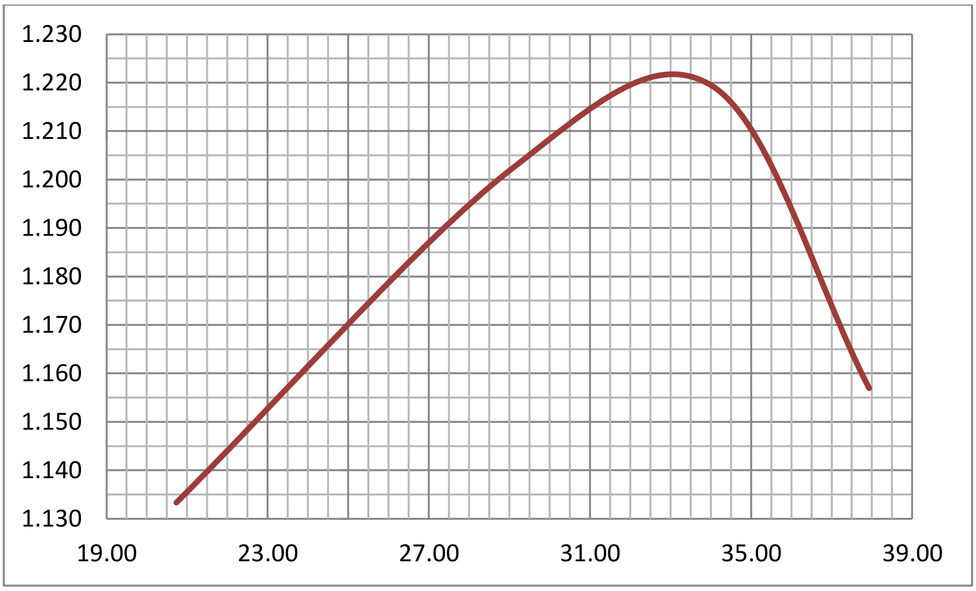

Figure D- 4 Compaction curve for TP-1 black cotton soil + 12 % sawdust ash

Table D- 5 Compaction test result for TP-1 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Trial	1	2	3	4
Wt. of mould + Wet sample(g)	4687.7	4926.6	5079.1	4928.1
Wt. of mould (g)	3538.3	3538.3	3538.3	3538.3
Wt. of wet soil(g)	1149.4	1388.3	1540.8	1389.8
Volume of mould cm3	944	944	944	944
Wet Density gm /cm3	1.22	1.47	1.63	1.47
Moisture content				
Wet soil + tin (g)	88.30	84.8	120.5	132.7
Dry soil + tin (g)	78.10	72.1	97.1	101
Wt. of tin (g)	16.6	16.7	16.4	17.5
Wt. of Water (g)	10.20	12.70	23.40	31.70
Wt. of Dry soil (g)	61.5	55.4	80.7	83.5
Moisture content %	16.59	22.92	29.00	37.96
Dry Density gm /cm^3	1.044	1.196	1.265	1.067

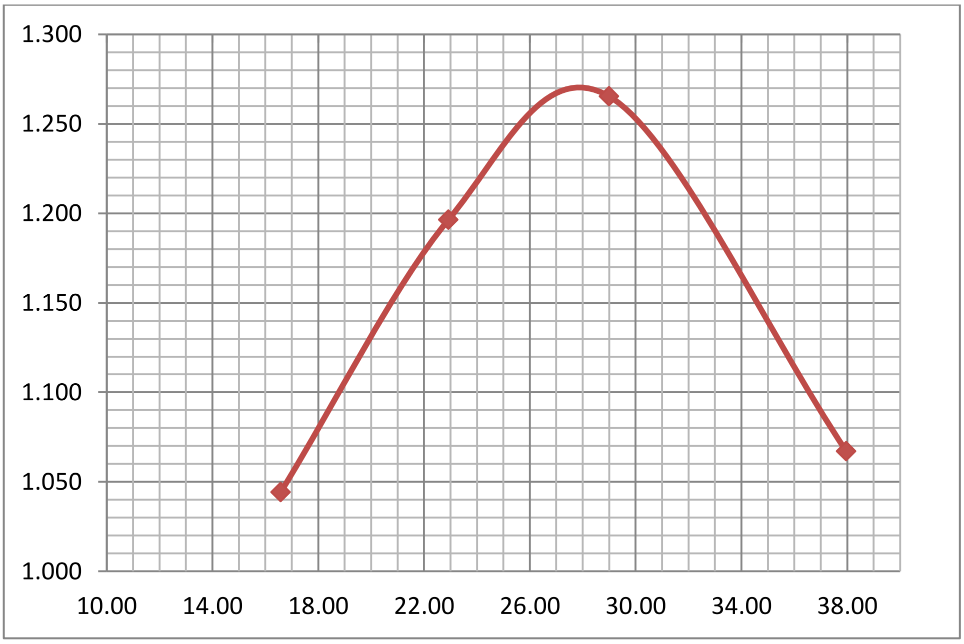

Figure D- 5 Compaction curve for TP-1 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Table D- 6 Compaction test result for TP-1 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Trial	1	2	3
Wt. of mould + Wet sample(g)	4892.6	5093.2	4991.7
Wt. of mould (g)	3538.3	3538.3	3538.3
Wt. of wet soil(g)	1354.3	1554.9	1453.4
Volume of mould cm^3	944	944	944
Wet Density gm/cm^3	1.43	1.65	1.54
Moisture content			
Wet soil + tin (g)	78.30	87.8	111.3
Dry soil + tin (g)	66.90	72.2	87.9
Wt. of tin (g)	15.6	16.1	16.1
Wt. of Water (g)	11.40	15.60	23.40
Wt. of Dry soil (g)	51.3	56.1	71.8
Moisture content %	22.22	27.81	32.59
Dry Density gm/cm^3	1.174	1.289	1.161

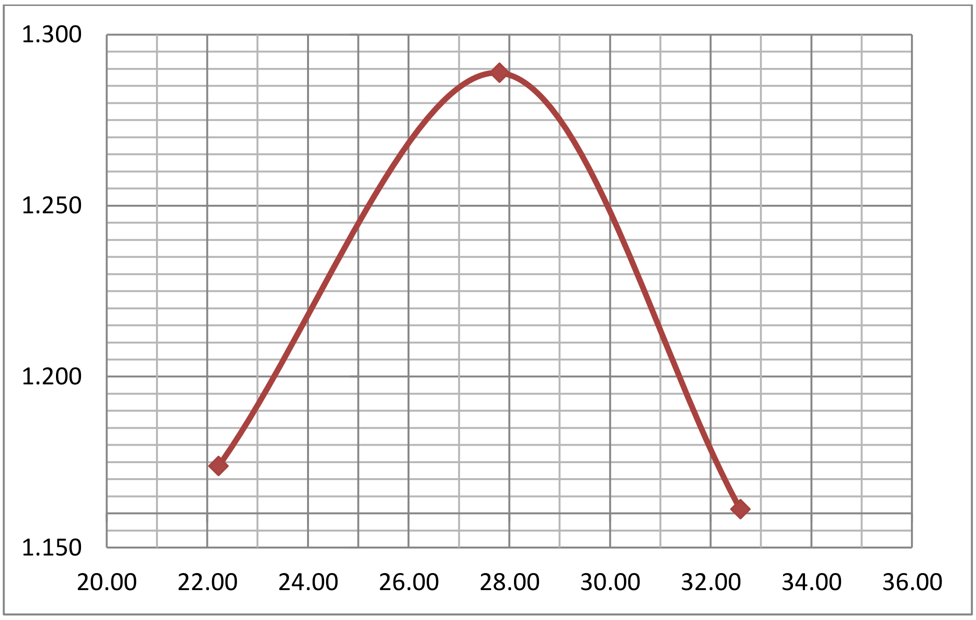

Figure D- 6 Compaction curve for TP-1 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Table D- 7 Compaction test result for TP-1 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Trial	1	2	3
Wt. of mould + Wet sample(g)	4903.8	5088.6	4960.9
Wt. of mould (g)	3538.3	3538.3	3538.3
Wt. of wet soil(g)	1365.5	1550.3	1422.6
Volume of mould cm^3	944	944	944
Wet Density gm /cm^3	1.45	1.64	1.51
Moisture content			
Wet soil + tin (g)	88.00	82.1	134.9
Dry soil + tin (g)	76.50	68.3	104.5
Wt. of tin (g)	16.6	16.2	9.9
Wt. of Water (g)	11.50	13.80	30.40
Wt. of Dry soil (g)	59.9	52.1	94.6
Moisture content %	19.20	26.49	32.14
Dry Density gm /cm^3	1.214	1.298	1.140

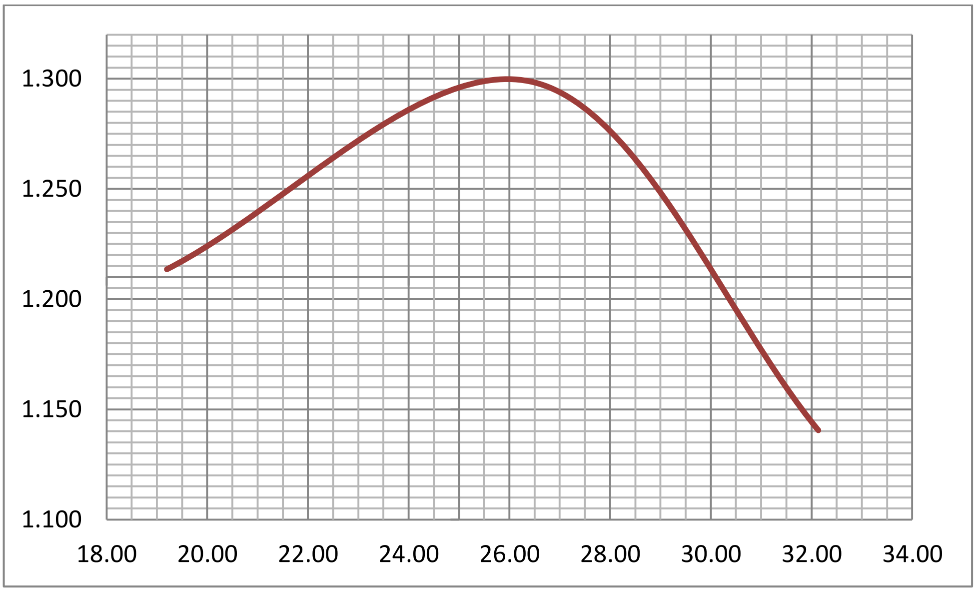

Figure D- 7 Compaction curve for TP-1 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Table D- 8 Compaction test result for TP-1 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Trial	1	2	3	4
Wt. of mould + Wet sample(g)	4892.2	4988.3	5125.6	4992.4
Wt. of mould (g)	3538.3	3538.3	3538.3	3538.3
Wt. of wet soil(g)	1353.9	1450.0	1587.3	1454.1
Volume of mould cm^3	944	944	944	944
Wet Density gm /cm^3	1.43	1.54	1.68	1.54
Moisture content				
Wet soil + tin (g)	87.00	86.2	147.4	178.7
Dry soil + tin (g)	74.90	72.9	120.2	138.5
Wt. of tin (g)	9.4	10.9	16.6	16.2
Wt. of Water (g)	12.10	13.30	27.20	40.20
Wt. of Dry soil (g)	65.5	62	103.6	122.3
Moisture content %	18.47	21.45	26.25	32.87
Dry Density gm /cm^3	1.211	1.265	1.332	1.159

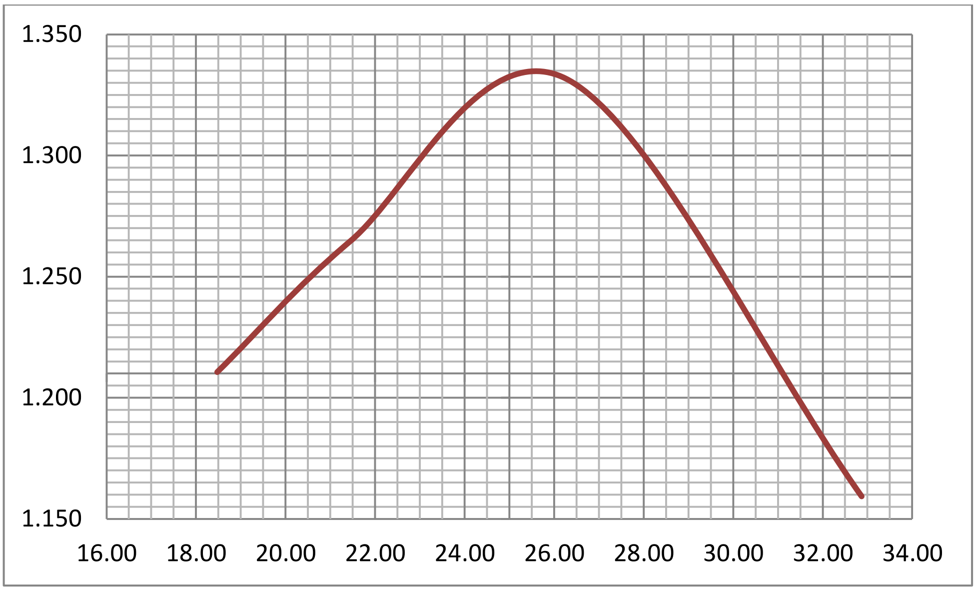

Figure D- 8 Compaction curve for TP-1 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Table D- 9 Compaction test result for TP-2 natural soil

Trial	1	2	3
Wt. of mould + Wet sample(g)	4964	5147.2	5116.3
Wt. of mould (g)	3554.5	3554.5	3554.5
Wt. of wet soil(g)	1409.5	1592.7	1561.8
Volume of mould cm^3	944	944	944
Wet Density gm /cm^3	1.49	1.69	1.65
Moisture content			
Wet soil + tin (g)	87.80	127.1	149.5
Dry soil + tin (g)	74.90	98.4	110.2
Wt. of tin (g)	16.3	10.2	16.7
Wt. of Water (g)	12.90	28.70	39.30
Wt. of Dry soil (g)	58.6	88.2	93.5
Moisture content %	22.01	32.54	42.03
Dry Density gm /cm^3	1.224	1.273	1.165

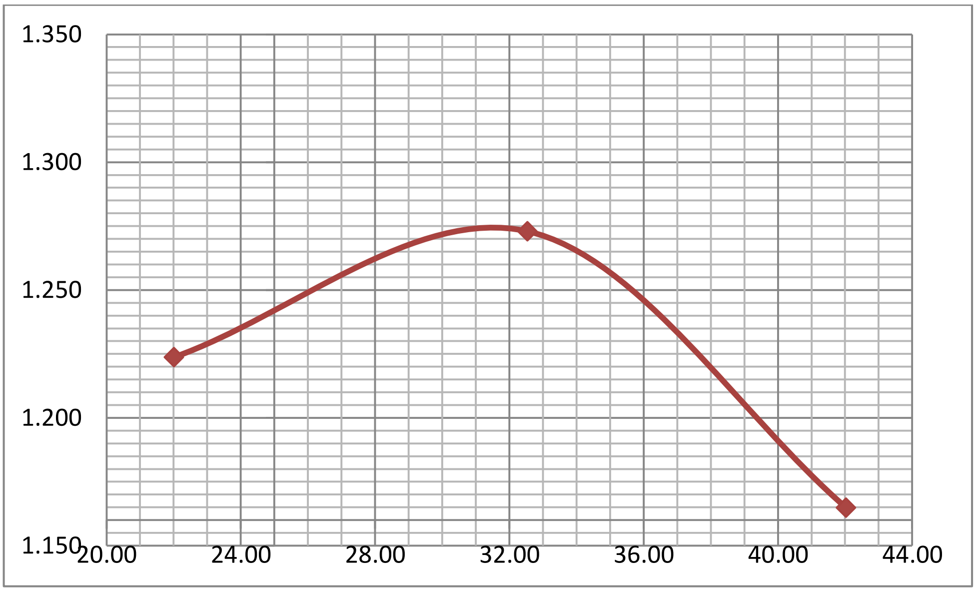

Figure D- 9 Compaction curve for TP-2 natural black cotton soil

Table D- 10 Compaction test result for TP-2 black cotton soil + 4 % sawdust ash

Trial	1	2	3
Wt. of mould + Wet sample(g)	4340	4584	4514.4
Wt. of mould (g)	2999.5	2999.5	2999.5
Wt. of wet soil(g)	1340.5	1584.5	1514.9
Volume of mould cm^3	944	944	944
Wet Density gm/cm^3	1.42	1.68	1.60
Moisture content			
Wet soil + tin (g)	88.30	93.9	119.1
Dry soil + tin (g)	70.30	74.5	89.9
Wt. of tin (g)	10.7	16.7	16.9
Wt. of Water (g)	18.00	19.40	29.20
Wt. of Dry soil (g)	59.6	57.8	73
Moisture content %	30.20	33.56	40.00
Dry Density gm/cm^3	1.091	1.257	1.146

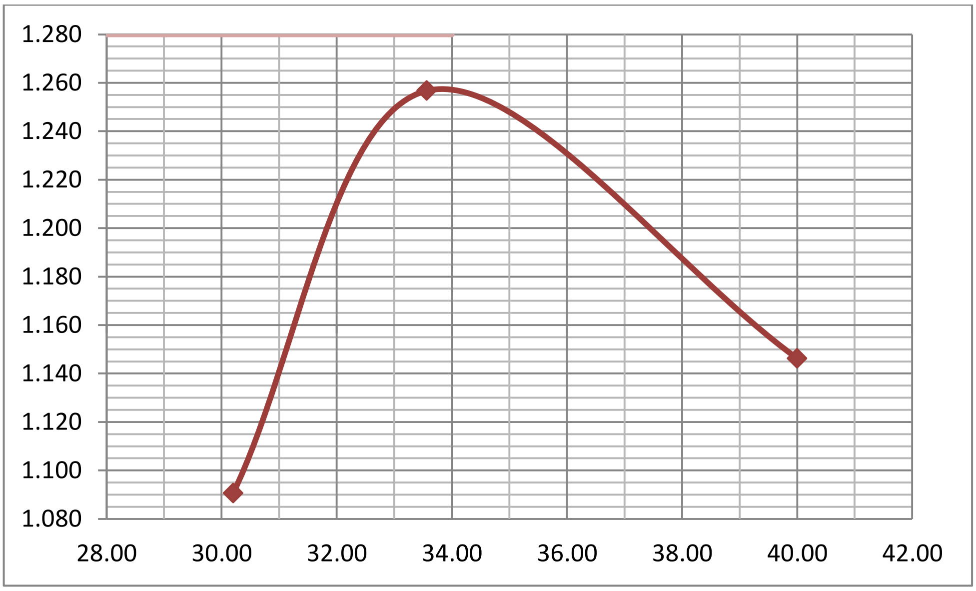

Figure D- 10 Compaction curve for TP-2 black cotton soil + 4 % sawdust ash

Table D- 11 Compaction test result for TP-2 black cotton soil + 8 % sawdust ash

Trial	1	2	3	4
Wt. of mould + Wet sample(g)	4206.8	4418.5	4440.5	4390.5
Wt. of mould (g)	2849.5	2849.5	2849.5	2849.5
Wt. of wet soil(g)	1357.3	1569.0	1591.0	1541.0
Volume of mould cm^3	944	944	944	944
Wet Density gm /cm^3	1.44	1.66	1.69	1.63
Moisture content				
Wet soil + tin (g)	103.70	104.7	128.6	130.9
Dry soil + tin (g)	86.20	82.4	98.3	97.3
Wt. of tin (g)	8.9	16.1	16.4	16.5
Wt. of Water (g)	17.50	22.30	30.30	33.60
Wt. of Dry soil (g)	77.3	66.3	81.9	80.8
Moisture content %	22.64	33.63	37.00	41.58
Dry Density gm /cm^3	1.172	1.244	1.230	1.153

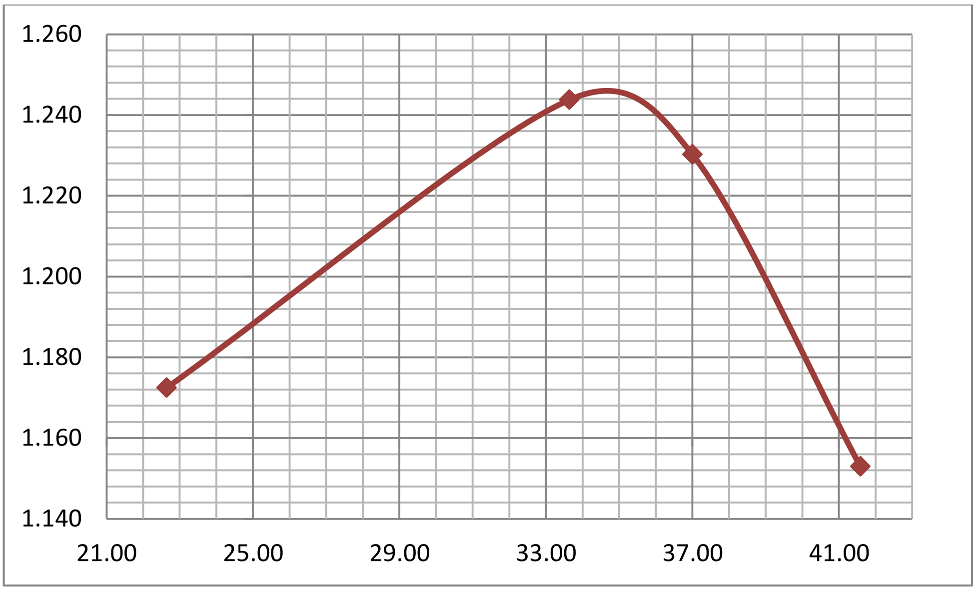

Figure D- 11 Compaction curve for TP-2 black cotton soil + 8 % sawdust ash

Table D- 12 Compaction test result for TP-2 black cotton soil + 12 % sawdust ash

Trial	1	2	3	4
Wt. of mould + Wet sample(g)	4177.1	4300.8	4398.6	4386.8
Wt. of mould (g)	2849.5	2849.5	2849.5	2849.5
Wt. of wet soil(g)	1327.6	1451.3	1549.1	1537.3
Volume of mould cm^3	944	944	944	944
Wet Density gm /cm^3	1.41	1.54	1.64	1.63
Moisture content				
Wet soil + tin (g)	79.90	122.5	103.3	109.4
Dry soil + tin (g)	65.60	95.6	79.7	82.1
Wt. of tin (g)	17.3	16.9	17.6	17.7
Wt. of Water (g)	14.30	26.90	23.60	27.30
Wt. of Dry soil (g)	48.3	78.7	62.1	64.4
Moisture content %	29.61	34.18	38.00	42.39
Dry Density gm /cm^3	1.085	1.146	1.189	1.144

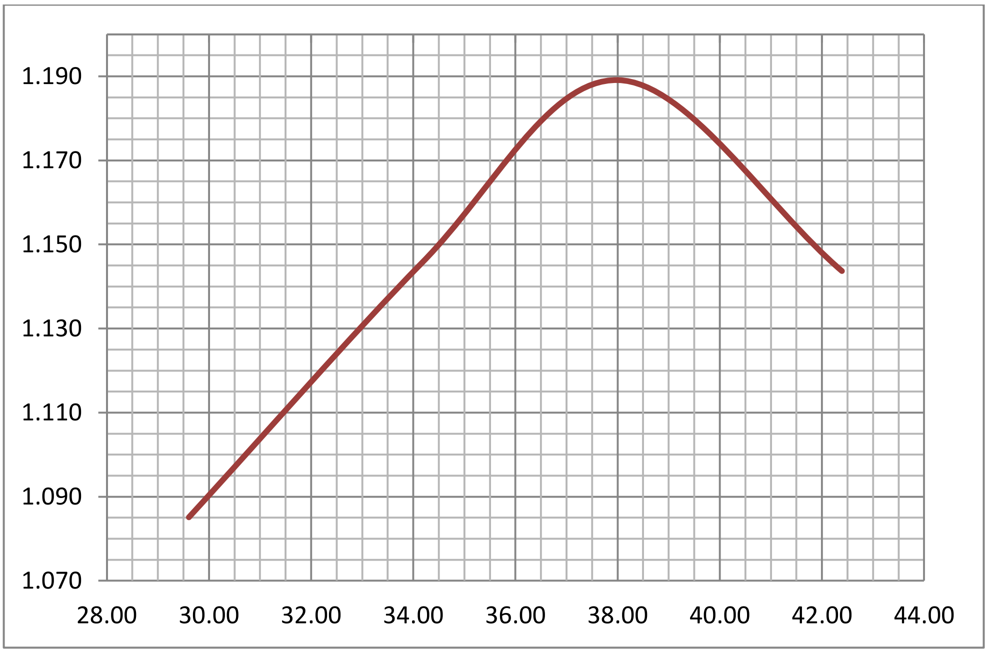

Figure D- 12 Compaction curve for TP-2 black cotton soil + 12 % sawdust ash

Table D- 13 Compaction test result for TP-2 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Trial	1	2	3
Wt. of mould + Wet sample(g)	4879.7	5105.1	5011.6
Wt. of mould (g)	3538.3	3538.3	3538.3
Wt. of wet soil(g)	1341.4	1566.8	1473.3
Volume of mould cm^3	944	944	944
Wet Density gm/cm^3	1.42	1.66	1.56
Moisture content			
Wet soil + tin (g)	109.00	73.3	114.6
Dry soil + tin (g)	90.40	59.6	89.8
Wt. of tin (g)	16.3	16.4	17.8
Wt. of Water (g)	18.60	13.70	24.80
Wt. of Dry soil (g)	74.1	43.2	72
Moisture content %	25.10	31.71	34.44
Dry Density gm/cm^3	1.136	1.260	1.161

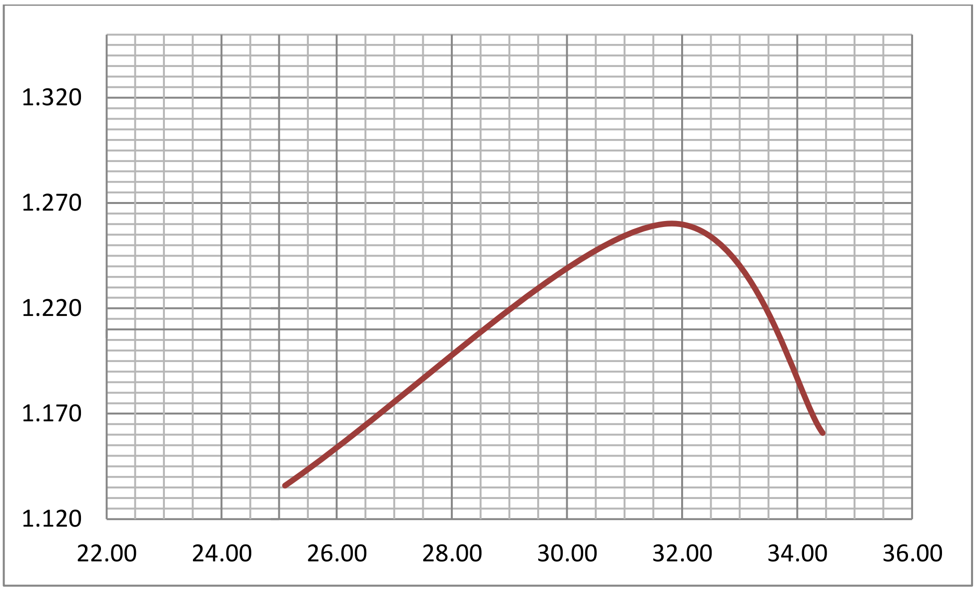

Figure D- 13 Compaction curve for TP-2 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Table D- 14 Compaction test result for TP-2 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Trial	1	2	3	4
Wt. of mould + Wet sample(g)	4805.7	4968.5	5118.8	5071.2
Wt. of mould (g)	3538.3	3538.3	3538.3	3538.3
Wt. of wet soil(g)	1267.4	1430.2	1580.5	1532.9
Volume of mould cm^3	944	944	944	944
Wet Density gm /cm^3	1.34	1.52	1.67	1.62
Moisture content				
Wet soil + tin (g)	102.70	99.7	131.5	152.6
Dry soil + tin (g)	88.40	82.8	104.7	113.6
Wt. of tin (g)	16.2	16.8	16.7	9.9
Wt. of Water (g)	14.30	16.90	26.80	39.00
Wt. of Dry soil (g)	72.2	66	88	103.7
Moisture content %	19.81	25.61	30.45	37.61
Dry Density gm /cm^3	1.121	1.206	1.283	1.180

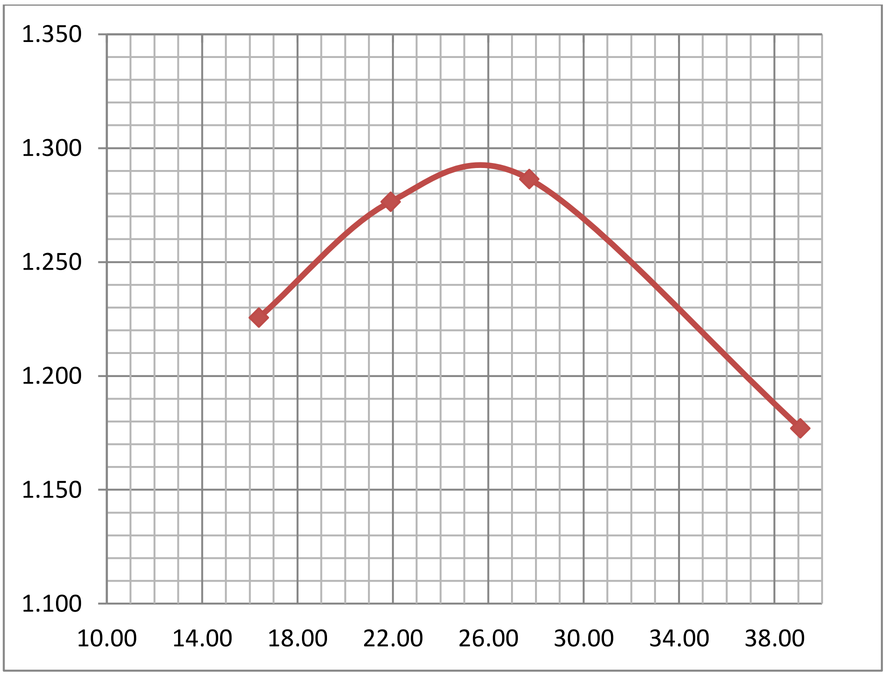

Figure D- 14 Compaction curve for TP-2 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Table D- 15 Compaction test result for TP-2 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Trial	1	2	3	4
Wt.of mould + Wet sample(g)	4864.8	4980.6	5116.7	4960.2
Wt. of mould (g)	3538.3	3538.3	3538.3	3538.3
Wt. of wet soil(g)	1326.5	1442.3	1578.4	1421.9
Volume of mould cm^3	944	944	944	944
Wet Density gm /cm^3	1.41	1.53	1.67	1.51
Moisture content				
Wet soil + tin (g)	88.20	72.6	149.6	164.7
Dry soil + tin (g)	73.60	61.2	119.5	130.2
Wt. of tin (g)	9.5	16.6	16.0	16.5
Wt. of Water (g)	14.60	11.40	30.10	34.50
Wt. of Dry soil (g)	64.1	44.6	103.5	113.7
Moisture content %	22.78	25.56	29.08	30.34
Dry Density gm /cm^3	1.145	1.217	1.295	1.156

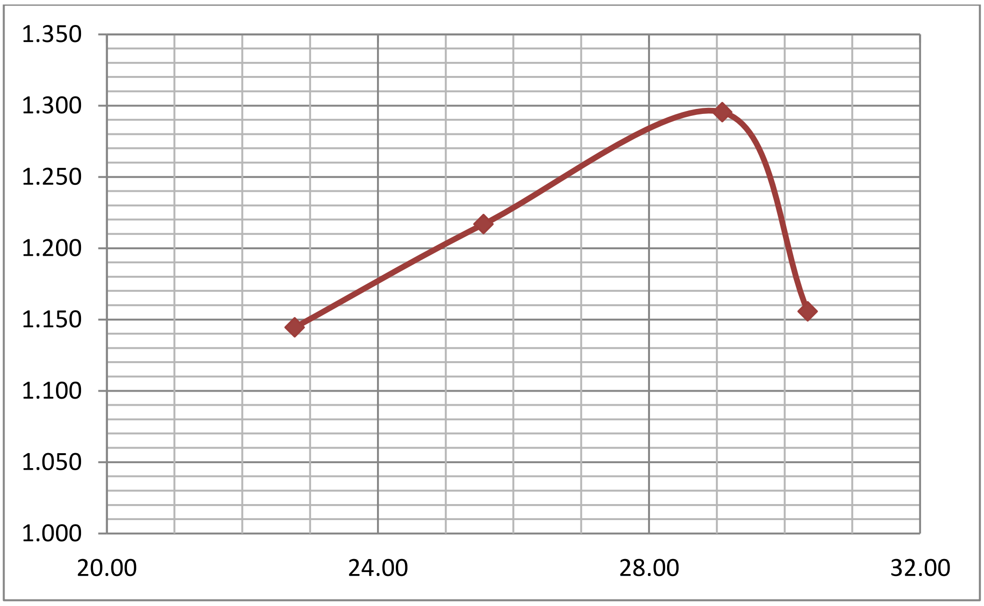

Figure D- 15 Compaction curve for TP-2 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Table D- 16 Compaction test result for TP-2 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Trial	1	2	3
Wt. of mould + Wet sample(g)	4874.3	5108.2	4999.5
Wt. of mould (g)	3538.3	3538.3	3538.3
Wt. of wet soil(g)	1336.0	1569.9	1461.2
Volume of mould cm^3	944	944	944
Wet Density gm/cm^3	1.42	1.66	1.55
Moisture content			
Wet soil + tin (g)	81.80	128	158.5
Dry soil + tin (g)	71.40	104.9	129.8
Wt. of tin (g)	16.5	17.3	33.4
Wt. of Water (g)	10.40	23.10	28.70
Wt. of Dry soil (g)	54.9	87.6	96.4
Moisture content %	18.94	26.37	29.77
Dry Density gm/cm^3	1.190	1.316	1.193

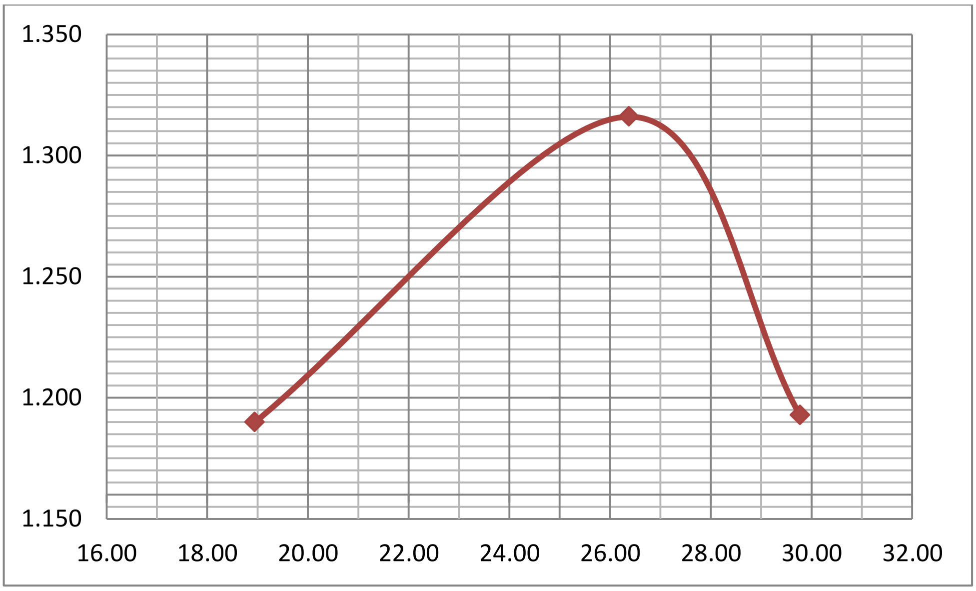

Figure D- 16 Compaction curve for TP-2 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Appendix E - California Bearing Ratio Test Results

CBR test has been done for all samples to determine the strength character of the treated and untreated black cotton soils. Detailed laboratory test analyses are given in this section.

Table E- 1 CBR test result for TP-1 natural black cotton soil

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046761	0.00		
0.64	1.0		0.05		
1.27	2.0		0.09		
1.96	2.5		0.12		
2.54	2.5		0.12	13.2	0.89
3.18	2.6		0.12		
3.81	2.7		0.13		
5.08	3.0		0.14	20	0.70
7.62	4.0		0.19		
Swell Data (%)		**1217**	**2118**	**7.09**	

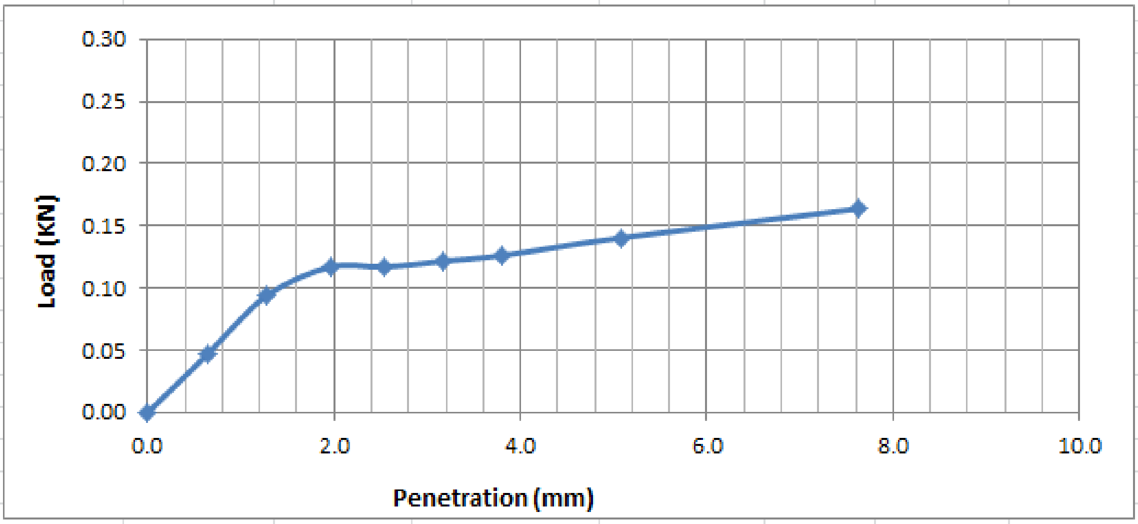

Figure E- 1 CBR load - penetration curve for TP-1 natural black cotton soil

Table E- 2 CBR test result for TP-1 black cotton soil + 4 % sawdust ash

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046761	0.00		
0.64	1.5		0.07		
1.27	2.0		0.09		
1.96	2.5		0.12		
2.54	3.0		0.14	13.2	1.06
3.18	3.0		0.14		
3.81	3.5		0.16		
4.45	3.5		0.16		
5.08	4.0		0.19	20	0.94
7.62	4.5		0.21		
Swell Data (%)		**994**	**1880**	**6.98**	

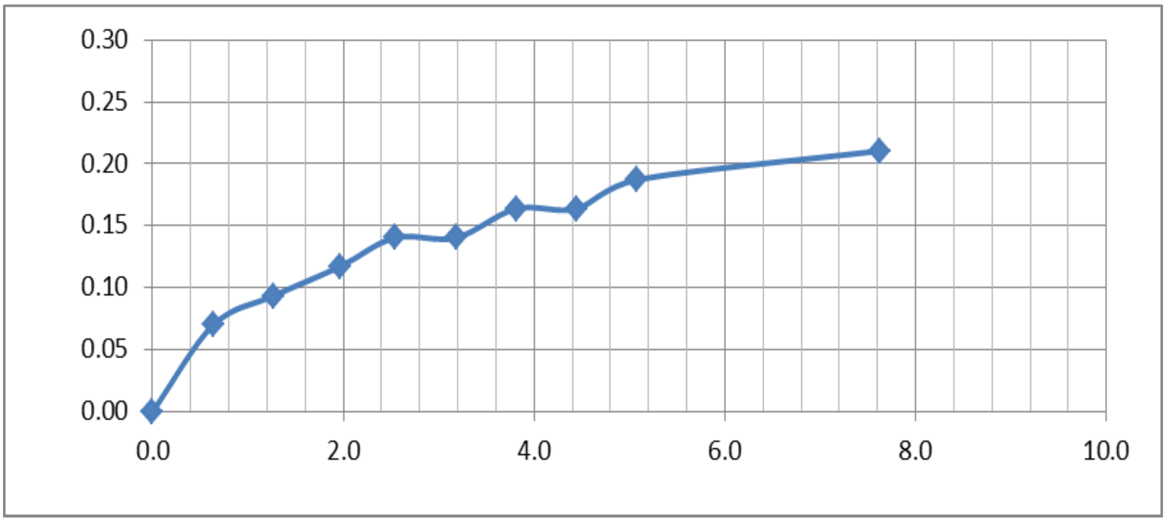

Figure E- 2 CBR load-penetration curve for TP-1 black cotton soil + 4 % sawdust ash

Table E-3 CBR test result for TP-1 black cotton soil + 8 % sawdust ash

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046450	0.00		
0.64	2.0		0.09		
1.27	3.0		0.14		
1.96	3.5		0.16		
2.54	4.0		0.19	13.2	1.42
3.18	4.5		0.21		
3.81	5.5		0.26		
4.45	6.0		0.28		
5.08	6.5		0.30	20	1.52
7.62	7.0		0.33		
Swell Data		**1982**	**2750**	**6.05**	

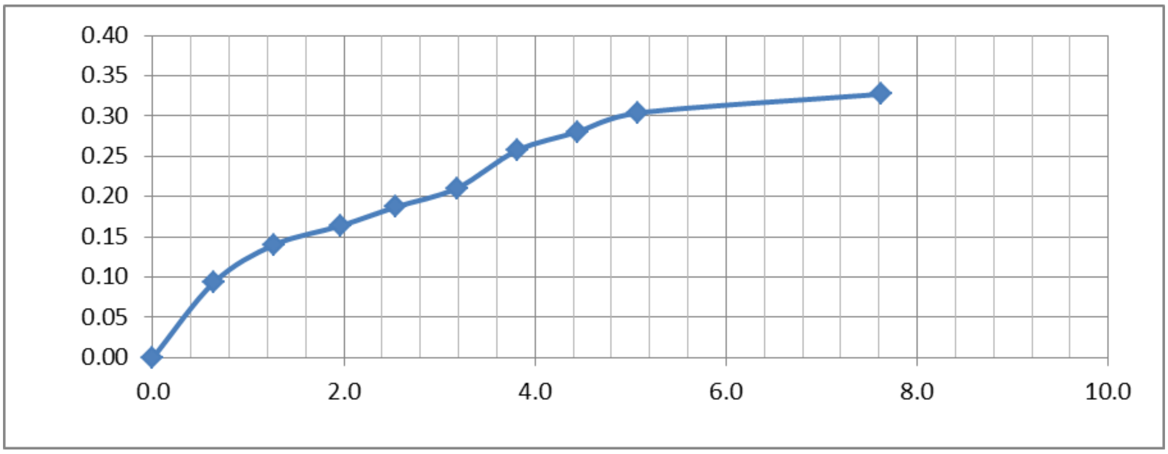

Figure E- 3 CBR load-penetration curve for TP-1 black cotton soil + 8 % sawdust ash

Table E- 4 CBR test result for TP-1 black cotton soil + 12 % sawdust ash

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046761	0.00		
0.64	2.0		0.09		
1.27	3.0		0.14		
1.96	3.5		0.16		
2.54	4.0		0.19	13.2	1.42
3.18	4.5		0.21		
3.81	5.0		0.23		
4.45	5.5		0.26		
5.08	6.0		0.28	20	1.40
7.62	6.5		0.30		
Swell Data (%)		**285**	**1055**	**6.06**	

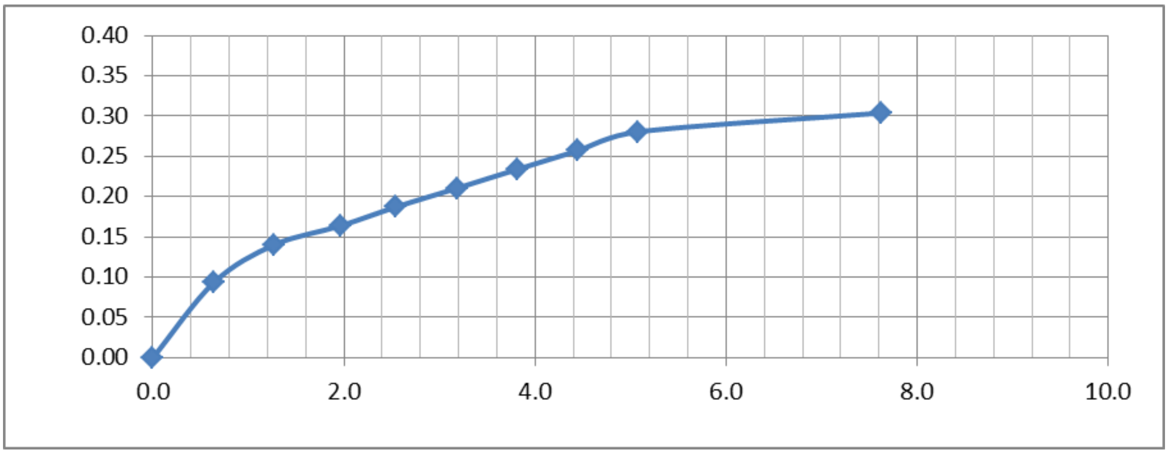

Figure E- 4 CBR load-penetration curve for TP-1 black cotton soil + 12 % sawdust ash

Table E- 5 CBR test result for TP-1 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046450	0.00		
0.64	1.0		0.05		
1.27	2.5		0.12		
1.96	4.0		0.19		
2.54	5.0		0.23	13.2	1.77
3.18	5.5		0.26		
3.81	6.5		0.30		
4.45	7.0		0.33		
5.08	7.0		0.33	20	1.75
7.62	8.0		0.37		
Swell Data		**1370**	**2122**	**5.92**	

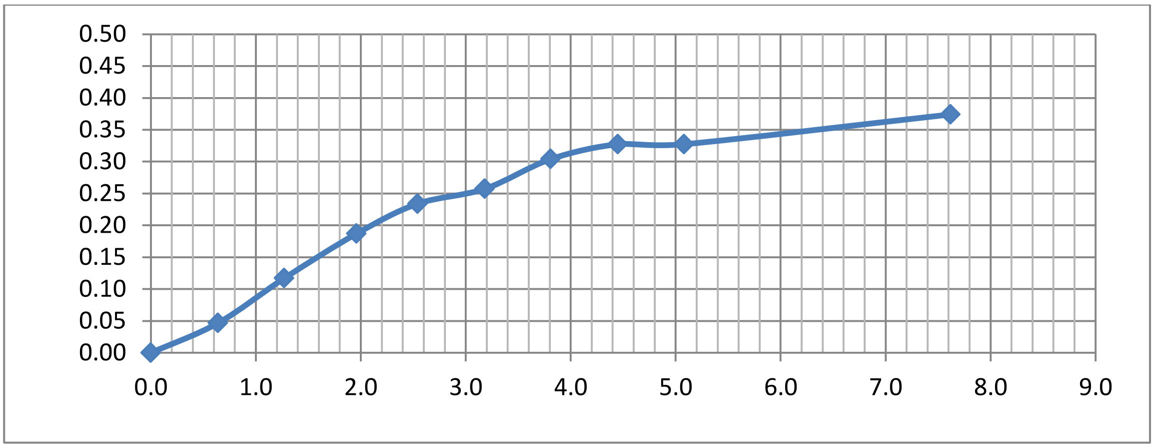

Figure E- 5 CBR load-penetration curve for TP-1 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Table E- 6 CBR test result for TP-1 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046450	0.00		
0.64	1.0		0.05		
1.27	3.0		0.14		
1.96	6.0		0.28		
2.54	7.0		0.33	13.2	2.48
3.18	7.5		0.35		
3.81	8.0		0.37		
4.45	8.5		0.40		
5.08	9.0		0.42	20	2.10
7.62	10.0		0.47		
Swell Data (%)		**327**	**1055**	**5.73**	

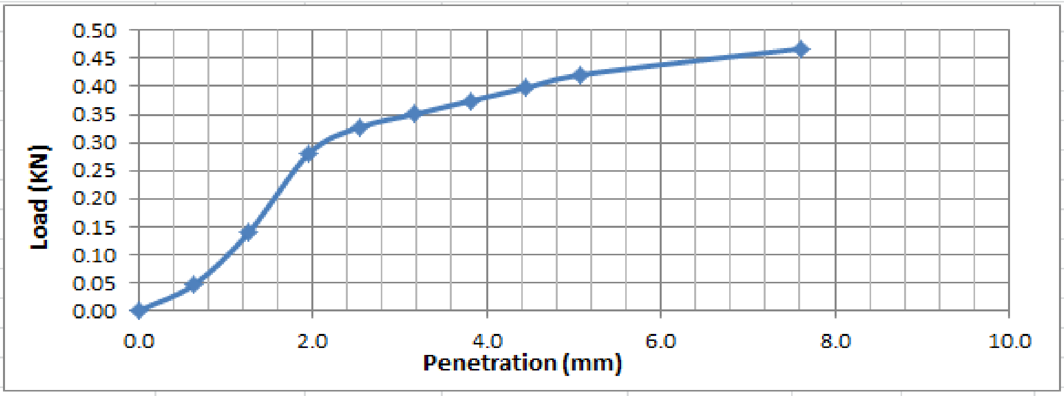

Figure E-6 CBR load-penetration curve for TP-1 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Table E- 7 CBR test result for TP-1 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046450	0.00		
0.64	3.0		0.14		
1.27	4.5		0.21		
1.96	6.0		0.28		
2.54	6.5		0.30	13.2	2.30
3.18	7.0		0.33		
3.81	7.5		0.35		
4.45	8.0		0.37		
5.08	8.5		0.40	20	1.99
7.62	10.0		0.47		
Swell Data (%)		**1970**	**2678**	**5.57**	

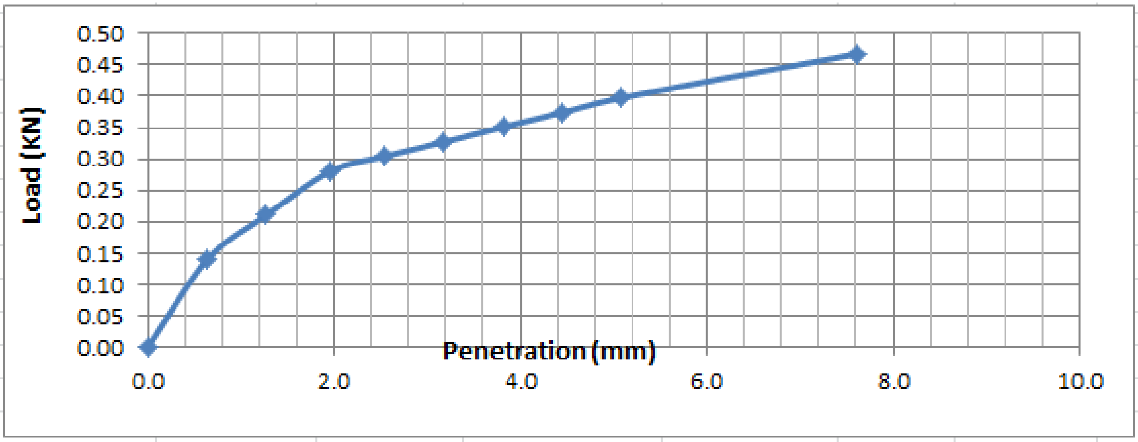

Figure E- 7 CBR load-penetration curve for TP-1 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Table E- 8 CBR test result for TP-1 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046450	0.00		
0.64	3.0		0.14		
1.27	4.0		0.19		
1.96	5.0		0.23		
2.54	6.0		0.28	13.2	2.13
3.81	6.5		0.30		
4.45	7.0		0.33		
5.08	7.5		0.35	20	1.75
7.62	9.0		0.42		
Swell Data (%)		**1448**	**2142**	**5.46**	

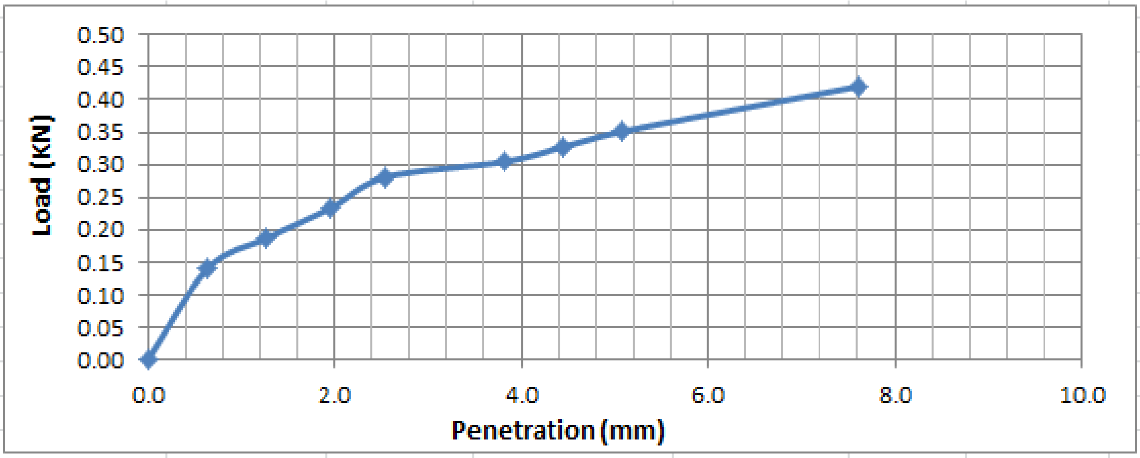

Figure E- 8 CBR load-penetration curve for TP-1 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Table E- 9 CBR test result for TP-2 natural black cotton soil

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046761	0.00		
0.64	2.0		0.09		
1.27	3.0		0.14		
1.96	3.5		0.16		
2.54	5.0		0.23	13.2	1.77
3.18	6.0		0.28		
3.81	6.0		0.28		
4.45	6.5		0.30		
5.08	7.0		0.33	20	1.64
7.62	7.5		0.35		
Swell Data (%)		**1833**	**2618**	**6.18**	

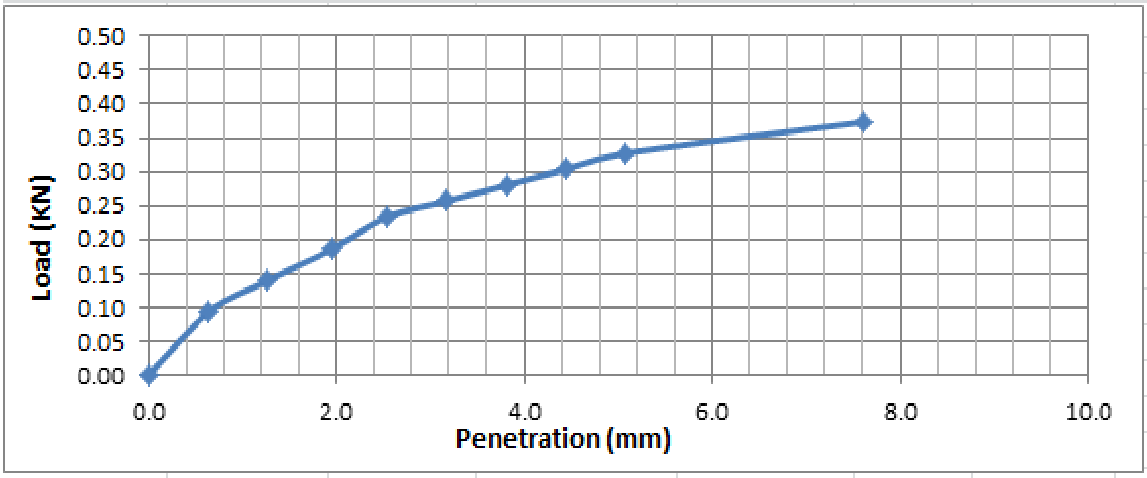

Figure E- 9 CBR load-penetration curve for TP-2 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Table E- 10 CBR test result for TP-2 black cotton soil + 4 % sawdust ash

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046761	0.00		
0.64	2.0		0.09		
1.27	3.0		0.14		
1.96	4.0		0.19		
2.54	5.0		0.23	13.2	1.77
3.18	5.5		0.26		
3.81	5.5		0.26		
4.45	6.0		0.28		
5.08	6.0		0.28	20	1.40
7.62	6.5		0.30		
Swell Data (%)		**590**	**1364**	**6.09**	

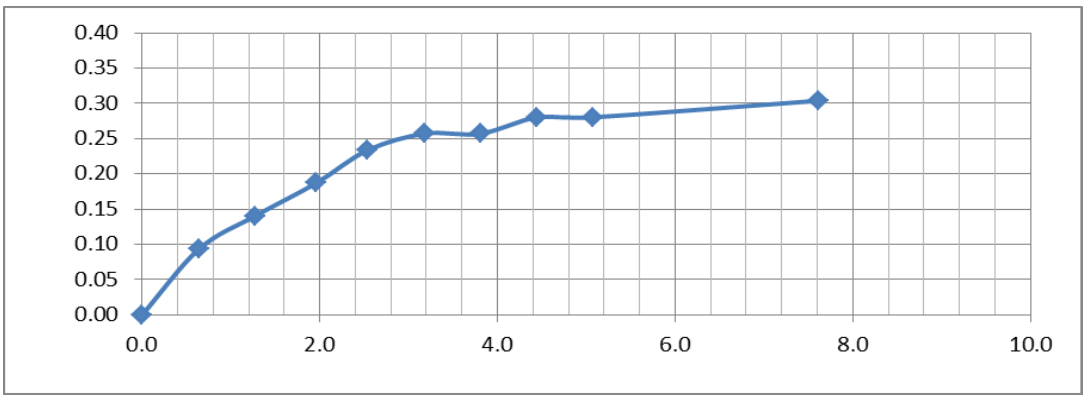

Figure E- 10 CBR load-penetration curve for TP-2 black cotton soil + 4 % sawdust ash

Table E- 11 CBR test result for TP-2 black cotton soil + 8 % sawdust ash

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046450	0.00		
0.64	2.0		0.09		
1.27	3.5		0.16		
1.96	5.0		0.23		
2.54	6.0		0.28	13.2	2.13
3.18	6.5		0.30		
3.81	6.5		0.30		
4.45	7.0		0.33		
5.08	7.5		0.35	20	1.75
7.62	8.0		0.37		
Swell Data (%)		**796**	**1537**	**5.83**	

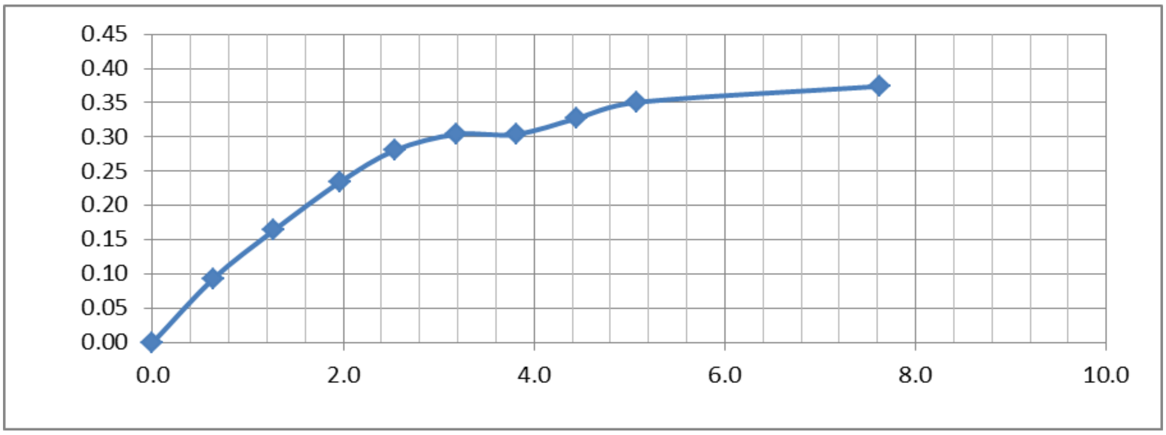

Figure E- 11 CBR load-penetration curve for TP-2 black cotton soil + 8 % sawdust ash

Table E- 12 CBR test result for TP-2 black cotton soil + 12 % sawdust ash

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046450	0.00		
0.64	2.0		0.09		
1.27	3.0		0.14		
1.96	3.5		0.16		
2.54	4.0		0.19	13.2	1.42
3.18	4.5		0.21		
3.81	5.0		0.23		
4.45	5.5		0.26		
5.08	5.5		0.26	20	1.29
7.62	6.0		0.28		
Swell Data (%)		**1685**	**2442**	**5.96**	

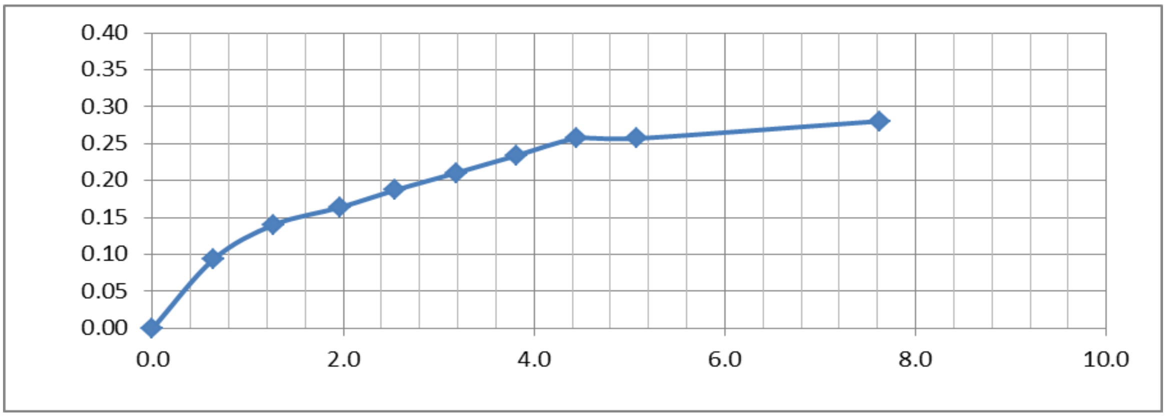

Figure E- 12 CBR load-penetration curve for TP-2 black cotton soil + 12 % sawdust ash

Table E- 13 CBR test result for TP-2 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046450	0.00		
0.64	1.0		0.05		
1.27	3.0		0.14		
1.96	5.0		0.23		
2.54	6.5		0.30	13.2	2.30
3.18	7.0		0.33		
3.81	7.5		0.35		
4.45	7.5		0.35		
5.08	8.0		0.37	20	1.87
7.62	9.0		0.42		
Swell Data (%)		**1833**	**2552**	**5.66**	

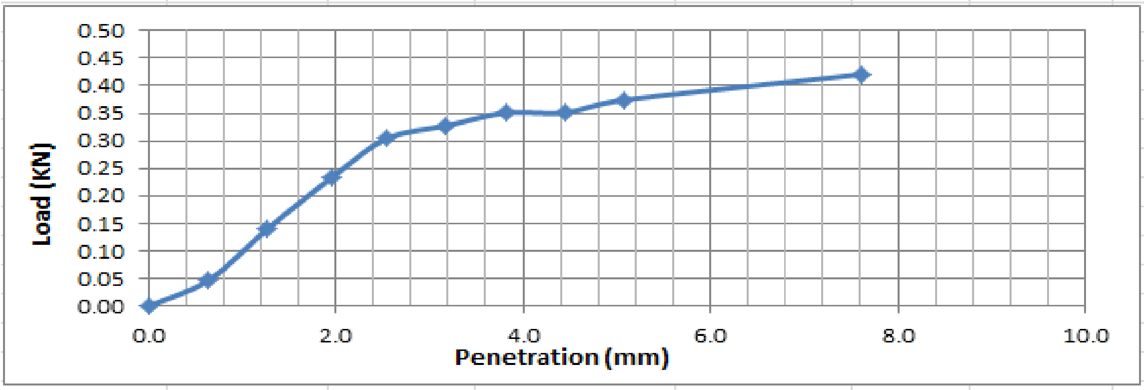

Figure E- 13 CBR load-penetration curve for TP-2 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Table E- 14 CBR test result for TP-2 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046761	0.00		
0.64	1.0		0.05		
1.27	4.0		0.19		
1.96	7.0		0.33		
2.54	9.0		0.42	13.2	3.19
3.18	9.5		0.44		
3.81	10.0		0.47		
4.45	10.0		0.47		
5.08	10.5		0.49	20	2.45
7.62	12.0		0.56		
Swell Data (%)		**1348**	**2032**	**5.39**	

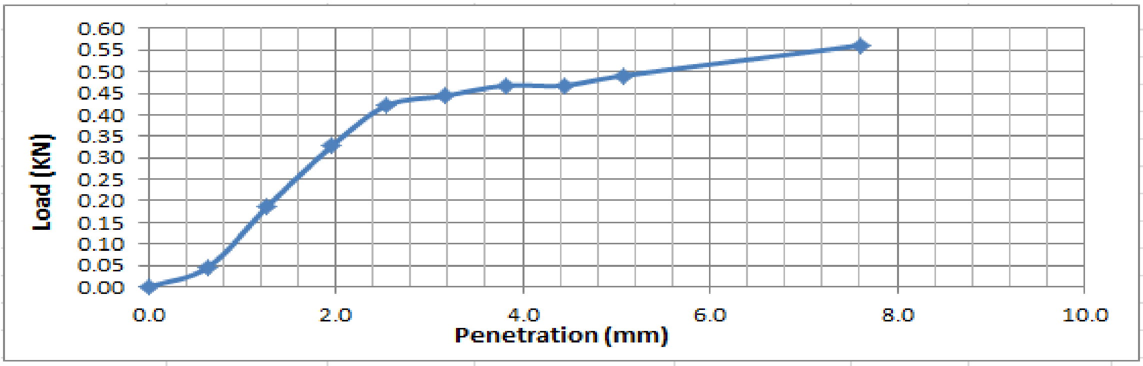

Figure E- 14 CBR load-penetration curve for TP- 2 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Table E- 15 CBR test result for TP-2 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046450	0.00		
0.64	2.0		0.09		
1.27	5.0		0.23		
1.96	6.5		0.30		
2.54	7.5		0.35	13.2	2.66
3.18	8.0		0.37		
3.81	8.0		0.37		
4.45	8.5		0.40		
5.08	9.0		0.42	20	2.10
7.62	10.5		0.49		
Swell Data (%)		**570**	**1198**	**4.94**	

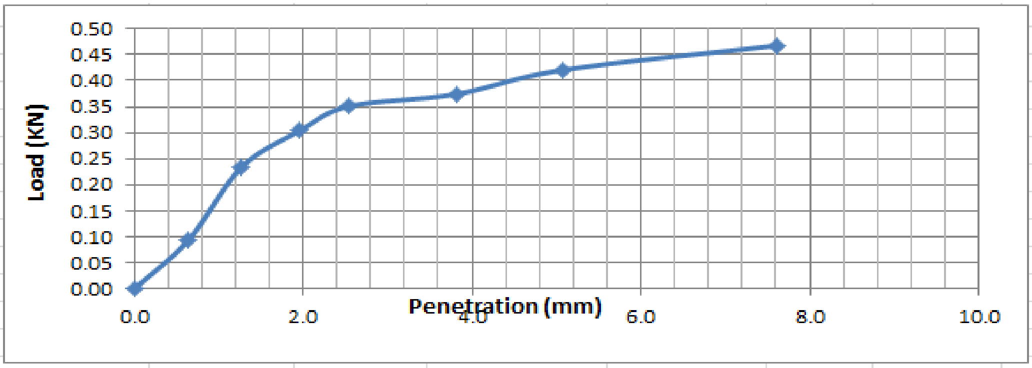

Figure E- 15 CBR load-penetration curve for TP-2 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Table E- 16 CBR test result for TP-2 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Penetration (mm)	Load dia rea	Ring f.(KN/d)	Load KN	Standard Load KN	CBR %
0.0	0.00	0.046450	0.00		
0.64	3.0		0.14		
1.27	5.0		0.23		
1.96	6.5		0.30		
2.54	7.0		0.33	13.2	2.48
3.18	7.5		0.35		
3.81	8.0		0.37		
4.45	8.5		0.40		
5.08	9.0		0.42	20	2.10
7.62	10.0		0.47		
Swell Data (%)		**993**	**1601**	**4.79**	

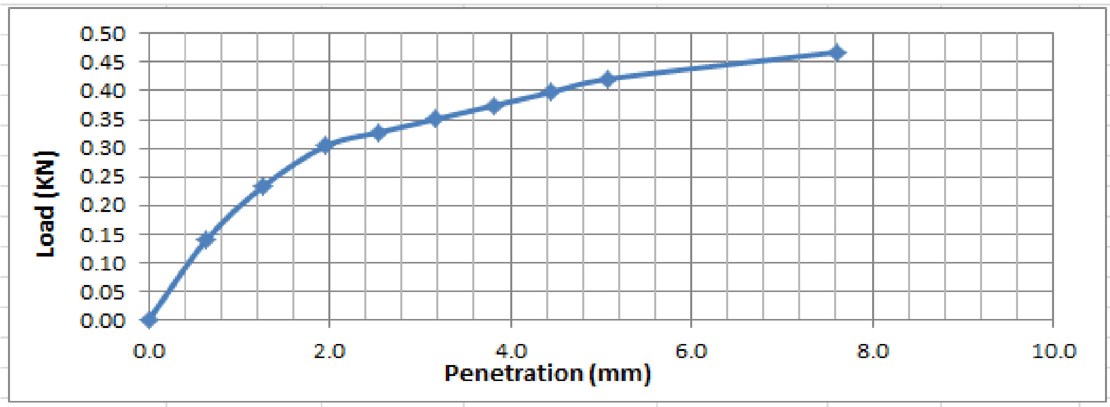

Figure E- 16 CBR load-penetration curve for TP-2 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Appendix F - Unconfined Compressive Strength Test Results

The UCS tests were performed according to ASTM Standard D2166 on both un-stabilized and stabilized soil samples of Test pit 1(TP-1) and Test pit 2(TP-2) which are blended at different ratios. The detailed UCS test results are given below.

Table F- 1 UCS test data sheet for TP-1 natural black cotton soil

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	159.60	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	126.8	Area, A_0 (mm^2)	1075.35
Wt. Of Water(gm)	32.8	Volume, (mm^3)	79575.86
Wt. Of Container (gm)	0	Bulk density(gm/cm^3)	2.006
Wt. of Dry Sample (gm)	126.80	Dry density(gm/cm^3)	1.593
Water Content (%)	25.87	Rate (mm/min):	1.50
Depth	1.5 m	Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation, ΔL(mm)	Strain(ε)	% Strain	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	33.0	0.20	0.003	0.270	1078.256	0.066	60.93
40	50.0	0.40	0.005	0.541	1081.162	0.100	92.08
60	69.0	0.60	0.008	0.811	1084.069	0.137	126.73
80	85.0	0.80	0.011	1.081	1086.975	0.169	155.69
100	100.0	1.00	0.014	1.351	1089.881	0.199	182.68
120	114.0	1.20	0.016	1.622	1092.788	0.227	207.70
140	126.0	1.40	0.019	1.892	1095.694	0.251	228.96
160	137.0	1.60	0.022	2.162	1098.600	0.273	248.29
180	148.0	1.80	0.024	2.432	1101.507	0.295	267.51
200	150.0	2.00	0.027	2.703	1104.413	0.299	270.42
220	151.0	2.20	0.030	2.973	1107.319	0.301	271.50
240	154.0	2.40	0.032	3.243	1110.226	0.307	276.17
260	154.0	2.60	0.035	3.514	1113.132	0.307	275.45
280	154.0	2.80	0.038	3.784	1116.038	0.307	274.73
300	154.0	3.00	0.041	4.054	1118.945	0.307	274.02
320	154.0	3.20	0.043	4.324	1121.851	0.307	273.31
340	154.0	3.40	0.046	4.595	1124.757	0.307	272.60
360	154.0	3.60	0.049	4.865	1127.664	0.307	271.90

qu = 276.17 KPa   cu = $\boldsymbol{qu/2}$ = 138.085 KPa

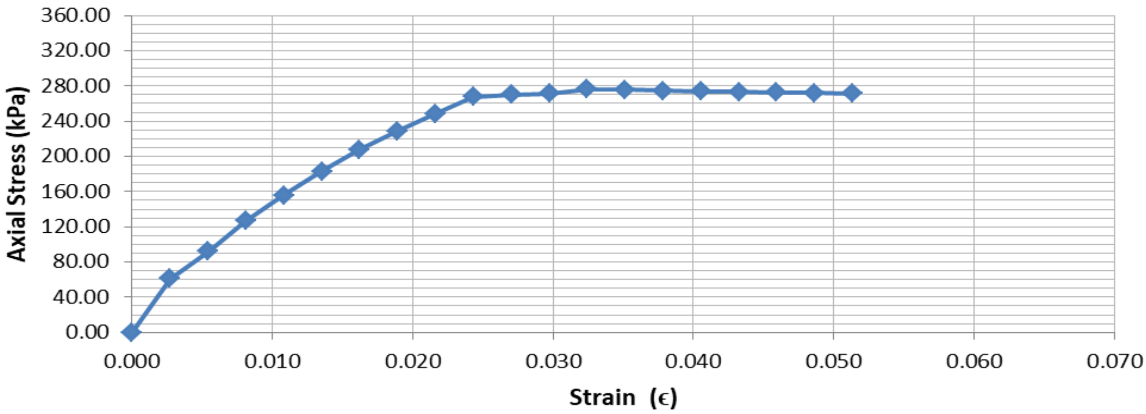

Figure F- 1 UCS stress-strain curve for TP-1 natural black cotton soil

Table F- 2 UCS test data sheet for TP-1 black cotton soil + 4 % sawdust ash

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	139.00	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	109.2	Area, A_0 (mm^2)	1075.35
Wt. Of Water(gm)	29.8	Volume, (mm^3)	79575.86
Wt. Of Container (gm)	0	Bulk density(gm/cm^3)	1.747
Wt. of Dry Sample (gm)	109.20	Dry density(gm/cm^3)	1.372
Water Content (%)	27.29	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation, ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	14.0	0.20	0.003	0.270	1078.256	0.028	25.85
40	21.0	0.40	0.005	0.541	1081.162	0.042	38.67
60	32.0	0.60	0.008	0.811	1084.069	0.064	58.77
80	48.0	0.80	0.011	1.081	1086.975	0.096	87.92
100	70.0	1.00	0.014	1.351	1089.881	0.139	127.88
120	87.0	1.20	0.016	1.622	1092.788	0.173	158.51
140	96.0	1.40	0.019	1.892	1095.694	0.191	174.44
160	110.0	1.60	0.022	2.162	1098.600	0.219	199.35
180	120.0	1.80	0.024	2.432	1101.507	0.239	216.90
200	136.0	2.00	0.027	2.703	1104.413	0.271	245.18
220	150.0	2.20	0.030	2.973	1107.319	0.299	269.71
240	160.0	2.40	0.032	3.243	1110.226	0.319	286.93
260	160.0	2.60	0.035	3.514	1113.132	0.319	286.18
280	160.0	2.80	0.038	3.784	1116.038	0.319	285.44
300	160.0	3.00	0.041	4.054	1118.945	0.319	284.70

320	160.0	3.20	0.043	4.324	1121.851	0.319	283.96
340	160.0	3.40	0.046	4.595	1124.757	0.319	283.23

qu = 286.93 Kpa cu $= \boldsymbol{qu/2}$ = 143.465 Kpa

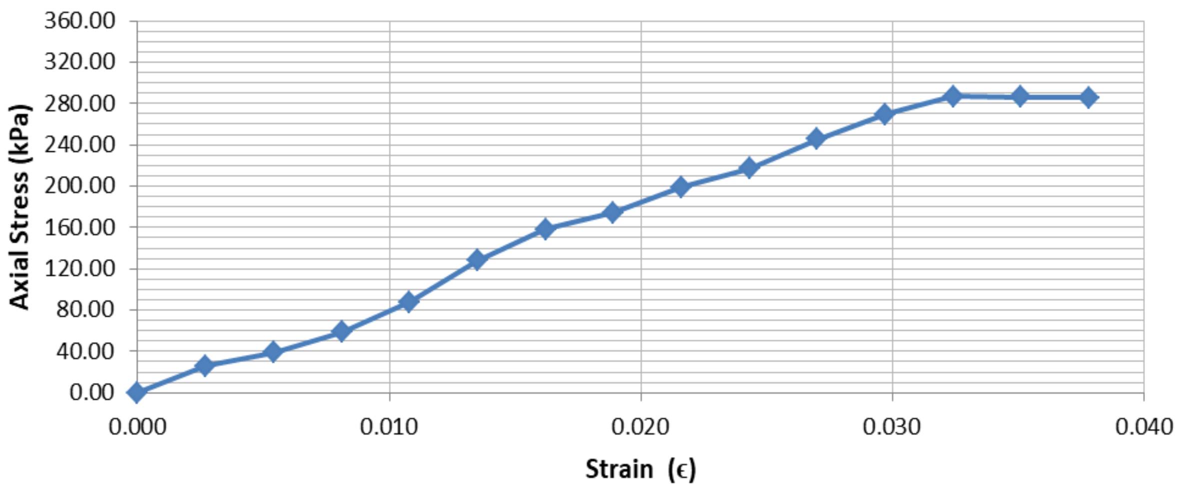

Figure F- 2 UCS stress-strain curve for TP-1 black cotton soil + 4 % sawdust ash

Table F- 3 UCS test data sheet for TP-1 black cotton soil + 8 % sawdust ash

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	128.38	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	100.2	Area, A_0 (mm^2)	1075.35
Wt. Of Water(gm)	28.18	Volume, (mm^3)	79575.86
Wt. Of Container (gm)	0	Bulk density(gm/cm^3)	1.613
Wt. of Dry Sample (gm)	100.20	Dry density(gm/cm^3)	1.259
Water Content (%)	28.12	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation, ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	30.0	0.20	0.003	0.270	1078.256	0.060	55.40
40	50.0	0.40	0.005	0.541	1081.162	0.100	92.08
60	62.0	0.60	0.008	0.811	1084.069	0.123	113.87
80	80.0	0.80	0.011	1.081	1086.975	0.159	146.54
100	94.0	1.00	0.014	1.351	1089.881	0.187	171.72
120	105.0	1.20	0.016	1.622	1092.788	0.209	191.30
140	115.0	1.40	0.019	1.892	1095.694	0.229	208.97
160	125.0	1.60	0.022	2.162	1098.600	0.249	226.54
180	134.0	1.80	0.024	2.432	1101.507	0.267	242.21

200	140.0	2.00	0.027	2.703	1104.413	0.279	252.39
220	146.0	2.20	0.030	2.973	1107.319	0.291	262.51
240	150.0	2.40	0.032	3.243	1110.226	0.299	269.00
260	153.0	2.60	0.035	3.514	1113.132	0.305	273.66
280	156.0	2.80	0.038	3.784	1116.038	0.311	278.30
300	158.0	3.00	0.041	4.054	1118.945	0.315	281.14
320	164.0	3.20	0.043	4.324	1121.851	0.327	291.06
340	166.0	3.40	0.046	4.595	1124.757	0.331	293.85
360	168.0	3.60	0.049	4.865	1127.664	0.334	296.62
380	171.0	3.80	0.051	5.135	1130.570	0.340	301.14
400	173.0	4.00	0.054	5.405	1133.477	0.344	303.88
420	175.0	4.20	0.057	5.676	1136.383	0.348	306.61

qu = 306.61 Kpa   cu $= \boldsymbol{qu/2}$ = 153.305 Kpa

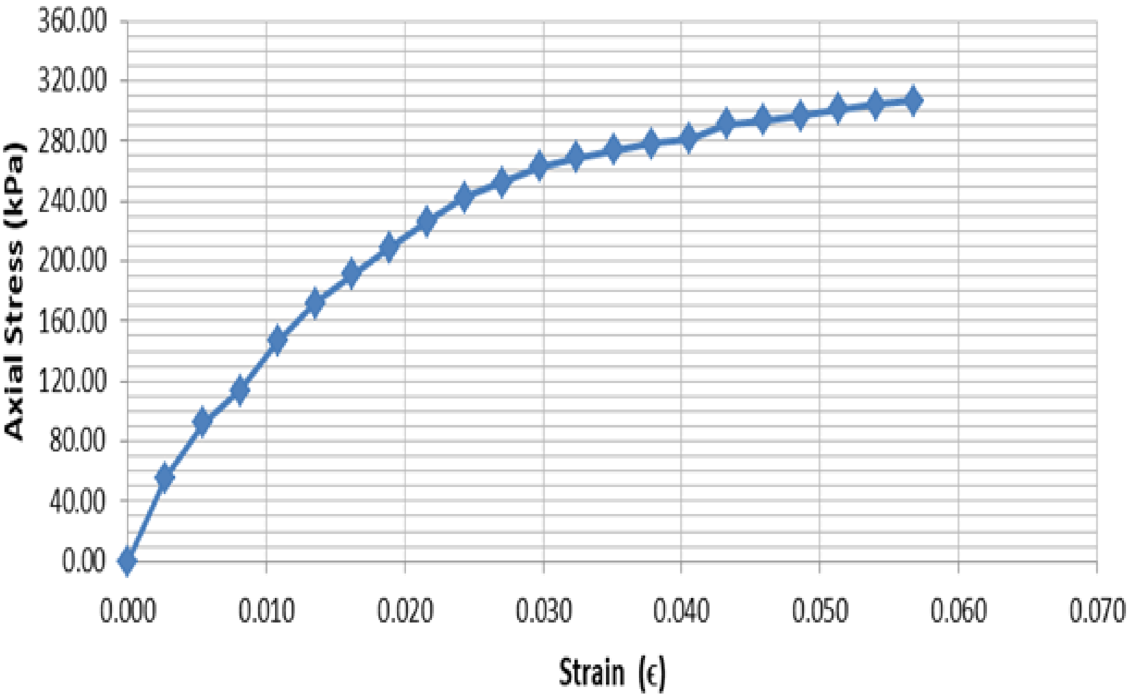

Figure F- 3 UCS stress-strain curve for TP-1 black cotton soil + 8 % sawdust ash

Table F- 4 UCS test data sheet for TP-1 black cotton soil + 12 % sawdust ash

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	128.02	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	96.5	Area,A_0 (mm^2)	1075.35
Wt. Of Water(gm)	31.52	Volume, (mm^3)	79575.86
Wt. Of Container (gm)	0	Bulk density(gm/cm^3)	1.609
Wt. of Dry Sample (gm)	96.50	Dry density(gm/cm^3)	1.213
Water Content (%)	32.66	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation, ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	25.0	0.20	0.003	0.270	1078.256	0.050	46.16
40	34.0	0.40	0.005	0.541	1081.162	0.068	62.61
60	45.0	0.60	0.008	0.811	1084.069	0.090	82.65
80	52.0	0.80	0.011	1.081	1086.975	0.104	95.25
100	60.0	1.00	0.014	1.351	1089.881	0.119	109.61
120	72.0	1.20	0.016	1.622	1092.788	0.143	131.18
140	83.0	1.40	0.019	1.892	1095.694	0.165	150.82
160	94.0	1.60	0.022	2.162	1098.600	0.187	170.36
180	105.0	1.80	0.024	2.432	1101.507	0.209	189.79
200	112.0	2.00	0.027	2.703	1104.413	0.223	201.91
220	123.0	2.20	0.030	2.973	1107.319	0.245	221.16
240	131.0	2.40	0.032	3.243	1110.226	0.261	234.93
260	145.0	2.60	0.035	3.514	1113.132	0.289	259.35
280	160.0	2.80	0.038	3.784	1116.038	0.319	285.44
300	163.0	3.00	0.041	4.054	1118.945	0.325	290.03
320	163.0	3.20	0.043	4.324	1121.851	0.325	289.28
340	163.0	3.40	0.046	4.595	1124.757	0.325	288.54
360	163.0	3.60	0.049	4.865	1127.664	0.325	287.79
380	163.0	3.80	0.051	5.135	1130.570	0.325	287.05
400	163.0	4.00	0.054	5.405	1133.477	0.325	286.32
420	163.0	4.20	0.057	5.676	1136.383	0.325	285.58

qu = 290.03 Kpa cu = $\boldsymbol{qu/2}$ 145.015 Kpa

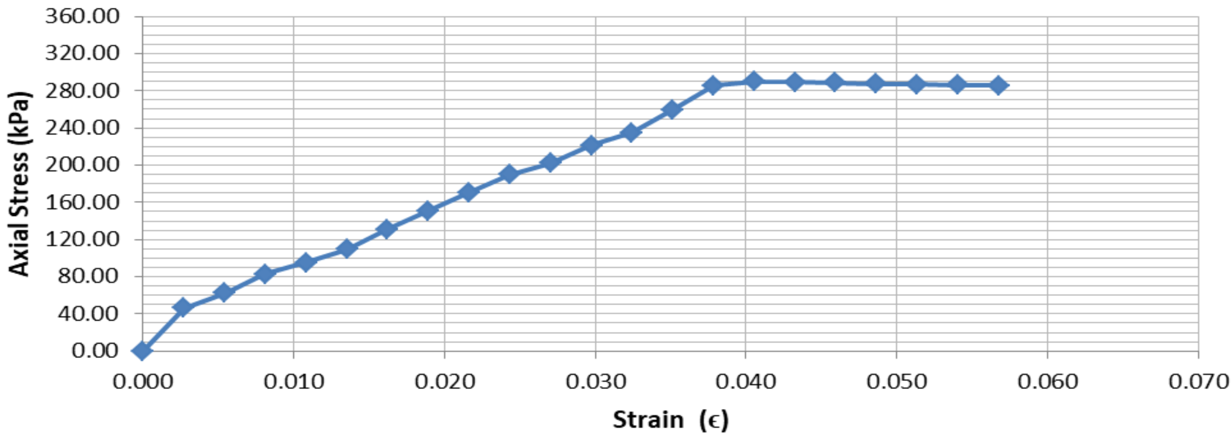

Figure F- 4 UCS stress-strain curve for TP-1 black cotton soil + 12 % sawdust ash

Table F- 5 UCS test data sheet for TP-1 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	133.90	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	102.43	Area,A_0 (mm^2)	1075.35
Wt. Of Water(gm)	31.47	Volume, (mm^3)	79575.86
Wt. Of Container (gm)	0	Bulk density(gm/cm^3)	1.683
Wt. of Dry Sample (gm)	102.43	Dry density(gm/cm^3)	1.287
Water Content (%)	30.72	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation, ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	23.0	0.20	0.003	0.270	1078.256	0.046	42.47
40	40.0	0.40	0.005	0.541	1081.162	0.080	73.66
60	58.0	0.60	0.008	0.811	1084.069	0.115	106.52
80	72.0	0.80	0.011	1.081	1086.975	0.143	131.88
100	87.0	1.00	0.014	1.351	1089.881	0.173	158.93
120	102.0	1.20	0.016	1.622	1092.788	0.203	185.84
140	118.0	1.40	0.019	1.892	1095.694	0.235	214.42
160	126.0	1.60	0.022	2.162	1098.600	0.251	228.35
180	135.0	1.80	0.024	2.432	1101.507	0.269	244.02
200	143.0	2.00	0.027	2.703	1104.413	0.285	257.80
220	151.0	2.20	0.030	2.973	1107.319	0.301	271.50
240	160.0	2.40	0.032	3.243	1110.226	0.319	286.93
260	166.0	2.60	0.035	3.514	1113.132	0.331	296.92
280	172.0	2.80	0.038	3.784	1116.038	0.342	306.85

300	176.0	3.00	0.041	4.054	1118.945	0.350	313.17
320	182.0	3.20	0.043	4.324	1121.851	0.362	323.00
340	182.0	3.40	0.046	4.595	1124.757	0.362	322.17
360	182.0	3.60	0.049	4.865	1127.664	0.362	321.34
380	182.0	3.80	0.051	5.135	1130.570	0.362	320.51

qu = 323 Kpa cu = $\boldsymbol{qu/2}$ = 161.5 Kpa

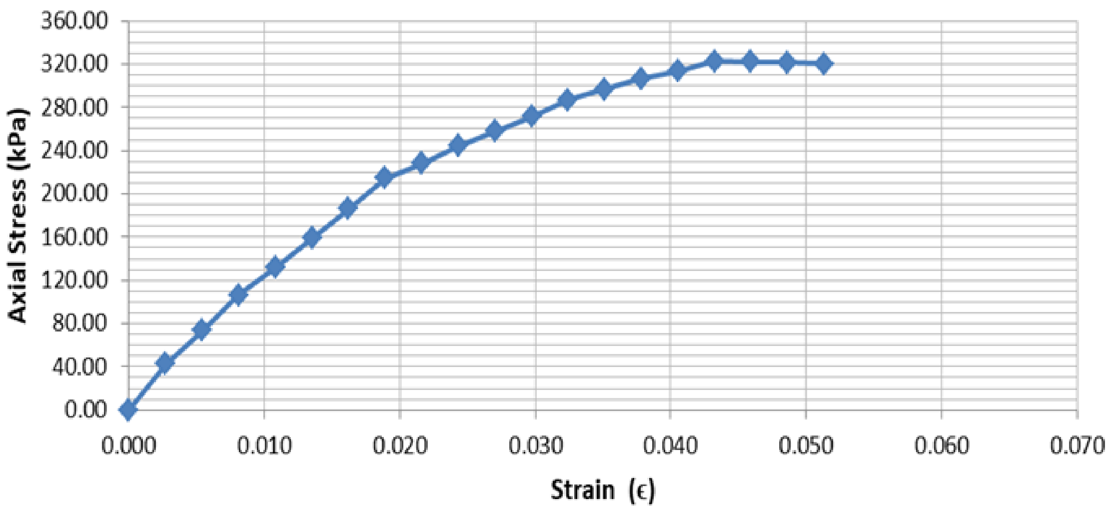

Figure F- 5 UCS stress-strain curve for TP-1 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Table F- 6 UCS test data sheet for TP-1 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	128.02	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	102.62	Area,A_0 (mm^2)	1075.35
Wt. Of Water(gm)	26.28	Volume, (mm^3)	79575.86
Wt. Of Container (gm)	0	Bulk density(gm/cm^3)	1.620
Wt. of Dry Sample (gm)	102.62	Dry density(gm/cm^3)	1.290
Water Content (%)	25.61	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation, ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	30.0	0.20	0.003	0.270	1078.256	0.060	55.40
40	51.0	0.40	0.005	0.541	1081.162	0.102	93.92

60	70.0	0.60	0.008	0.811	1084.069	0.139	128.56
80	92.0	0.80	0.011	1.081	1086.975	0.183	168.52
100	108.0	1.00	0.014	1.351	1089.881	0.215	197.29
120	120.0	1.20	0.016	1.622	1092.788	0.239	218.63
140	132.0	1.40	0.019	1.892	1095.694	0.263	239.86
160	145.0	1.60	0.022	2.162	1098.600	0.289	262.78
180	154.0	1.80	0.024	2.432	1101.507	0.307	278.36
200	162.0	2.00	0.027	2.703	1104.413	0.323	292.05
220	170.0	2.20	0.030	2.973	1107.319	0.338	305.67
240	178.0	2.40	0.032	3.243	1110.226	0.354	319.21
260	186.0	2.60	0.035	3.514	1113.132	0.370	332.69
280	194.0	2.80	0.038	3.784	1116.038	0.386	346.09
300	202.0	3.00	0.041	4.054	1118.945	0.402	359.43
320	207.0	3.20	0.043	4.324	1121.851	0.412	367.37
340	213.0	3.40	0.046	4.595	1124.757	0.424	377.04
360	215.0	3.60	0.049	4.865	1127.664	0.428	379.60
380	218.0	3.80	0.051	5.135	1130.570	0.434	383.91
400	220.0	4.00	0.054	5.405	1133.477	0.438	386.44

qu = 386.44 Kpa cu = $qu/2$ = 193.22 Kpa

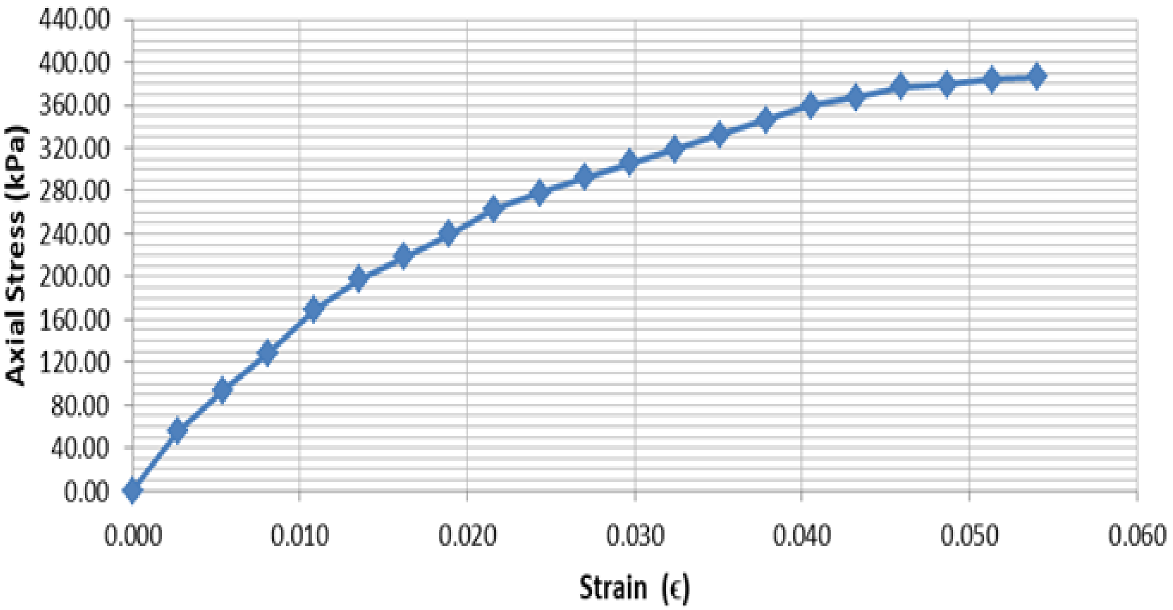

Figure F- 6 UCS stress-strain curve for TP-1 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Table F- 7 UCS test data sheet for TP-1 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	132.36	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	103.46	Area, A_0 (mm^2)	1075.35
Wt. Of Water(gm)	28.90	Volume, (mm^3)	79575.86
Wt. Of Container (gm)	0	Bulk density(gm/cm^3)	1.663
Wt. of Dry Sample (gm)	103.46	Dry density(gm/cm^3)	1.300
Water Content (%)	27.93	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation, ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	30.0	0.20	0.003	0.270	1078.256	0.060	55.40
40	45.0	0.40	0.005	0.541	1081.162	0.090	82.87
60	68.0	0.60	0.008	0.811	1084.069	0.135	124.89
80	86.0	0.80	0.011	1.081	1086.975	0.171	157.53
100	100.0	1.00	0.014	1.351	1089.881	0.199	182.68
120	114.0	1.20	0.016	1.622	1092.788	0.227	207.70
140	126.0	1.40	0.019	1.892	1095.694	0.251	228.96
160	139.0	1.60	0.022	2.162	1098.600	0.277	251.91
180	150.0	1.80	0.024	2.432	1101.507	0.299	271.13
200	158.0	2.00	0.027	2.703	1104.413	0.315	284.84
220	166.0	2.20	0.030	2.973	1107.319	0.331	298.47
240	173.0	2.40	0.032	3.243	1110.226	0.344	310.25
260	180.0	2.60	0.035	3.514	1113.132	0.358	321.96
280	186.0	2.80	0.038	3.784	1116.038	0.370	331.82
300	192.0	3.00	0.041	4.054	1118.945	0.382	341.64
320	198.0	3.20	0.043	4.324	1121.851	0.394	351.40
340	206.0	3.40	0.046	4.595	1124.757	0.410	364.65
360	210.0	3.60	0.049	4.865	1127.664	0.418	370.78
380	212.0	3.80	0.051	5.135	1130.570	0.422	373.34
400	214.0	4.00	0.054	5.405	1133.477	0.426	375.90
420	216.0	4.20	0.057	5.676	1136.383	0.430	378.44

qu = 378.44 Kpa cu = $\boldsymbol{qu/2}$ = 189.22 Kpa

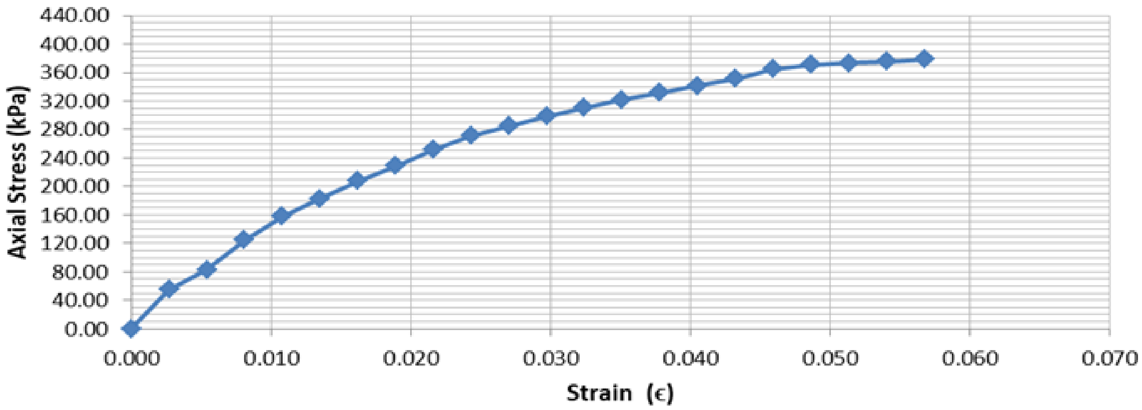

Figure F- 7 UCS stress-strain curve for TP-1 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Table F- 8 UCS test data sheet for TP-1 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	132.74	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	103.72	Area,A_0 (mm^2)	1075.35
Wt. Of Water(gm)	29.02	Volume, (mm^3)	79575.86
Wt. Of Container (gm)	0	Bulk density(gm/cm^3)	1.668
Wt. of Dry Sample (gm)	103.72	Dry density(gm/cm^3)	1.303
Water Content (%)	27.98	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation, ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	22.0	0.20	0.003	0.270	1078.256	0.044	40.62
40	38.0	0.40	0.005	0.541	1081.162	0.076	69.98
60	56.0	0.60	0.008	0.811	1084.069	0.111	102.85
80	68.0	0.80	0.011	1.081	1086.975	0.135	124.55
100	82.0	1.00	0.014	1.351	1089.881	0.163	149.80
120	97.0	1.20	0.016	1.622	1092.788	0.193	176.73
140	110.0	1.40	0.019	1.892	1095.694	0.219	199.88
160	122.0	1.60	0.022	2.162	1098.600	0.243	221.10
180	134.0	1.80	0.024	2.432	1101.507	0.267	242.21
200	143.0	2.00	0.027	2.703	1104.413	0.285	257.80
220	151.0	2.20	0.030	2.973	1107.319	0.301	271.50
240	160.0	2.40	0.032	3.243	1110.226	0.319	286.93
260	168.0	2.60	0.035	3.514	1113.132	0.334	300.49

280	175.0	2.80	0.038	3.784	1116.038	0.334	299.71
300	181.0	3.00	0.041	4.054	1118.945	0.348	311.39
320	185.0	3.20	0.043	4.324	1121.851	0.360	321.23
340	189.0	3.40	0.046	4.595	1124.757	0.368	327.48
360	192.0	3.60	0.049	4.865	1127.664	0.376	333.70
380	194.0	3.80	0.051	5.135	1130.570	0.382	338.12
400	196.0	4.00	0.054	5.405	1133.477	0.386	340.77
420	198.0	4.20	0.057	5.676	1136.383	0.390	343.40

.qu = 343.40 Kpa cu $=\boldsymbol{qu}/\mathbf{2}$ = 171.7 Kpa

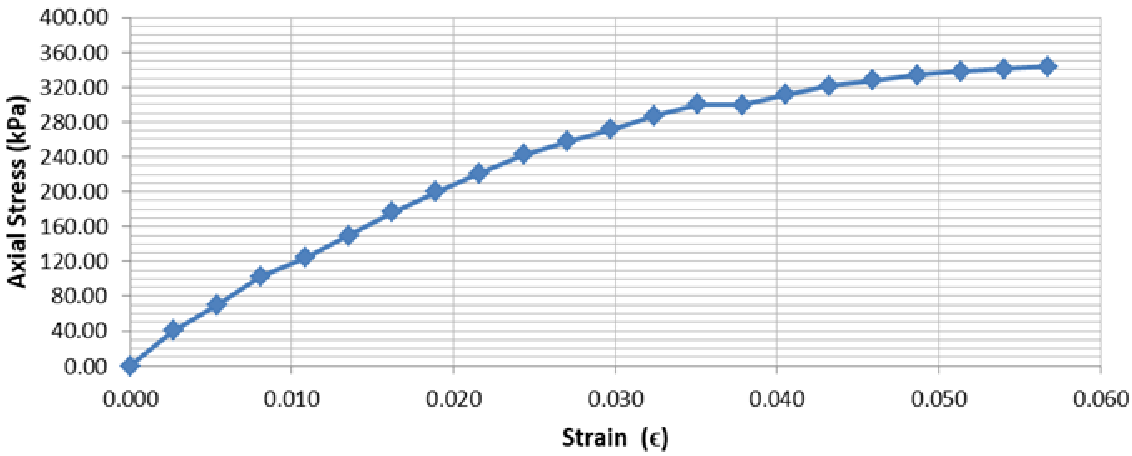

Figure F- 8 UCS test data sheet for TP-1 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Table F- 9 UCS test data sheet for TP-2 natural black cotton soil

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	132.74	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	103.72	Area,A_0 (mm^2)	1075.35
Wt. Of Water(gm)	29.02	Volume, (mm^3)	79575.86
Wt. Of Container (gm)	0	Bulk density(gm/cm^3)	1.668
Wt. of Dry Sample (gm)	103.72	Dry density(gm/cm^3)	1.303
Water Content (%)	27.98	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation, ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	40.0	0.20	0.003	0.270	1078.256	0.080	73.86

40	65.0	0.40	0.005	0.541	1081.162	0.129	119.70
60	82.0	0.60	0.008	0.811	1084.069	0.163	150.60
80	100.0	0.80	0.011	1.081	1086.975	0.199	183.17
100	124.0	1.00	0.014	1.351	1089.881	0.247	226.52
120	140.0	1.20	0.016	1.622	1092.788	0.279	255.07
140	161.0	1.40	0.019	1.892	1095.694	0.321	292.56
160	175.0	1.60	0.022	2.162	1098.600	0.348	317.15
180	182.0	1.80	0.024	2.432	1101.507	0.362	328.97
200	185.0	2.00	0.027	2.703	1104.413	0.368	333.51
220	185.0	2.20	0.030	2.973	1107.319	0.368	332.64
240	185.0	2.40	0.032	3.243	1110.226	0.368	331.77
260	185.0	2.60	0.035	3.514	1113.132	0.368	330.90

qu = 333.51 Kpa cu $= \boldsymbol{qu/2}$ = 166.755 Kpa

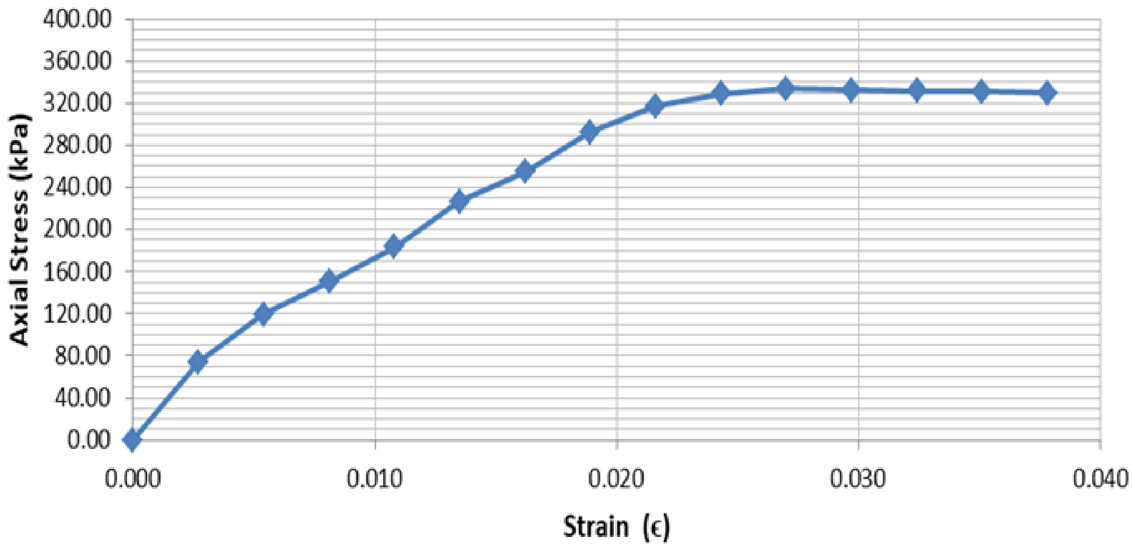

Figure F- 9 UCS test data sheet for TP-2 natural black cotton soil

Table F- 10 UCS test data sheet for TP-2 black cotton soil + 4 % sawdust ash

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	145.06	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	108.27	Area,A_0 (mm^2)	1075.35
Wt. Of Water(gm)	36.79	Volume, (mm^3)	79575.86
Wt. Of Container (gm)	0	Bulk density(gm/cm^3)	1.823
Wt. of Dry Sample (gm)	108.27	Dry density(gm/cm^3)	1.26
Water Content (%)	33.98	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation, ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	38.0	0.20	0.003	0.270	1078.256	0.076	70.17
40	54.0	0.40	0.005	0.541	1081.162	0.108	99.44
60	80.0	0.60	0.008	0.811	1084.069	0.159	146.93
80	100.0	0.80	0.011	1.081	1086.975	0.199	183.17
100	115.0	1.00	0.014	1.351	1089.881	0.229	210.08
120	130.0	1.20	0.016	1.622	1092.788	0.259	236.85
140	142.0	1.40	0.019	1.892	1095.694	0.283	258.03
160	153.0	1.60	0.022	2.162	1098.600	0.305	277.28
180	170.0	1.80	0.024	2.432	1101.507	0.338	307.28
200	178.0	2.00	0.027	2.703	1104.413	0.354	320.89
220	184.0	2.20	0.030	2.973	1107.319	0.366	330.84
240	190.0	2.40	0.032	3.243	1110.226	0.378	340.73
260	190.0	2.60	0.035	3.514	1113.132	0.378	339.84
280	190.0	2.80	0.038	3.784	1116.038	0.378	338.96
300	190.0	3.00	0.041	4.054	1118.945	0.378	338.08
320	190.0	3.20	0.043	4.324	1121.851	0.378	337.20
340	190.0	3.40	0.046	4.595	1124.757	0.378	336.33
360	190.0	3.60	0.049	4.865	1127.664	0.378	335.46

qu = 340.73 Kpa cu = $\boldsymbol{qu/2}$ = 170.365 Kpa

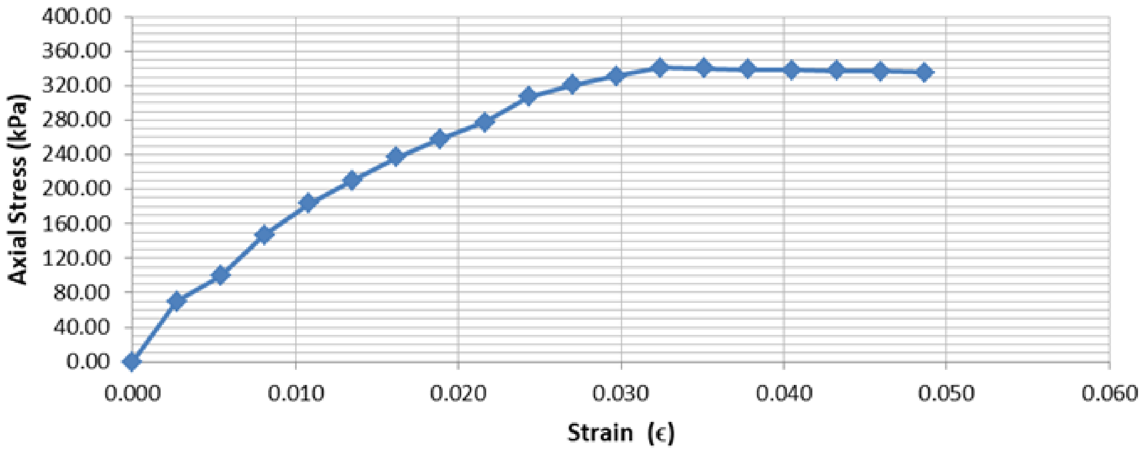

Figure F- 10 UCS test data sheet for TP-2 black cotton soil + 4 % sawdust ash

Table F- 11 UCS test data sheet for TP-2 black cotton soil + 8 % sawdust ash

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	134.85	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	100.12	Area,A_0 (mm^2)	**1075.35**
Wt. Of Water(gm)	34.73	Volume, (mm^3)	**79575.86**
Wt. Of Container (gm)		Bulk density(gm/cm^3)	**1.695**
Wt. of Dry Sample (gm)	100.12	Dry density(gm/cm^3)	**1.258**
Water Content (%)	34.73	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation ,ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	36.0	0.20	0.003	0.270	1078.256	0.072	66.47
40	54.0	0.40	0.005	0.541	1081.162	0.108	99.44
60	68.0	0.60	0.008	0.811	1084.069	0.135	124.89
80	85.0	0.80	0.011	1.081	1086.975	0.169	155.69
100	98.0	1.00	0.014	1.351	1089.881	0.195	179.03
120	116.0	1.20	0.016	1.622	1092.788	0.231	211.35
140	128.0	1.40	0.019	1.892	1095.694	0.255	232.59
160	136.0	1.60	0.022	2.162	1098.600	0.271	246.47
180	149.0	1.80	0.024	2.432	1101.507	0.297	269.32
200	155.0	2.00	0.027	2.703	1104.413	0.309	279.43
220	162.0	2.20	0.030	2.973	1107.319	0.323	291.28
240	167.0	2.40	0.032	3.243	1110.226	0.332	299.49
260	169.0	2.60	0.035	3.514	1113.132	0.336	302.28
280	171.0	2.80	0.038	3.784	1116.038	0.340	305.06

300	175.0	3.00	0.041	4.054	1118.945	0.348	311.39
320	180.0	3.20	0.043	4.324	1121.851	0.358	319.45
340	185.0	3.40	0.046	4.595	1124.757	0.368	327.48
360	190.0	3.60	0.049	4.865	1127.664	0.378	335.46
380	193.0	3.80	0.051	5.135	1130.570	0.384	339.88
400	196.0	4.00	0.054	5.405	1133.477	0.390	344.28
420	200.0	4.20	0.057	5.676	1136.383	0.398	350.41
440	204.0	4.40	0.059	5.946	1139.289	0.406	356.51
460	206.0	4.60	0.062	6.216	1142.196	0.410	359.09

qu = 359.09 Kpa cu = $\boldsymbol{qu/2}$ = 179.545 Kpa

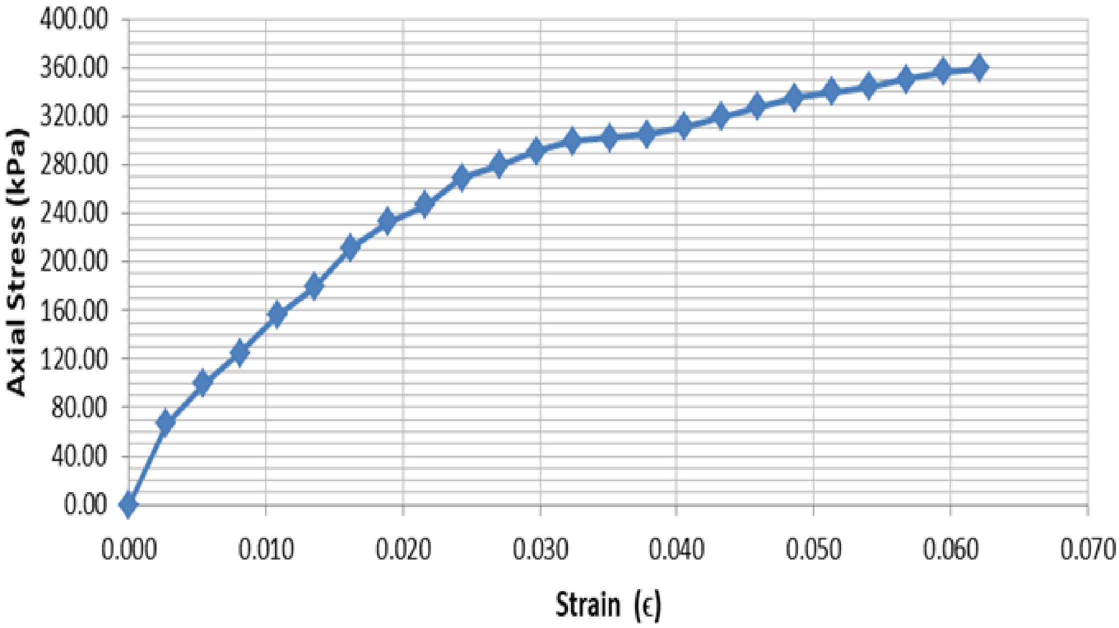

Figure F- 11 UCS test data sheet for TP-2 black cotton soil + 8 % sawdust ash

Table F- 12 UCS test data sheet for TP-2 black cotton soil + 12 % sawdust ash

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	128.77	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	94.66	Area,A_0 (mm^2)	**1075.35**
Wt. Of Water(gm)	34.11	Volume, (mm^3)	**79575.86**
Wt. Of Container (gm)		Bulk density(gm/cm^3)	**1.618**
Wt. of Dry Sample (gm)	94.66	Dry density(gm/cm^3)	**1.19**
Water Content (%)	34.11	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation ,ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	25.0	0.20	0.003	0.270	1078.256	0.050	46.16
40	33.0	0.40	0.005	0.541	1081.162	0.066	60.77
60	43.0	0.60	0.008	0.811	1084.069	0.086	78.97
80	61.0	0.80	0.011	1.081	1086.975	0.121	111.73
100	74.0	1.00	0.014	1.351	1089.881	0.147	135.18
120	83.0	1.20	0.016	1.622	1092.788	0.165	151.22
140	100.0	1.40	0.019	1.892	1095.694	0.199	181.71
160	105.0	1.60	0.022	2.162	1098.600	0.209	190.29
180	110.0	1.80	0.024	2.432	1101.507	0.219	198.83
200	110.0	2.00	0.027	2.703	1104.413	0.219	198.30
220	110.0	2.20	0.030	2.973	1107.319	0.219	197.78
240	110.0	2.40	0.032	3.243	1110.226	0.219	197.27
260	110.0	2.60	0.035	3.514	1113.132	0.219	196.75
280	110.0	2.80	0.038	3.784	1116.038	0.219	196.24

qu = 198.83 Kpa cu =$\boldsymbol{qu/2}$ = 99.415 Kpa

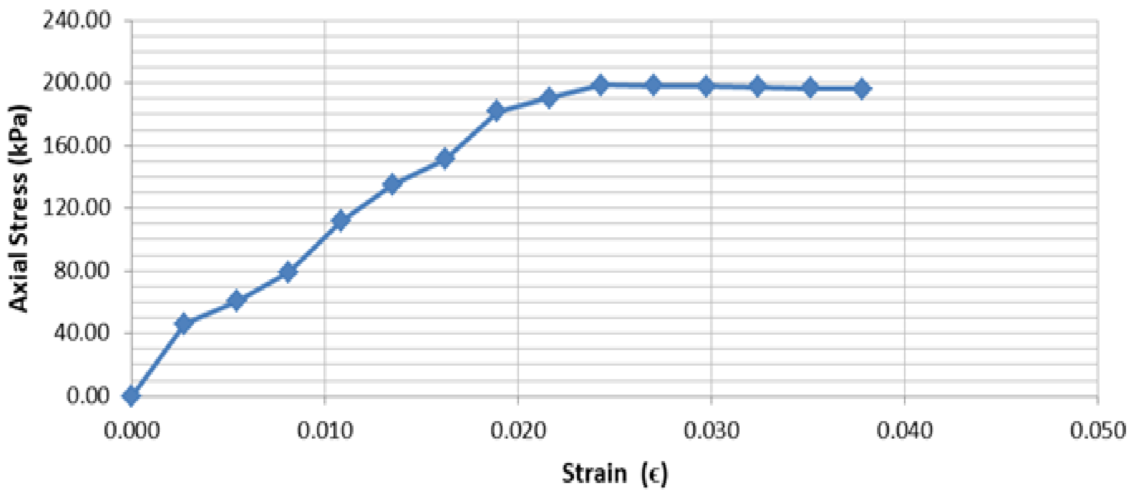

Figure F- 12 UCS test data sheet for TP-2 black cotton soil + 12 % sawdust

Table F- 13 UCS test data sheet for TP-2 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	134.85	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	100.12	Area,A_0 (mm^2)	**1075.35**
Wt. Of Water(gm)	34.73	Volume, (mm^3)	**79575.86**
Wt. Of Container (gm)		Bulk density(gm/cm^3)	**1.695**
Wt. of Dry Sample (gm)	100.12	Dry density(gm/cm^3)	**1.258**
Water Content (%)	34.73	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation ,ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	25.0	0.20	0.003	0.270	1078.256	0.050	46.16
40	42.0	0.40	0.005	0.541	1081.162	0.084	77.34
60	58.0	0.60	0.008	0.811	1084.069	0.115	106.52
80	75.0	0.80	0.011	1.081	1086.975	0.149	137.38
100	88.0	1.00	0.014	1.351	1089.881	0.175	160.76
120	105.0	1.20	0.016	1.622	1092.788	0.209	191.30
140	118.0	1.40	0.019	1.892	1095.694	0.235	214.42
160	130.0	1.60	0.022	2.162	1098.600	0.259	235.60
180	142.0	1.80	0.024	2.432	1101.507	0.283	256.67
200	154.0	2.00	0.027	2.703	1104.413	0.307	277.63
220	164.0	2.20	0.030	2.973	1107.319	0.327	294.88
240	172.0	2.40	0.032	3.243	1110.226	0.342	308.45
260	180.0	2.60	0.035	3.514	1113.132	0.358	321.96
280	188.0	2.80	0.038	3.784	1116.038	0.374	335.39
300	195.0	3.00	0.041	4.054	1118.945	0.388	346.97
320	202.0	3.20		0.000	1075.350	0.402	374.00
340	208.0	3.40	0.046	4.595	1124.757	0.414	368.19
360	212.0	3.60	0.049	4.865	1127.664	0.422	374.31
380	214.0	3.80	0.051	5.135	1130.570	0.426	376.87
400	216.0	4.00	0.054	5.405	1133.477	0.430	379.41

qu = 379.41Kpa cu = $\boldsymbol{qu/2}$ = 189.705 Kpa

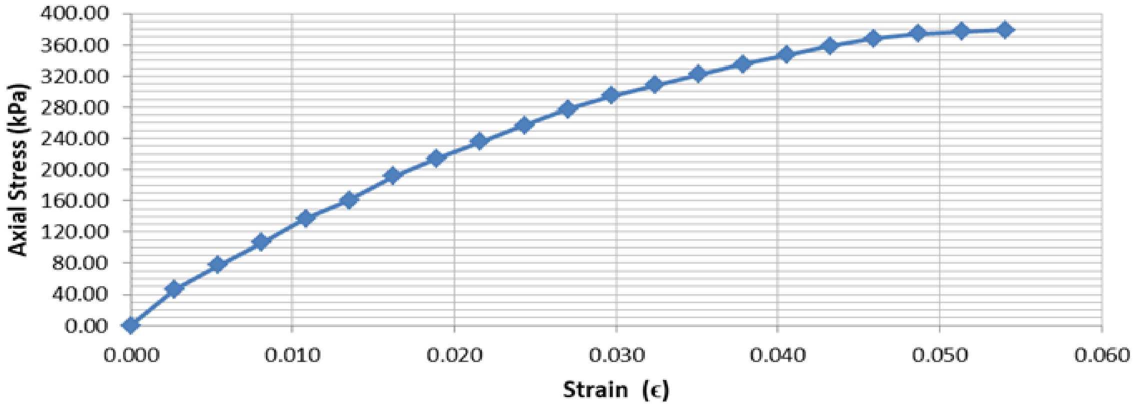

Figure F- 13 UCS test data sheet for TP-2 black cotton soil + 8 % sawdust ash+ 5 % induction furnace slag

Table F- 14 UCS test data sheet for TP-2 black cotton soil + 8 % sawdust ash+ 10 % induction furnace slag

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	132.78	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	102.55	Area,A_0 (mm^2)	1075.35
Wt. Of Water(gm)	30.23	Volume, (mm^3)	79575.86
Wt. Of Container (gm)		Bulk density(gm/cm^3)	1.669
Wt. of Dry Sample (gm)	102.55	Dry density(gm/cm^3)	1.289
Water Content (%)	29.48	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation, ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	33.0	0.20	0.003	0.270	1078.256	0.066	60.93
40	50.0	0.40	0.005	0.541	1081.162	0.100	92.08
60	69.0	0.60	0.008	0.811	1084.069	0.137	126.73
80	85.0	0.80	0.011	1.081	1086.975	0.169	155.69
100	100.0	1.00	0.014	1.351	1089.881	0.199	182.68
120	114.0	1.20	0.016	1.622	1092.788	0.227	207.70
140	127.0	1.40	0.019	1.892	1095.694	0.253	230.77
160	143.0	1.60	0.022	2.162	1098.600	0.285	259.16
180	157.0	1.80	0.024	2.432	1101.507	0.313	283.78
200	172.0	2.00	0.027	2.703	1104.413	0.342	310.08
220	187.0	2.20	0.030	2.973	1107.319	0.372	336.23
240	202.0	2.40	0.032	3.243	1110.226	0.402	362.25
260	212.0	2.60	0.035	3.514	1113.132	0.422	379.19
280	220.0	2.80	0.038	3.784	1116.038	0.438	392.48

300	228.0	3.00	0.041	4.054	1118.945	0.454	405.69
320	232.0	3.20	0.043	4.324	1121.851	0.462	411.74
340	236.0	3.40	0.046	4.595	1124.757	0.470	417.76
360	239.0	3.60	0.049	4.865	1127.664	0.476	421.98
380	240.0	3.80	0.051	5.135	1130.570	0.478	422.65

qu = 422.65 Kpa cu =$qu/2$ = 211.325 Kpa

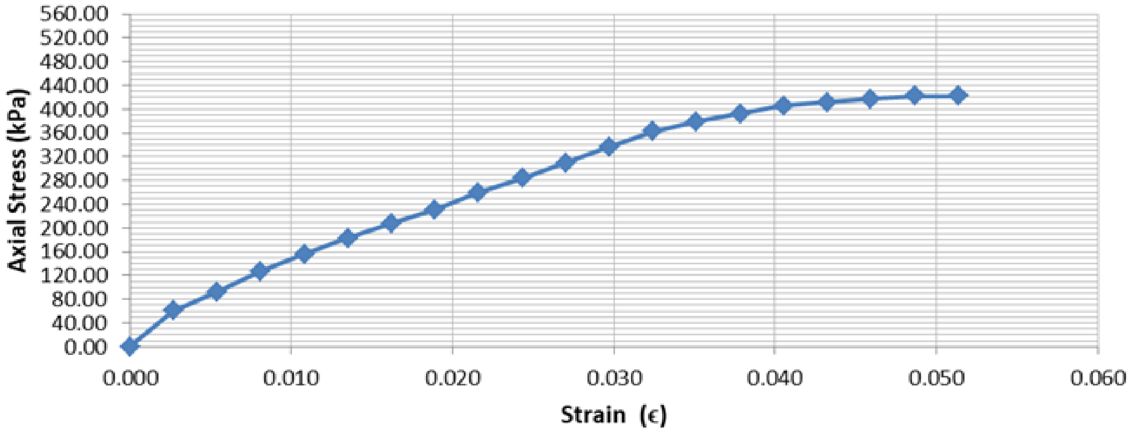

Figure F- 14 UCS test data sheet for TP-2 black cotton soil + 8 % sawdust ash+10 % induction furnace slag

Table F- 15 UCS test data sheet for TP-2 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	127.25	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	103.21	Area,A_0 (mm^2)	**1075.35**
Wt. Of Water(gm)	24.04	Volume, (mm^3)	**79575.86**
Wt. Of Container (gm)		Bulk density(gm/cm^3)	**1.599**
Wt. of Dry Sample (gm)	103.21	Dry density(gm/cm^3)	**1.297**
Water Content (%)	23.29	Rate (mm/min):	1.50
Depth		Ring Factor (KN/div)	0.001991

Deformation Dial Reading	Load Dial Reading	Sample Deformation, ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	20.0	0.20	0.003	0.270	1078.256	0.040	36.93
40	38.0	0.40	0.005	0.541	1081.162	0.076	69.98
60	56.0	0.60	0.008	0.811	1084.069	0.111	102.85
80	63.0	0.80	0.011	1.081	1086.975	0.125	115.40
100	77.0	1.00	0.014	1.351	1089.881	0.153	140.66

120	91.0	1.20	0.016	1.622	1092.788	0.181	165.80
140	105.0	1.40	0.019	1.892	1095.694	0.209	190.80
160	118.0	1.60	0.022	2.162	1098.600	0.235	213.85
180	130.0	1.80	0.024	2.432	1101.507	0.259	234.98
200	142.0	2.00	0.027	2.703	1104.413	0.283	255.99
220	151.0	2.20	0.030	2.973	1107.319	0.301	271.50
240	160.0	2.40	0.032	3.243	1110.226	0.319	286.93
260	167.0	2.60	0.035	3.514	1113.132	0.332	298.70
280	174.0	2.80	0.038	3.784	1116.038	0.346	310.41
300	180.0	3.00	0.041	4.054	1118.945	0.358	320.28
320	188.0	3.20	0.043	4.324	1121.851	0.374	333.65
340	194.0	3.40	0.046	4.595	1124.757	0.386	343.41
360	200.0	3.60	0.049	4.865	1127.664	0.398	353.12
380	206.0	3.80	0.051	5.135	1130.570	0.410	362.78
400	212.0	4.00	0.054	5.405	1133.477	0.422	372.39
420	214.0	4.20	0.057	5.676	1136.383	0.426	374.94

qu = 374.94 Kpa cu = $\boldsymbol{qu}/\mathbf{2}$ = 187.47 Kpa

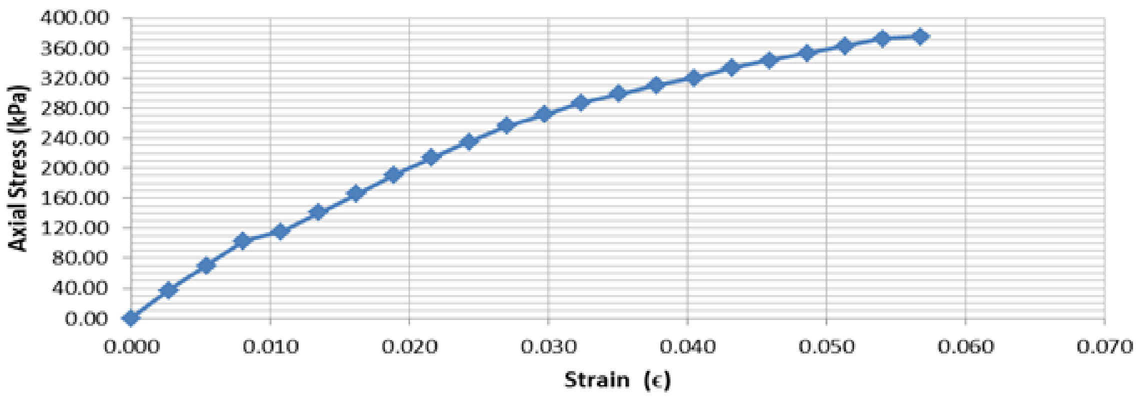

Figure F- 15 UCS test data sheet for TP-2 black cotton soil + 8 % sawdust ash+ 15 % induction furnace slag

Table F- 16 UCS test data sheet for TP-2 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Moisture Content determination		Diameter (mm)	37.00
Wt. of Wet Sample + Container(gm)	132.72	Length (mm)	74.00
Wt. of Dry Sample + Container(gm)	106.72	Area,A_0 (mm^2)	1075.35
Wt. Of Water(gm)	26	Volume, (mm^3)	79575.86
Wt. Of Container (gm)	0	Bulk density(gm/cm^3)	1.668
Wt. of Dry Sample (gm)	106.72	Dry density(gm/cm^3)	1.341
Water Content (%)	26	Rate (mm/min):	1.50

Depth				Ring Factor (KN/div)		0.001991	
Deformation Dial Reading	Load Dial Reading	Sample Deformation ,ΔL(mm)	Strain(ε)	**% Strain**	Corrected Area A'	Load (KN)	Stress (KPa)
0	0.0	0.00	0.00	0.000	1075.350	0.000	0.00
20	33.0	0.20	0.003	0.270	1078.256	0.066	60.93
40	50.0	0.40	0.005	0.541	1081.162	0.100	92.08
60	69.0	0.60	0.008	0.811	1084.069	0.137	126.73
80	85.0	0.80	0.011	1.081	1086.975	0.169	155.69
100	100.0	1.00	0.014	1.351	1089.881	0.199	182.68
120	114.0	1.20	0.016	1.622	1092.788	0.227	207.70
140	126.0	1.40	0.019	1.892	1095.694	0.251	228.96
160	137.0	1.60	0.022	2.162	1098.600	0.273	248.29
180	148.0	1.80	0.024	2.432	1101.507	0.295	267.51
200	157.0	2.00	0.027	2.703	1104.413	0.313	283.03
220	167.0	2.20	0.030	2.973	1107.319	0.332	300.27
240	175.0	2.40	0.032	3.243	1110.226	0.348	313.83
260	182.0	2.60	0.035	3.514	1113.132	0.362	325.53
280	188.0	2.80	0.038	3.784	1116.038	0.374	335.39
300	194.0	3.00	0.041	4.054	1118.945	0.386	345.19
320	199.0	3.20	0.043	4.324	1121.851	0.396	353.17
340	202.0	3.40	0.046	4.595	1124.757	0.402	357.57
360	204.0	3.60	0.049	4.865	1127.664	0.406	360.18
380	208.0	3.80	0.051	5.135	1130.570	0.414	366.30

qu = 366.3 Kpa   cu = $\boldsymbol{qu/2}$ = 183.15 Kpa

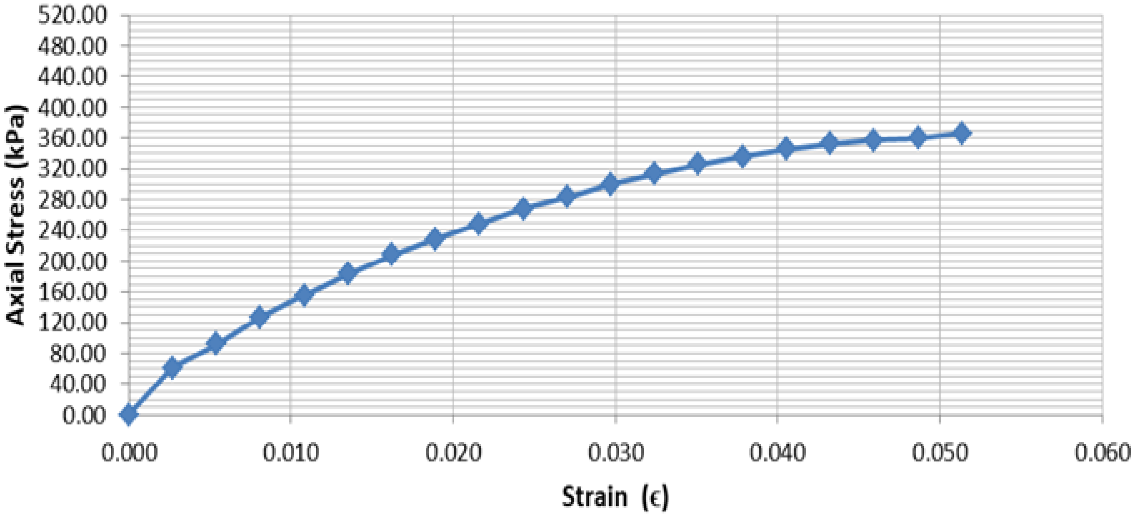

Figure F- 16 UCS test data sheet for TP-2 black cotton soil + 8 % sawdust ash+ 20 % induction furnace slag

Appendix G - Cost Analysis

Comparison made between the cost of constructing road using removal and replacement method and constructing by stabilizing the black cotton soil using sawdust ash and induction furnace slag. The details of cost breakdown analyses for quantitative parameters are given in this section.

G.1 Cost Analysis for Replacing

	Detailed Breakdown of Unit Prices by Work Item								
Work Item:Clearing and Grubbing									
					Performance rate : 0.13 Ha/hr				
Unit Quantity of work item:1 m2									
labour cost					**Equipment cost**				
Labour assigned	**no**	**uf**	**hourly cost**	**total**	**Equipment type**	**No.**	**UF**	**Hourly Rental**	**Total Hourly**
			(in birr)	**hourly cost**	**Equipment type**			**cost**	**rental cost**
E/ work forman	1	0.25	59.47	14.8675	Dozer	1	1	2453.89	2453.89
v.driver	1	0.25	29.79	7.4475	loader	1	1	1000	1000
data collector	1	1	15.96	15.96	dump truck	2	1	432.69	865.38
daily labourer	5	1	15.96	79.8	service vehicle	1	0.25	302	75.5
Dozer Operator	1	1	79.3	79.3					
Excavator Operator	1	1	46.26	46.26					
Dump truck driver	2	1	33.04	66.08					
total				309.715	total				4394.77
B =Manpower unit Cost - Birr/m3			**2382.42308**		**C= Equipment Unit Cost - Birr/m3**				**33805.92308**
Direct Cost of Work Item = A + B + C =			36188.3462						
Over head cost + Profit: 0.35			12665.9212						
Total Unit Cost =			**48854.2673**	birr/Ha					
Total Cost =			**4.88542673**	birr/m2					
Total Cost =			48854.2673	birr/Km					

Work Item: under cut excavation				Performance rate : 65 m3/hr					
Unit Quantity of work item:1 m3									
labour cost					**Equipment cost**				
Labour assigned	**no**	**uf**	**hourly cost**	**total**	**Equipment type**	**No.**	**UF**	**Hourly Rental**	**Total Hourly**
			(in birr)	**hourly cost**	**Equipment type**			**cost**	**rental cost**
E/work forman	1	0.25	59.47	14.8675	excavator	1	1	1300	1300
S/vehicle driver	1	0.25	29.79	7.4475	service vehicle	1	0.5	302	151
survayor	2	1	37.91	75.82					
data collector	1	1	15.96	15.96					
Excavator Operator	1	1	46.26	46.26					
daily labourer	5	1	15.96	79.8					
total			205.35		**total**				1451
B =Manpower unit Cost - Birr/m3			3.15923077		**C= Equipment Unit Cost - Birr/m3 r**				22.32307692
Direct Cost of Work Item = A + B + C =			25.4823077						
	Over head cost + Pro		8.91880769						
Total Unit Cost =			**34.4011154**	birr/m3					
Total Cost =			447214.5	birr/Km					

Work Item:Disposal of Undercut Excavation				Performance rate : 77 m3/hr					
Unit Quantity of work item:1 m3									
labour cost					**Equipment cost**				
Labour assigned	**no**	**uf**	**hourly cost**	**total**	**Equipment type**	**No.**	**UF**	**Hourly Rental**	**Total Hourly**
			(in birr)	**hourly cost**	**Equipment type**			**cost**	**rental cost**
E/work forman	1	1	59.47	59.47	Loader, Wheel	1	1	1000	1000
S/v.driver	1	1	29.79	29.79	service vehicle	6	1	302	1812
data collector	1	1	15.96	15.96	Dump Truck	4	0.25	432.69	432.69
daily labourer	4	1	15.96	63.84					
loader oprator	1	1	46.26	46.26					
dump truck driver	1	1	33.04	33.04					
total			200.48		**total**				3244.69
B =Manpower unit Cost - Birr/m3			**2.60363636**		**C= Equipment Unit Cost - Birr/m3 r**				**42.13883117**
Direct Cost of Work Item = A + B + C =			44.7424675						
Over head cost + Profit: 0.35			15.6598636						
Total Unit Cost =			**60.4023312**	birr/m3					
Total Cost =			785230.305	birr/Km					

Work Item:Clearing and Grubbing for Borrow Production					Performance rate : 0.13 Ha/hr				
Unit Quantity of work item:1 m3									
labour cost					Equipment cost				
Labour assigned	no	uf	hourly cost	total	Equipment type	No.	UF	Hourly Rental	Total Hourly
			(in birr)	hourly cost	Equipment type			cost	rental cost
E/work forman	1	0.25	59.47	14.8675	Dozer	1	1	2453.89	2453.89
S/v.driver	1	0.25	29.79	7.4475	loader	1	1	1000	1000
dozer oprator	1	1	79.3	79.3	dump truck	2	1	432.69	865.38
loader operator	1	1	46.26	46.26	service vehicle	1	0.25	302	75.5
dump truck driver	2	1	33.04	66.08					
data collector	1	1	15.96	15.96					
daily labourer	5	1	15.96	79.8					
total			309.715		total				4394.77
B =Manpower unit Cost - Birr/m3			2382.42308		C= Equipment Unit Cost - Birr/m3 r				33805.92308
Direct Cost of Work Item = A + B + C			36188.3462						
Over head cost + Profit: 0.35			12665.9212						
Total Unit Cost =			**48854.2673**	birr/Ha					
Total Cost =			**4.88542673**	birr/m2					
Total Cost =			48854.2673	birr/Km					

Work Item: Excavation of Overburden					Performance rate : 60 m3/hr				
Unit Quantity of work item:1 m3									
labour cost					Equipment cost				
Labour assigned	no	uf	hourly cost	total	Equipment type	No.	UF	Hourly Rental	Total Hourly
			(in birr)	hourly cost	Equipment type			cost	rental cost
E/work forman	1	0.5	59.47	29.735	Dozer	1	1	2453.89	2453.89
S/v.driver	1	0.5	29.79	14.895	service vehicle	1	0.5	302	151
dozer oprator	1	1	79.3	79.3					
daily labourer	5	1	15.96	79.8					
total				203.73	**total**				2604.89
B =Manpower unit Cost - Birr/m3			3.3955		C= Equipment Unit Cost - Birr/m3				43.41483333
Direct Cost of Work Item = A + B + C			46.8103333						
Over head cost + Profit: 0.35			16.3836167						
Total Unit Cost =			**63.19395**	birr/m3					
Total Cost =			821521.35	birr/Km					

Work Item: Borrow/Select Material production				Performance rate : 80 m3/hr					
Unit Quantity of work item:1 m3									
labour cost					**Equipment cost**				
Labour assigned	**no**	**uf**	**hourly cost**	**total**	**Equipment type**	**No.**	**UF**	**Hourly Rental**	**Total Hourly**
			(in birr)	**hourly cost**	**Equipment type**			**cost**	**rental cost**
Quarry Forman	1	1	33.04	33.04	Dozer	1	1	2453.89	2453.89
data collector	1	1	15.96	15.96	service vehicle	1	1	302	302
daily labourer	2	1	15.96	31.92					
dozer oprator	1	1	79.3	79.3					
S/v.driver	1	1	29.79	29.79					
total			190.01		**total**				2755.89
B =Manpower unit Cost - Birr/m3			2.375125		**C= Equipment Unit Cost - Birr/m3 r**				34.448625
Direct Cost of Work Item = A + B + C =			36.82375						
Over head cost + Profit: 0.35			12.8883125						
Total Unit Cost =			**49.7120625**	birr/m3					
Total Cost =			646256.813	birr/Km					

	Work Item: Select Material Hauling			Performance rate : 77 m3/hr					
	Unit Quantity of work item:1 m3								
labour cost					**Equipment cost**				
Labour assigned	**no**	**uf**	**hourly cost**	**total**	**Equipment type**	**No.**	**UF**	**Hourly Rental**	**Total Hourly**
			(in birr)	**hourly cost**	**Equipment type**			**cost**	**rental cost**
Quarry Forman	1	0.5	59.47	29.735	Loader, Wheel	1	1	1000	1000
S/v.driver	1	1	29.79	29.79	Dump Truck 6x4	6	1	432.69	2596.14
loader oprator	1	1	4.26	4.26	service vehicle	1	0.5	302	151
dump truck driver	6	1	33.04	198.24					
total			262.025		**total**				3747.14
B =Manpower unit Cost - Birr/m3			3.40292208		**C= Equipment Unit Cost - Birr/m3 r**				48.66415584
Direct Cost of Work Item = A + B + C =			52.0670779						
Over head cost + Profit: 0.35			18.2234773						
Total Unit Cost =			**70.2905552**	birr/m3					
Total Cost =			913777.218	birr/Km					

Work Item:Road bed preparation and Placing				Performance rate : 96 m3/hr					
Unit Quantity of work item:1 m3									
labour cost					**Equipment cost**				
Labour assigned	**no**	**uf**	**hourly cost**	**total**	**Equipment type**	**No.**	**UF**	**Hourly Rental**	**Total Hourly**
			(in birr)	**hourly cost**	**Equipment type**			**cost**	**rental cost**
Construction Engine	1	1	99.12	99.12	Grader	1	1	1700	1700
Site Engineer	1	1	79.3	79.3	Roller	1	1	1000	1000
survayor	2	1	37.91	75.82	Water Truck	1	1	593.33	593.33
E/work Forman	1	1	59.47	59.47	Service Vehicle	3	1	302	906
S/vehicle driver	3	1	29.79	89.37					
data collector	1	1	15.96	15.96					
daily labourer	20	1	15.96	319.2					
Grader oprator	1	1	99.12	99.12					
Roller oprator	1	1	19.82	19.82					
Water Truck oprator	1	1	33.04	33.04					
total				890.22	**total**				4199.33
B =Manpower unit Cost - Birr/m3			9.273125		**C= Equipment Unit Cost - Birr/m3 r**				43.74302083
Direct Cost of Work Item = A + B + C =			53.0161458						
Over head cost + Profit: 0.35			18.555651						
Total Unit Cost =			**71.5717969**	birr/m3					
Total Cost =			930433.359	birr/Km					

Work Item: Reinstatment Borrow Pit				Performance rate : 80 m3/hr					
Unit Quantity of work item:1 m3									
labour cost					**Equipment cost**				
Labour assigned	**no**	**uf**	**hourly cost**	**total**	**Equipment type**	**No.**	**UF**	**Hourly Rental**	**Total Hourly**
			(in birr)	**hourly cost**	**Equipment type**			**cost**	**rental cost**
Quarry Forman	1	1	59.47	59.47	Dozer	1	1	2453.89	2453.89
data collector	1	1	15.96	15.96	service vehicle	1	1	302	302
daily labourer	2	1	15.96	31.92					
dozer oprator	1	1	79.3	79.3					
total				186.65	**total**				2755.89
B =Manpower unit Cost - Birr/m3			2.333125	**C= Equipment Unit Cost - Birr/m3 r**					34.448625
Direct Cost of Work Item = A + B + C =			36.78175						
Over head cost + Profit: 0.35			12.8736125						
Total Unit Cost =			**49.6553625**	birr/m3					
Total Cost =			645519.713	birr/Km					

G.2 Cost Analysis for Stabilizing

Work Item:Clearing and Grubbing				Performance rate : 0.13 Ha/hr					
Unit Quantity of work item:1 m2									
labour cost					**Equipment cost**				
Labour assigned	**no**	**uf**	**hourly cost**	**total**	**Equipment type**	**No.**	**UF**	**Hourly Rental**	**Total Hourly**
			(in birr)	**hourly cost**	**Equipment type**			**cost**	**rental cost**
E/ work forman	1	0.25	59.47	14.8675	Dozer	1	1	2453.89	2453.89
v.driver	1	0.25	29.79	7.4475	loader	1	1	1000	1000
data collector	1	1	15.96	15.96	dump truck	2	1	432.69	865.38
daily labourer	5	1	15.96	79.8	service vehicle	1	0.25	302	75.5
Dozer Operator	1	1	79.3	79.3					
Excavator Operator	1	1	46.26	46.26					
Dump truck driver	2	1	33.04	66.08					
total				309.715	total				4394.77
B =Manpower unit Cost - Birr/m3			**2382.42308**	**C= Equipment Unit Cost - Birr/m3 r**					**33805.92308**
Direct Cost of Work Item = A + B + C =			36188.3462						
Over head cost + Profit: 0.35			12665.9212						
Total Unit Cost =			**48854.2673**	birr/Ha					
Total Cost =			**4.88542673**	birr/m2					
Total Cost =			48854.2673	birr/Km					

Work Item:Mixing saw dust ash and induction furnace slag with black cotton soil						Performance rate :96 m3/hr			
Unit Quantity of work item:1 m3									
labour cost					**Equipment cost**				
Labour assigned	**no**	**uf**	**hourly cost**	**total**	**Equipment type**	**No.**	**UF**	**Hourly Rental**	**Total Hourly**
			(in birr)	**hourly cost**	**Equipment type**			**cost**	**rental cost**
Construction Engineer	1	0.5	99.12	49.56	Grader	1	1	1700	1700
Site Engineer	1	1	79.3	79.3	service vehicle	3	1	302	906
Surveyer	2	1	37.91	75.82					
E/work Forman	1	1	59.47	59.47					
S/vehicle driver	3	1	29.79	89.37					
data collector	1	1	15.96	15.96					
daily labourer	20	1	15.96	319.2					
Grader oprator	1	1	99.12	99.12					
total				787.8	total				2606
B =Manpower unit Cost - Birr/m3			8.20625	C= Equipment Unit Cost - Birr/m3 r					27.14583333
Direct Cost of Work Item = A + B + C =			35.3520833						
Over head cost + Profit: 0.35			12.3732292						
Total Unit Cost =			**47.7253125**	birr/m3					
Total Cost =			620429.063	birr/Km					

Work Item: Placing of mixed soil				Performance rate : 96 m3/hr					
Unit Quantity of work item:1 m3									
labour cost					**Equipment cost**				
Labour assigned	**no**	**uf**	**hourly cost**	**total**	**Equipment type**	**No.**	**UF**	**Hourly Rental**	**Total Hourly**
			(in birr)	**hourly cost**	**Equipment type**			**cost**	**rental cost**
Construction Engineer	1	0.5	99.12	49.56	Grader	1	1	1700	1700
Site Engineer	1	1	79.3	79.3	Roller	1	1	1000	1000
Surveyer	2	1	37.91	75.82	Water Truck	1	0.25	593.33	148.3325
E/work Forman	1	1	59.47	59.47	service vehicle	3	0.25	302	226.5
S/vehicle driver	3	1	29.79	89.37					
data collector	1	1	15.96	15.96					
daily labourer	20	1	15.96	319.2					
Grader oprator	1	1	99.12	99.12					
roller oprator	1	0.25	19.82	4.955					
water truck driver	1	0.25	33.04	8.26					
total				801.015	total				3074.8325
B =Manpower unit Cost - Birr/m3			8.34390625	C= Equipment Unit Cost - Birr/m3				32.02950521	
Direct Cost of Work Item = A + B + C =			40.3734115						
Over head cost + Profit: 0.35			14.130694						
Total Unit Cost =			**54.5041055**	birr/m3					
Total Cost =			708553.371	birr/Km					