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INVESTIGATING THE MECHANISHIM OF EXPANSIVE BLACK COTTON SOIL STABLIZATION WITH SEWAGE SLUGDE ASH USING EXPERIMENTAL AND IMAGE ANALAYSIS METHODS

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BEREKET MULUGETA NIGAT

ADDIS ABABA UNIVERSITY, ADDIS ABABA, ETHIOPIA

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INVESTIGATING THE MECHANISHIM OF EXPANSIVE BLACK COTTON SOIL STABLIZATION WITH SEWAGE SLUGDE ASH USING EXPERIMENTAL & IMAGE ANALAYSIS METHODS

ADVISOR

Dr. ANTENEH MARILIGN

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ADVISORS' APPROVAL SHEET

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This is to certify that the thesis proposal entitled **"Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods."** submitted in partial fulfillment of the requirements for the degree of **Master's** with specialization in **Materials Engineering**, the Graduate Program of **Center for Materials Engineering,** and has been carried out by Bereket Mulugeta Nigat Id. No GSR/8347/13, under my supervision. Therefore I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Dr. Anteneh Marilign	_____	_____
Name of advisor	Signature	Date

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School of Graduate Studies

Addis Ababa University

We, the undersigned, members of the Board of Examiners of the thesis proposal defense by **have** read and evaluated his thesis proposal entitled "**Investigating The Mechanism Of Expansive Black Cotton Soil Stabilization With Sewage Sludge Ash Using Experimental & Image Analysis Methods"**, and examined the candidate. This is, therefore, to certify that the thesis proposal has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Material Engineering.

Name of Major Advisor	Signature	Date
_____	_____	_____
Name of Internal Examiner	Signature	Date
_____	_____	_____
Name of External examiner	Signature	Date
_____	_____	_____

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Bereket Mulugeta

Declaration

I hereby declare that this M Sc. thesis proposal is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis proposal have been duly acknowledged.

Name: BEREKET MULUGETA NIGAT

Signature: _____

Place of Submission: Addis Ababa University, Institute of Technology, Addis Ababa

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List of Symbols

Symbols	Description
ASCM	Alternative Supplementary cementitious material
EBCS	Expansive Black Cotton Soil
SSA	Sewage Sludge Ash
SCM	Supplementary cementitious Material
SEM	Scanning Electron Microscopy
XRD	X-ray Diffraction
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
ERA	Ethiopian Roads Authority
CBR	California Bearing Ratio
ASTM	American Society for Testing of Materials
LL	Liquid Limit
PI	Plastic Index
PL	Plastic Limit
OMC	Optimum Moisture Content
MDD	Maximum Dry Density
AASHTO	American Association of State highway and transportation Officials
SS	Sewage Sludge
AAWSA	Addis Ababa Water and Sewerage Authority
V	VALUE
C	COUNT
LUT	Light Look up Table

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ABSTRACT

Huge machineries and lots of earthmovings are needed for soil stabilization procedure, which makes it an expensive and labor-intensive process. Finding novel, affordable materials that can advance construction methods and permit the growth of the road network is currently in high demand. Particularly, there has been a rise in interest in the hunt for novel, less expensive soil stabilizers and construction methods. At a height of about 2000 meters above mean sea level, Addis Ababa, the capital city of Ethiopia, is mostly covered in clay expansive soil. In engineering, it is crucial to enhance expansive soil; mechanical strength and swelling-shrinkage characteristics. In this study, an experimental investigation has been carried out to determine the possibility of stabilizing expansive black cotton soil (EBCS) using municipal sewage sludge ash (SSA). Prior to the experimental study compositional analysis of the EBCS and the SSA have been made using complete silicate analysis.

The results revealed that the SSA can be used as Alternative supplementary cementitious materials (ASCM) and has more CaO content, which makes it suitable for Hydration and pozolanic reaction. Effect of adding variable composition of SSA, from 4 to 10%, in the EBCS performance characteristic has been analyzed. Parameters which were analyzed as performance indicators were stability conducted in the laboratory to obtain the California bearing ratio (CBR),Maximum Dry Density(MDD), and Atterberg limit (PI, LL, SL).

Studying microstructural analysis of soil samples that passed through a 32μm sieve, the EBCS, SSA and soil-SSA composite were analyzed for surface area using a BET, and the results revealed a sizable reduction. Surface area for expansive soil is168.422 m^2/gm and after SSA treatment, it was reduced to 145.646 m^2/gm. Moreover, microstructural analysis using a scanning electron microscope (SEM) and complete silicate analysis was conducted to gain insight into the material behavior, and images from the SEM were analyzed through the Fiji Image J analyzer in order to characterize the surface texture characteristics of EBCS, SSA and soil-SSA composite. It is concluded from the present study that the SSA could be used for the stabilization of EBCS for highway subgrade.

By reducing surface area and filling soil pores with sewage sludge ash, along with hydration reaction and some pozzolanic reaction between EBCS clay particle and SSA, it is possible to change the physical properties of soils to increase their capacity for bearing loads.

Key words: Sewage sludge Ash, Soil stabilization, Black Cotton Expansive Soil

1. Introduction

1.1 General Overview

A broad network of highways linking rural communities with metropolitan centers is essential for the movement of goods in emerging countries like Ethiopia. As a result, their construction must be done very carefully. The lack of sufficient building materials that match the standards within a practical hauling distance hinders efforts to build numerous and high-quality highways. In order to achieve quality standards, it is required to use locally accessible pavement layer construction materials. Highway pavement's primary function is to distribute applied vehicle loads to the subgrade. The subgrade of the natural soil is covered with layers of processed materials to form a roadway pavement. The typical pavement layers that make up a roadway are wearing course, base course, sub-base, and sub-grade. Many natural materials can be stabilized to make them suitable for road pavement; however, this technique is only cost-effective when the cost of importing another material that is adequate without stabilization is less than the cost of resolving a defect in one material. Soil stabilization processes can also be utilized to build the top layer of pavements. The position of the stabilized material inside the pavement construction and the volume of traffic will determine the minimum permissible strength. The soil must be strong enough to withstand traffic loads, but the upper strength limits are often chosen to reduce the possibility of reflection cracking.

In the construction of roads, stabilizing pavement materials is a common process. Since the beginning of this stabilization process, the majority of soil materials that were previously deemed useless have been shown to be valuable in a variety of construction fields. Stabilization can result in an increase in soil strength, stiffness, and durability as well as a decrease in the swelling potential of wet clay soils and other desired qualities including dust proofing and waterproofing of unsealed roadways. The pavements are made up of several layers of design materials that typically give cars access in all seasonal changes, enabling them to move around safely and efficiently. In order to create a structure that can withstand the imposed vehicular loads under a variety of environmental circumstances for a stipulated minimum life, the layers of materials are chosen and engineered. A good pavement design aims to make it possible for cars to travel both

safely and affordably. In this study, the effects of SSA additives on the performance characteristics of Soil-SSA composite and the stabilization mechanisms will be investigated through a comprehensive program of experiments and image analysis. Based on the literature review provided, SSA improvements to soil characteristics for engineering road construction purposes seem to have been the subject of very few investigations. Since the usage of these stabilization chemicals has not yet been completely realized, more study on the crack propagation potential and water affinity features is required. This study also investigated the effect of surface roughness characteristics of SSA, EBCS and Soil-SSA composite on water affinity.

1.2 Problem Statement

A tremendous increase in infrastructure development has been taking place in Ethiopia. These enormous infrastructure development projects are demanding large quantities of valuable natural materials and thus has depleted and created scarcity of these valuable natural materials. One of the most widespread problematic soils in Ethiopia is EBCS. Consequently, most pavement layer is being laid on weak subgrade materials.to. Fifteen (15) years of service life is expected from a newly built asphalt road before a major rehabilitation is made on it; however, it is common to observe in Ethiopia that newly built roads undergoing major rehabilitation most frequently than expected time[1]**.** Thus, this practice of building roads on weak subgrade material is causing the country to undergo frequent rework of roads which intern causes wastage of the rather stringent finance of the country. For a country like Ethiopia where financing is the limiting factor for development, an alternative economical and technical feasible approach of road construction could be conversion of locally available difficult subgrade soil into a suitable mechanically stable construction material. Reinforcing weak subgrade soils with materials having cementitious properties such as calcium carbonate, cement, lime and fly ash has been a common practice to stabilization of native soils locally. Nevertheless, since these materials have applications in other areas too, they have commercial values themselves. On the other hand, handling sewage sludge (SS) is a huge burden on the municipal water treatment facility of Addis Ababa city. There has not been a viable option so far which can steadily remove the SS at the same rate as its generation[2, 3]. In this work, the potential of municipal SSA as a stabilizing agent to change the engineering characteristics of the naturally problematical EBCS to satisfy design requirements is examined and the study tackle problem associated with SS disposal.

1.3 Objectives

1.3.1 General Objectives

- The aim of this research is to study the effects of SSA addition on the performance Characteristics of EBCS to be used in the pavement structure as sub-grade material and to investigate the mechanisms of Soil-SSA composite.

1.3.2 Specific Objectives

- To identify and analyze the characteristics of the EBCS and that of SSA.
- To determine the effect of complementing the EBCS with different percentage of SSA on enhancing the mechanical properties of the EBCS such as CBR, MDD, OMC &PI.

1.4 Significance of the Study

Urbanization has led to increased living standards but also pollution and solid waste production. Inadequate solid waste management can lead to water pollution, health issues, and costly restoration costs, making cities unsustainable. Recycling and reuse are suggested methods for sustainable development. SS, produced after wastewater treatment, is a significant challenge in wastewater management. Solutions include aerobic digestion, anaerobic digestion, chemical fixation composting, heat drying, air drying, lime stabilization, landfilling, agricultural reuse, sea or surface water disposal, and sewage sludge incineration. Safe reusing and discarding sludge is essential to reduce sludge production. SSA contains pozzolanic elements that can be used in resource recovery studies. Traditional soil stabilizing methods are expensive and environmentally unfriendly, and less expensive options are needed to reduce soil stabilization. In order to address issues with soft subgrade soils and environmental contamination due to SS, this study will contribute on some of the issues related to striking above-mentioned problems.

1.5 Scope of the Study

This research work will cover the study of SSA, soil-SSA composite and EBCS physical properties, the chemical composition of SSA and EBCS, and the study of MDD, OMC& CBR strength. The morphological study conducted with the help of complementary characterization techniques such as SEM; Surface area analysis was done using a BET, identification of the chemical composition of SSA & EBCS was done using Complete Silicate Analysis and microstructural analysis using the Fiji Image-J analyzer.

1.6 Limitation of the Study

One of the problems associated with EBCS is its shrink-swell characteristics directly associated with water affinity characteristics which is measured by wettability. Even though, wettability is measured by contact angle and affected by many factors. In this study we are limited to study the effect of surface roughness and geometry on microstructural analysis of SSA, EBCS and Soil-SSA composite.

2. Literature Review

2.1 Origin of Expansive Soils

The dry and semi-arid regions of the world are where expansive soils are most commonly found[4]. The distribution of expansive soil in Ethiopia have been identified by prior researchers and the coverage exceeds 40%[5]. Expansive clay is produced as a result of the weathering of the original rocks, which can include volcanic rocks like granite (rocks that include silica), basalts, and sedimentary rocks like shales, alluvial deposits, and limestones. A well-known expansive soil with a high volume change tendency is black cotton soil. Typically weathered debris from the volcanic Ethiopian Highlands makes up the broad clay soils. This clay is often alkaline, contains gypsum and calcium carbonate, and the majority of the clay component is montmorillonite[6].

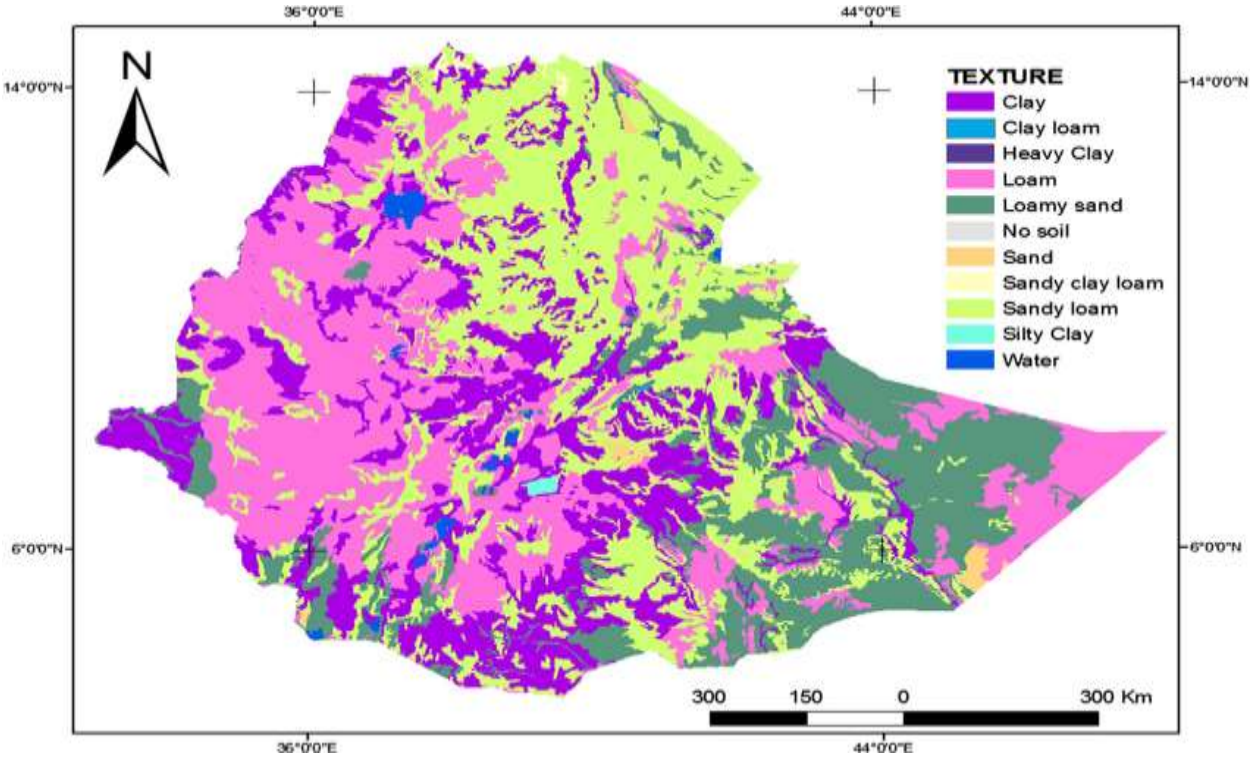


Figure 1: GIS based Textural classification of Ethiopian soils [7]

The parent materials that can be linked to expanding soil were divided into two classes by Donaldson (1969). The first group consists of common igneous rocks such basalts, gabbros, and norits. In these soils, feldspar and pyroxene minerals from the parent rocks have disintegrated to form secondary minerals like montmorillonite.

Sedimentary rocks in the second type physically breakdown to create expansive soils. The formation of montmorillonite likely had two distinct beginnings. Streams conveyed the byproducts of the weathering and erosion of the rocks in the Highlands to the coastal lowlands. Shale eventually formed from the fine-grained soils and accumulated in the ocean basin. In the meantime, ash clouds from volcanic explosions rained on the seas and the plains. They go through modification to become montmorillonite[6].

2.2 Expansion mechanism

Clay mineralogy, soil water chemistry, soil suction, soil plasticity, initial dry density, soil structure and fabric, initial moisture content, moisture change, and various other climates- and stress-related parameters are among the factors that affect expanding behavior of soil. Moisture change causes swell-shrink behavior. Due to water's attraction to EBCS particles, swelling happens. The positively charged exchangeable cations (Na+, Ca+, etc.) in the pore water are drawn to the negatively charged surfaces of clay particles. Cations are first hydrated with the first water that is added. More water is added to meet the osmosis forces. Depending on the clay minerals, either kaolinite or illite clay or montmorillonite clay, there are two mechanisms of hydrating cations that occur. Illite and kaolinite crystals' external surfaces have spaces between them called pores that are permeable to water (inter-crystalline swelling). The pore gap between each sheet of the montmorillonite crystals is where water can enter (intra-crystalline swelling). The fine-grained clay mineral composition of expansive soils is primarily responsible for their inherent volume change properties [7].

Clays are small particle sizes, Clays are unaffected by gravitational forces but are affected by surface forces. Clays have a shape similar to a plate, resulting in a large specific surface area ratio. This leads to more contact between particles and inter-particle forces. The electrical charge on the clay interacts with the water dipole; finally, clay absorbs more water.

Clay soils, especially with water, can cause problems like excessive settlement and volume change. The specific surface area is crucial for clay's physical processes[8].

Clay particles in expansive soils, like montmorillonite, exhibit significant isomorph substitution and exhibit weak intermolecular forces of attraction. These minerals, such as montmorillonite, exhibit a diffuse double layer, which separates particles and minerals, resulting in swelling behavior. The diffuse double layer influences hydraulic conductivity, which decreases as the layer thickness increases or decreases. The swell-shrink behavior of expansive soils with moisture change is influenced by the diffuse double layer, which is characterized by an expanding clay lattice [7].

2.3 Problems of Expansive Soils in Civil Engineering Perspective

Expansive soils subject structures to stresses and movements that are significantly greater than those that normal soils encounter. Additionally, the costs of building on expansive soil are considerably higher than those of building on non-expansive soil. To lightly laden constructions like road pavements, expansive soil frequently varies in volume in response to changes in moisture content. Flexible pavements built on this soil continuously display signs of degradation throughout their useful lives, which raises maintenance expenses. 40% of Ethiopia's total road sector development spending over the previous 13 years has gone towards improving and repairing trunk highways, with an additional 11% going into maintenance-only projects [9]. According to reports from 2004, Addis Ababa City Roads Authority spent almost 300 million Ethiopian Birr annually on road development and maintenance, of which more than 30 million Ethiopian Birr went into unnecessary regular maintenance that calls for particular attention [10] .Globally, billions of dollars are thought to have been lost as a result of substantial damage to buildings built on expansive soils. According to the United States alone, annual losses resulting from expanding soils range from $6 billion to $11 billion in damages to structures like buildings, highways, airports, pipelines, and other infrastructure. More than $6 million has been reported to have been spent in Sudan on building and light structure damage [11].

Seasonal cyclical shifts, water supply leaks, poor surface drainage, and seasonal changes all contribute to variations in moisture content. Roads on expansive clay will undoubtedly be

impacted by crucial moisture content variation, which could lead to rutting, boreholes, depression, alligator cracks, or complete collapse**.** Long droughts and strong rainfall are two examples of significant climatic variations that lead to cyclical moisture changes and structural edge displacement[11].

2.4 Sewage sludge Management of Addis Ababa Municipal City

Less than 3% of Addis Ababa's population relies on a small sewer network near the city's heart. About 75% of homes have pit latrines that discharge to open drains, 15% have flush toilets and septic tanks, and 5% practice open excretion. AAWSA is working to improve sanitary conditions but faces financial limitations. They are building sludge transfer stations, drying beds, and sludge lagoons at Kaliti and Kotebe, as well as boosting the capacity of sludge collecting trucks. To increase access to the sewage system, AAWSA is gradually increasing the network of secondary sewer lines[12].

Addis Ababa city has three main catchments: Kaliti catchment, Eastern catchment, and Akaki catchment. The waste water treatment works in Kaliti treat sewage waste, with a capacity of 7600 m^3/day and a Biochemical Oxygen Demand load of 3,500 kg/day. In Kaliti and Kotebe, sludge from septic tanks and dry pit latrines is processed. The sludge drying beds and lagoons in Kaliti can process 125,000 m^3 of sludge each year, but current data indicates an average daily dry season flow of only 4500 m^3/day. The total sewer length is 120 km, with an average infiltration rate of 0.25 l/s/km, resulting in 3,000 m3 per day.

Kotebe receives sludge from most households, which is discharged into tributaries of the Akakai and eventually to the Awash River. The sludge disposal facility at Kotebe has a capacity of 150,000 m^3/year and consists of 20 drying beds and 10 lagoons[12].The sludge lagoons are used in the rainy season to store sludge until the dry season. From the sludge lagoons the sludge can be pumped to the drying beds[12].

The sludge cannot be directly used as a fertilizer for agriculture as it is contaminated with pathogens and helminth (intestinal worm) eggs[2]. Construction and operation of the planned sewage system would help to enhance the health and level of living of the inhabitants of Addis Abeba, which currently has around 2000 connections and foul sewage flows of about 1,500 m^3 per day. According to estimations, the drying beds generate about 15,000 m^3 of dried sludge per

year. Due to the large increase in sludge from the dry pit latrines, it will be required to dispose of the sludge at sanitary landfill sites in Kaliti and Kotebe[12].

2.5 Soil stabilization

For the purpose of giving vehicles a stable and level surface, a hard crust called pavement is built over an existing soil. Subgrade, subbase, base course, and wearing course are the typical components of pavement. Both flexible and rigid pavement structures must include subgrade soil in their designs. The main factors contributing to pavement failure are subgrade settlement and a high vulnerability to moisture, which weakens the subgrade. On EBCS, pavements are typically prone to degradation [13].

The development of highways using naturally occurring, unsuitable soils will create new opportunities for the sector. Soil stabilization is the process of making unsuitable, found naturally soil suitable. EBCS is not good for building because it expands greatly when it comes in touch with water. Making EBCS water resistant and having a strong binding strength can modify unsuitability [14].The procedures for treating soil are used to change the soil's strength, stability, permeability, and resistance to erosion. The only option to remove and replace unstable soil is soil adjustment, which saves a tremendous amount of time and money.

The term soil stabilization" refers to the alteration of soil characteristics using artificial or physical techniques with the intention of enhancing the soil's design characteristics [15]. Due to the behavior of the clay mineral component, which causes them to display shrink-swell properties, EBCS are problematic. Numerous materials and methods have been explored to improve soil quality in an effort to make them more practical for construction. Studies made by postgraduate students at Addis Abeba University, Ehitabezahu Negussie and Abebe Dinku (2014)[9], School of Civil & Hydraulics Engineering at the Gondar University Institute of Technology, Amsalu Asmamaw (2021)[16], Addis Abeba University School of Earth science, Sisay Negash[17] and numerous other studies conducted across the country on soil stabilization which shows that the topic is comparatively well researched.

2.6 Expansive soil stabilization Methods

The process of soil stabilization comprises mechanical, electrical, chemical, and biological mechanisms for bettering the soil. Engineers may use the mechanisms of soil stabilization for each category to make a foresighted selection of any kind of material based on the desired degree of physicochemical change.

2.6.1 Mechanical technique

Compaction is a widely used method for EBCS, aiming to achieve the optimum moisture content (OMC) at a maximum dry density (MDD). Soil-dependent factors influencing OMC and MDD include grain size distribution, soil grain shape, soil specific gravity, and clay mineral content. On a macroscopic scale as opposed to the microstructure, the impact of compaction on the bulk of the expansive soil is more noticeable. Pre-wetting, a mechanical method, creates a moisture-rich environment, but maintaining high moisture levels is difficult under field conditions. Wetting-drying cycles investigate equilibrium conditions, while reinforcement uses fibrous materials and solid wastes. The impact of moisture content, density, and solid wastes on soil properties and performance has been a topic of interest in recent years[18].

2.6.2 Chemical Method

Traditional agents are well-known chemical additions used to stabilize expansive soils, including lime, cement, and fly ash. They interact chemically with the soil or other additives, improving the soil matrix as a whole. Cation exchange, flocculation and agglomeration, pozzolanic reaction, and carbonate cementation are some of these agents. Non-traditional agents (Unusual substances), such as industrial byproducts, waste materials containing calcium oxide, sulphonated oils, ionic compounds, and polymers, chemically react with the soil and/or other additives, frequently in the presence of enough moisture to cause physicochemical interactions in the soil matrix[7].

2.6.3 Electrical Method

The electro-osmosis technique is used to electrically stabilize clayey soils. This costly technique for stabilizing soil is primarily employed to allow cohesive soils to drain. Those soils that acquire certain mineralogical features and are chemically active should use electro kinetic

stabilization. Since fine-grained soils have a higher proportion of clayey particles and are less permeable, they are suitable for this treatment. Less permeable soils are ones that are difficult to drain[19].

2.6.4 Biological Method

In engineering construction projects, refining soil shear strength is a goal, and biotic soil stabilization methods have developed as environmentally friendly methods. However, their impact on soil mechanical properties has not been comprehensively agreed. Rahim safari et al. studies the effect of bacteriological induced calcite precipitation on swelling fine-grained soil, focusing on the influence of bacterial concentration and culture media. The results show that increasing bacterial concentration increases soil cohesion and friction angle, indicating that the enhancement is induced by bio-geochemical processes rather than chemical compounds[20].

Common practice to enhance soil geotechnical properties includes cement, fly ash, and lime. However, sustainable development principles dictate moderation to limit the release of gases like CO_2 and NO_2 and particulate matter[21]. Scientists are constantly seeking eco-friendly substances for widespread soil stabilization. The mechanism of soil stabilization varies, with some materials using a similar mechanism as traditional stabilizers, while others use different processes. Sulfonated oils and polymers, for example, improve soil binding and reduce moisture sensitivity by aligning clay particles and altering clay surface charge polarity [22].

2.7 SSA Soil Stabilization

Sludge from sewage treatment plants is now being used in construction, which is a new and creative non-traditional soil stabilization method. Many nations forbid the landfill dumping or fertilizer usage of SS due to the potential presence of heavy metals or other harmful compounds in it. Numerous studies have shown that it is feasible to use wastewater sludge in the creation of eco-construction materials like cement. This reduces the negative effects of an increase in the amount of sludge produced by treatment plants due to population growth, as well as the costs associated with handling and disposing of sludge[24, 25, 26]. A laboratory study (compaction tests, Atterberg limits, and grain size distribution tests) aimed to enhance soil engineering

qualities using SSA was conducted by *Ahmad Hussaini Jagaba* et al (2020). The results showed that SSA addition improved soil type and properties. The best soil-SSA ratio, which is anticipated to perform better as construction material, was 7.5% SSA. An acceptable alternative was a blend of 5% and 7.5% SSA[24]. The advantages of using SSA as Alternative Supplementary cementitious material (ASCM) have been extensively researched.

2.8 Assessment of the Pozzolanic Activity of SSA

When discussing ASCM, Fig.2 explains where SSA is located and what its components are in comparison to other well-known supplementary contentious materials (SCM). The image shows a ternary phase diagram of SCM basic ingredients, Calcium Oxide (CaO), Silica (SiO_2) and Aluminum Oxide (Al_2O_3).The ternary phase diagram is composed of several different shapes and orientation of SCMs like fly ash , Blast furnace slag, OPC,Metkaolin, Silica fume and SSA [25]. Silica fume, fly ash, and blast furnace slag are examples of typical SCMs. Their broad usage is supported by research and development initiatives, and environmental responsibility and sustainability are driving the development of novel ASCM materials and techniques. The three fundamental components of SCMs are calcium (CaO), silica (SiO2), and alumina (Al2O3). The three components might be classed as cementitious, pozzolanic, or both depending on their chemical make-up[28, 29].

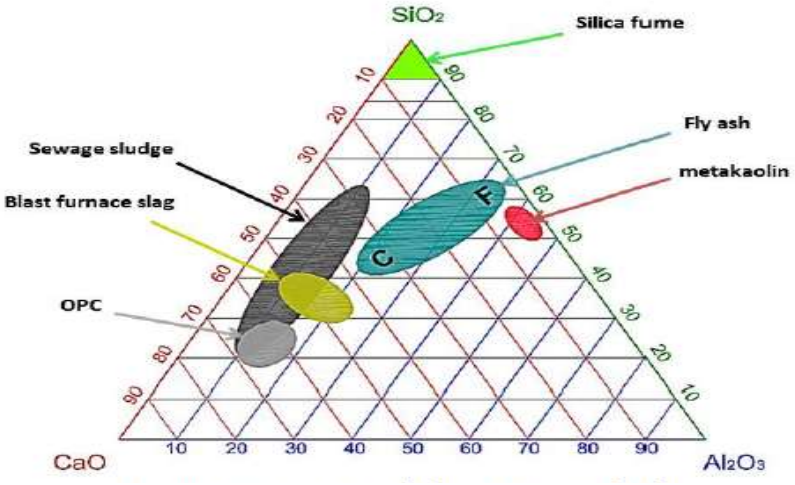


Figure 2: SCM pozolanic component [25]

Deng-Fong Lin **et al**.(2012) [27] and M. A. Tantawy **et al(2012)** [28] experimented the pozolanic activity of SSA in comparison with silica fume and fly ash and suggested SSA as ASCM.

2.9 Burning temperature of Sewage Sludge

The chemical makeup of SS is significantly altered by incineration at 600-1000°C, affecting its pozzolanic activity. Burning SS at different temperatures, such as 700°C, 800°C, or 850°C, can produce high, moderate, or low levels of reactive SSA, which can affect the workability of cementitious materials. The incinerating of SS at 800°C preserves the amorphous nature of the ash, while at temperatures higher than 800°C; it enhances the crystallization of amorphous silica. *M. A. Tantawy et al* (2012) conducted Chappelle test to examine the impact of ignition temperature on the microstructure and pozzolanic activity of the SSA. Amorphous silica collects fixed carbon produced by incomplete combustion during burning at temperatures lower than 800°C, but crystallization of amorphous silica is improved at higher temperatures. In order to maintain pozzolanic activity, burning of SSA must be optimum around 800°C, while at higher temperatures, amorphous silica crystallization is increased, resulting in decreased pozzolanic activity in SSA[28]. *T. Karayildirim et al (*2005) conducted TGA, FTIR, DTG and SEM techniques to describe raw SS burned for two hours at 650-950°C and found that the microstructure and pozzolanic activity of the resulting ash are impacted by the combustion of SS. At temperatures below 800°C, amorphous silica gathers fixed carbon created by incomplete combustion, while crystallization of amorphous silica is enhanced at higher temperatures [29].

2.10 Microstructural interaction of Stabilized expansive soil

Engineers must be aware of the physicochemical modifications to the stabilized soil. As a result, the physicochemical changes are explained by the microstructural analysis. Such analysis can be displayed using quantitative charts, like in X-ray diffraction, or qualitative digital image analysis, like in SEM. They aid in shedding light on how stabilization affects the pore structure, micro fabric, and soil constituents.

The effect of polymers on soil micro fabric microstructurally was studied by Mirzababaei et al. (2009) [30]. Three expansive soils compacted at OMC and MDD had their free swell percentage

gradually reduced with the addition of the polymer furan at 3%, 5%, and 10% by weight of the soil, with an average maximum decline of roughly 83.5%.The natural soil appears to be primarily composed of discrete granules in combination with sparse aggregations, a few silt particles, and few connectors at the two distinct image magnification ratios (X500 and X1000). Between the discrete and sparse aggregations, there are clear interassemblage pores. Furan, when added at 5% and 10%, causes the soil fabric to shift into dense aggregations. As a result of the creation of these dense aggregations, assemblage pores form, and the inter-assemblage pores become less noticeable, indicating a reduction in pore diameters. Additionally, silt grains that have been covered are more visible than those on bare soil. The observed decrease in the soil's ability to swell is the result of changes in the pore structure and soil fabric. However, the completed microstructural analysis was solely qualitative[30]**.**

The occurrence of calcite, which was qualitatively validated from the FTIR spectroscopy and SEM examination of optimally preserved soil, was examined by Roland Kufre Etim et al (2022) [31]. The untreated soil revealed a clear presence of loose aggregated porous materials with intra- and inter-assemblage pores inside the grains, as well as a dispersed structure with these pores. The surface of the clay fabrics seems to be dense, and there aren't many inter-assemblage pores that dominate the clay matrices, which make the morphologies of the treated soil quite unique from those of the untreated soil. The application of the stabilizers also caused the clay structures to flocculate, especially as a result of a rise in calcium ions, which results in the production of white lumps on the surface, further confirming the existence of CSH and CAH [31].

2.11 Basics of Image Analysis

Image processing plays a crucial role in enhancing visual quality and extracting relevant data from pictures. It is used in various scientific and technological disciplines to evaluate visible qualities of materials, such as color, size, form, and surface texture. Image analysis, a subset of image processing, focuses on enhancing a picture's visual quality and extracting relevant data. Three sub-areas of image processing operations are picture compression, picture preprocessing,

and image analysis. These operations help improve the visual quality of pictures and increase the dependability of the image analysis phase based on established standards[32].

Understanding the form characteristics, microstructure, and morphology of SSA and stabilized EBCS is crucial for effective real-world applications. Combining SEM and image analysis can determine circularity, roundness, solidity, axial ratio, surface porosity, and surface roughness of pozzolans and admixtures[35, 36]. Image processing is becoming a crucial topic in various industries, including food processing, medical science, particle technology, cement, and powder industries[34]. The structuring characteristics of mineral and chemical admixtures may be evaluated using image analysis, which simply needs SEM images. [35]. Digital image analysis is becoming more relevant and widespread as a result of the quick development of hardware platforms and software frameworks.

2.12 Summary of Literature Review and Gap

According to the literature review that was just given, it seems that not many studies have been done to apply SSA to enhance soil qualities for road construction purpose. Among those studies most of the study focus on mechanical strength but problem associated with expansive black cotton soil swelling-shrinkage characteristics, with additive SSA remain as the gap. Further research is required to better understand the microstructural interactions between EBCS and SSA. Understanding shape parameters, microstructure and morphology of Soil-SSA composite for utilizing them more efficiently for practical applications is critically required. Since the deployment of these stabilization solutions has not yet been completely grasped, additional study on the features of swelling-shrinkage characteristics is required.

3. Materials and Methods

3.1 Overview

In this experimental study on the evaluation of investigating the effect of partial substitution of municipal sewage sludge ash on the performance characteristics and mechanisms of the stabilization of EBCS for road subgrade application property of host EBCS, SSA and soil-SSA composite characteristics identified. The experimental program was directed to the evaluation of physical and chemical property of natural soil and soil-SSA composite; these are Atterberg limit, moisture density relationship, California bearing ratio, mineralogical composition and specific surface area. Additionally, untreated samples of soil were obtained as control samples, and each treatment was put through its own test, necessitating the fabrication and testing of several specimens. The methods and protocols for material characterization, specimen preparation, testing and image analysis employed throughout the study project are presented in this section. As a control test, the natural soil is used in the experiment along with altering the stabilizer content.

3.2 Description of Study Area

3.2.1 Topographic, geological and climatic condition of the study area

The research area is located inside and around a 40/60 condominium site in the Lemi-Kura sub-city in the south-east area of Addis Abeba, starting at the Bole Beshale roundabout and terminating at the Bole Ayat site -4 condominium housing construction projects. On the left side of the main road heading to the Bole-Arabssa Condominium, the location is visible. On the map, the position is shown as being at 8 59 41.81"N, 38 53 28.77"E. The location of the study area is shown in fig 3.

According to the 1996 edition of Ethiopia's Geological Map, Addis Ababa area is covered by four main types of volcanic rock formations. Nazareth series (Nn), Alagae formation (PNa), Tarmaber - Megezez formation (Ntb) and Chilalo formation (lower part) (NC) [36]. From the map, it is observed that Ayat area is located on the east south part of the city, which is dominated by Nathareth series and basaltic formations. As observed during the field investigation, the types

of rocks observed adjacent to the road, have basaltic formation, which is fractured and weathered on the surface but underlain by solid, hard basaltic formation[37].

Figure 3: Study area's location map[38]

The study area Addis Ababa, located at an altitude of 2350-2405m above sea level, has a comfortable temperature below 25^0c. The city experiences mean annual rainfall ranging from 918mm to 1567mm, with a rainy period from June to September. Monthly rainfall is maximum in July and August and minimum in November and December. The temperature is highest in March and lowest in January.

3.3 Study design

This research was designed to meet its objectives based on experimental findings and image analysis. The first step in the research work was sample collection. The second step was sample preparation. The third step, by varying the content of SSA conducted a series of laboratory tests. In this step, tests used to determine stabilizer content with good bearing capacity, provide

sustainable construction platform performed. The final step was analysis and interpretation of laboratory test data followed by presentation of the research findings and recommendations.

3.4 Sample collection and preparation

Dewatered sludge sample, EBCS black cotton soil, and distilled water were the materials employed for this investigation.

3.4.1 Sewerage Sludge

The stabilizer material utilized and sources are described in this section. Following the main and secondary stages of wastewater treatment, the sludge was collected. About 500 kg of dewatered sludge was collected from Kotebe sewage sludge treatment plant. To assist burning, the resulting sludge was air-dried by natural evaporation in an open area, as shown in Fig. 4 (a).

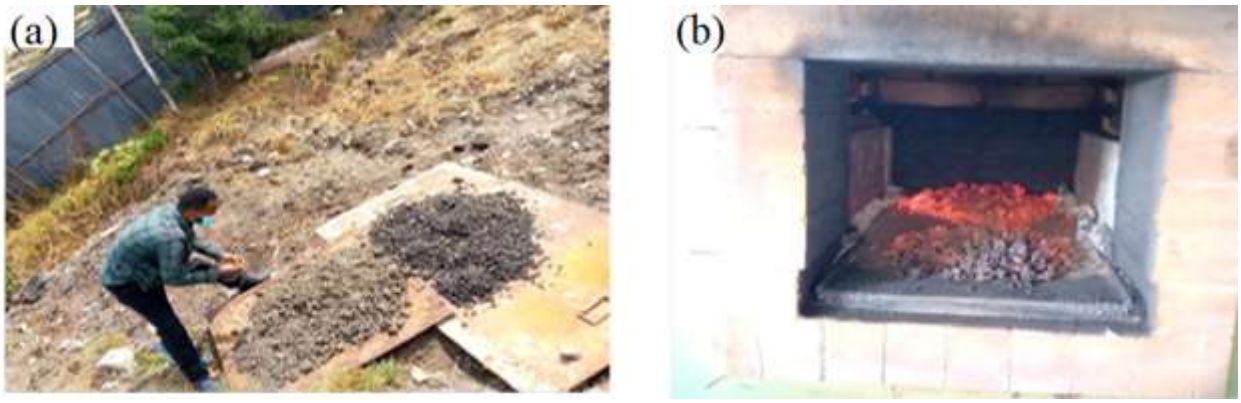


Figure 4: SS air drying by natural evaporation in an open space (a) and burning of air dried SS in Industrial furnace (b)

In order to characterize the SS, it was dried, burned in a brick kiln industrial furnace between 0°C and 850°C, and then pulverized into the particles .The ground SSA was sieved via sieve size 75 micron. Following sieving, 100 kg of sieved SSA were recovered.

3.4.2 Expansive black cotton Soil

After making approximate calculation on the number of sacks of soil required to conduct laboratory tests on material strength tests, characterization, moisture density relation, 10 sacks of sample weighing 300kg collected, the soil samples were obtained from a roadside in the central part of Ethiopia, Addis Ababa City. The soil was a dark reddish brown color. After loading to

working laboratory, break up coarser particles to finer sizes, to get more of less uniform soil samples. The destruction of the original soil fabric during mixing and compaction operations often has no impact on the sample's quality or suitability for testing .We blend each of sacks together in clean and dry area and refill after mix to original sacks. Pour and blend again sacks which are not previously mixed together and refill after remix to the sacks. We put these processed soil samples in a room where it will not be exposed for significant moisture variation.

Figure 5: Expansive soil collection (a) and sample depth measurement (b)

3.4.3 Soil Sample Reduction

Gross sample of the soil mass reduced using a mechanical splitter. As the material moves through the slots between the splitter's bars, the sample is roughly split in half by the mechanical splitter. The smaller sample remains representative since the same number of each particle size is used in each half of the sample, for this procedure AASHTO M 92 was used[39].

Figure 6: Soil Sample Reduction Using Mechanical Splitter (a) and Soil-SSA Composite Soaking (b)

3.4.4 Sample proportions for the laboratory experiments

The quantity of required SSA (4%,-10%) weight in percent and EBCS for experiments was measured using the measuring meter and determined as shown on table 1. The soil is manually mixed with stabilizer in the laboratory. We added weighted processed soil and proportionate binder SSA (4%, 6%, 8%, and 10%) and we thoroughly mixed it to obtain a homogeneous sample.

Table 1: Sample preparation for the MDD, OMC & CBR laboratory experiments

Sn	SSA (%)	No of CBR tests	Soil mass for single CBR test(Kg)	Total soil mass for CBR tests(Kg)	No of MDD test	Soil mass for single MDD tests(Kg)	Total mass of soil for MDD(Kg)	Total of tests (C+F)	SSA Content in wt.% (Kg)	Total SSA mass in wt. %(Kg)
1	0	3	6.8	20.4	5	4.5	22.5	8	0	0
2	4	3	6.8	20.4	5	4.5	22.5	8	1.8	13.8
3	6	3	6.8	20.4	5	4.5	22.5	8	2.6	20.6
4	8	3	6.8	20.4	5	4.5	22.5	8	3.4	27.5
5	10	3	6.8	20.4	5	4.5	22.5	8	4.3	34.3
SUM		**15**		**102**	**25**		**113**		**12**	**96**

The SSA is applied in accordance with the natural weight of EBCS in percent proportion of 4%, 6%, 8% and 10%. Each specimen's prepared sample was placed in sacks individually, with a tag on each one showing the weight in percent proportion. The Soil-SSA composite is then allowed

to fully saturate with pure distilled water. The specimen next undergoes the appropriate seven-day soaking on the bath as shown on fig. 6(b) .Hence, hydration is effectively provided by soaking. The specimen was allowed to fully saturate so that it might obtain the necessary strength from hydration reaction with water. The specimen moved from curing to drying after a seven-day period soaking.

3.5 Methods

3.5.1 Standard testing Methods used

This is a controlled experimental study and the analysis was carried out based on primary data that had been obtained from laboratory tests. AASHTO standard was used for testing soil in laboratory. Specific standards considered in this study are summarized in table 2.

Table 2: Standard testing Methods used

Sn	Test type	Test Code
1	CBR	AASHTO T 193-99
2	Consistency limits(LL, PL & PI)	AASHTO T89,T90
3	Compaction	AASHTO T 180-97
4	Natural Moisture content	AASHTO T 265
5	Sample preparation	AASHTO M 92

3.5.2 Desirable subgrade material requirements

Ethiopian road authority (ERA) standard technical specification, 2014 requirement of fill or embankment material is listed in table 3.

Table 3: Desirable subgrade material requirements

LL	PI	CBR@95% MDD	Swell
≤60%	≤30%	≥5%	≤2%

3.5.3 Compaction Test

The link between the moisture content and the dry density of native EBCS and Soil-SSA composite was examined using a compaction laboratory test. The percentages of SSA (4%, 6%,

8% and 10%) in the Soil-SSA composite were selected according to previous research recommendation. In accordance with the AASHTO T 180-97 [40] natural EBCS and Soil-SSA composite were compacted. In laboratory soil-SSA composite was mixed manually for determining the moisture-density relation of untreated EBCS and soil-SSA composite. In order to obtain a homogenous sample, we produced a weighed amount of 5 kg of untreated EBCS and added 200 ml of water for the first trial. We set the mould and collar assembly on a stable surface, add about half of the EBCS, and start compacting with a standard hammer (2.5 kg) by giving it 25 blows.

Distribute the blows evenly throughout the EBCS surface inside the mould. The process was done twice more until the final layer was just above the mold's level. We took off the collar and used the cutting edge to remove the extra EBCS from the mould. We measured the combined mass of the mould and the compacted EBCS and record it A-1. Employing an extruder to extract the specimen from the mould, We divided this EBCS into three little specimens to determine its water content as per AASHTO T 265[41] (B-1, B-2, and B-3), and we used the average of the three to get the specimen's moisture content. Until the mass of the mould plus the compacted (A-5) soil is less than or equal to the previous measurements (A-1, A-2, A-3, -4), we repeated the trials for the aforementioned phases. For each compacted specimen, the bulk density and dry density are then calculated using equations 1 and 2. The water content vs dry unit weight graph plotted and the separate points connected using smooth line.

$$\text{Wet bulk density} = \frac{\text{Mass of soil plus liquids}}{\text{Volume}} \quad \text{----------Equation 1}$$

$$\text{Dry Bulk density} = \frac{\text{Wet bulk density}}{1 + \text{moisture content}} \quad \text{---------- Equation 2}$$

The dry density, MDD, is inferred as the highest point on the resultant curve from the values of the dry densities as derived from Eq.1. The optimal moisture content (OMC) is the moisture content value that corresponds to the highest dry density (MDD) on the graph of dry density

against moisture content. The result obtained for EBCS used as control point and the procedure for different percentile of Soil-SSA repeated as mentioned above. The result obtained in this laboratory report used for data analysis and discussion section.

3.5.4 Consistency limits

Consistency limit tests are performed to assess water affinity status of the soil system when various water contents are applied. For the prepared sample, they involve figuring out the liquid limit, plastic limit and plasticity index. According to AASHTO T89,T90[42] liquid limit, plastic limit and plasticity index tests are carried out using the conventional Casagrande apparatus.

3.5.4.1 Plastic limit

The plastic limit, measured using a soil sample that passed through a 0.425mm screen, is the water content at which a soil can no longer be distorted by rolling in to 3mm diameter treads without collapsing. The prepared sample of EBCS is rolled between the palms of the hands and molded between the fingers until it has adequately dried. After then, the sample is split into equal halves. Between the first finger and the thumb, each component is rolled into a tread. Then, the thread is rolled between the glass and the tip of one hand's fingers. This procedure went on until the tread's diameter was down to roughly 3mm. Until the thread shears longitudinally and transversally, we preceded the movement of the hand. After the sample has been crushed we take two specimens and make record mass of moisture cane and EBCS soil and oven dried at 105° C - 110° C for 24 hours. The moisture content, which is the sample's plastic limit, is measured as the difference of two specimen moisture content. The result obtained for EBCS used as control point and the procedure for different percentile of Soil-SSA repeated as mentioned above. The sample for Soil-SSA composite was used from previous compaction test samples.

3.5.4. 2 Liquid Limit

Liquid limit is determination of the water content at which the soil has small shear strength .To determine the liquid limit of the soil and SSA-soil mixture , the fine soils passing sieve No.4(0.075mm) were used. The soil samples were oven dried at 105-110° C for 24 hours before experimentation. Standard mechanical casagrande apparatus with splitting the moist sample in to two and applying repeated blows was used. For preparation of a specimen we take 150 g of SSA-

soil composite from sample from compaction test using 4% SSA and EBCS. By adding water we mix the soil-SSA composite in an evaporating dish thoroughly to form a paste of uniform consistency. Hence, liquid limit test on soil involves adjusting the drop of the liquid limit device by releasing two screws at the top and using the handle of the grooving tool. We fix the drop to be exactly 1 cm at the point of contact on the base. Keep the mix under humid conditions for a sufficient period of moisture distribution. We remix the saturated paste and place it in the cup of the device, leveling it with a minimum depth of 1cm at the point of maximum thickness and we transfer excess soil to the evaporating dish. Then we turn the handle of the device at a rate of 2 revolutions per second and count the number of blows until the two halves of the soil specimen come in contact at the bottom of the groove. Using the grooving tool we draw the grooving tool through the paste along the symmetrical axis. We collect a representative sample of the soil by moving a spatula width-wise from one edge to the other edge of the soil paste at right angles to the groove. We take three specimens for moisture content test. Remove the remaining soil from the cup and mix it with the soil left in the evaporating dish. Change the water content of the mix in the evaporating dish by adding more water to the soil. Repeat steps and determine the number of blows (N) and water content in each case. We draw the flow curve between log N and w and determine the liquid limit corresponding to N=25 which is the liquid limit of the sample. The procedure for 4% Soil-SSA composite repeated for different percentile of Soil-SSA composite and EBCS.

3.5.4.3 Plasticity Index

The plasticity index is the difference between the LL and PL of the corresponding specimens. PI is calculated as

$$PI=LL-PL \quad \text{---------- Equation 3}$$

3.5.5 California Bearing Ratio (CBR)

The CBR test gauges a soil's ability to withstand shearing under regulated moisture and density condition. The California Bearing Ratio (CBR) test is a surface load test used in soil investigations to assist in pavement design. In the laboratory test, a circular piston continuously penetrates material that has been compressed in a mould. The CBR is calculated as the

ratio of the unit load needed to penetrate the unit load needed to penetrate the test soil at depths of 0.1 in. (2.5 mm) and 0.2 in. (5 mm) and a standard material of well-graded crusted stone.

According to AASHTO T 193-99 [43] the test is conducted. Compaction experiments which were conducted earlier used to identify the ideal moisture content and ideal dry density with 8% SSA additive composition. For both untreated EBCS and soil-SSA composite, three specimens were compacted in three separate compactivity attempts in order to achieve a specimen prepared below and above to the appropriate unit weight at one OMC. Before the ideal quantity of water is added, 5 kg of the natural EBCS and 15 Kg of Soil-SSA composite with 8% SSA prepared. We transfer these to a clean, damp metal bowl that is in a state that prevents it from absorbing water and from releasing more moisture into the soil sample when it is being mixed to create a homogenous combination. We calculate the amount of water needed for compaction for EBCS and Soil-SSA composite at 95% of MDD ranging from 24.13%-25.5% and 16.82%- 17.70 % respectively. We stirred the prepared sample thoroughly. Before compacting we allow for 2 hour to simulate with the actual site condition where it takes time to mixing before compaction. We divide the prepare sample in to three equal groups and compact the three specimens using different number of blows per layer of each specimen. The number of blows per each layer was varied to prepare specimen of each having unit weight above and below the desired value. As per AASHTO T 193-99 standard test method using 10, 30 and 65 number of blows was used to attain at 95% of MDD. We fasten the mold with extension collar attached on to the base plate and insert spacer discover the base plate and put on filter paper over it. The sample was compacted in three layers with the specified number of blows using 4.5kg rammer in a rigid cylindrical metal mold of diameter 152.4mm and height of 177.8mm and removed the extension collar carefully and trimmed using straight edge. We take a representative sample from compacted and trimmed excess sample for moisture content determination. Loosen the mold and turn up to down and remove spacer disk and weigh and recorded the mass of mold and compacted sample.

Then allow the specimen for respective seven day curing and seven day soaking, the soaking act as an efficient means of curing providing hydration. We placed on top of compacted specimen

place plastic cover to prevent the compacted specimen from drying out too. No surcharge load have been applied to compacted samples during curing duration assuming no traffic flow is allowed during construction. After allowing the specimens to curing each specimen is subjected to penetration by cylindrical rod. Set both the stress and penetration gauges to zero and apply load on the penetration piston. Record stress reading in penetration values of 0.64mm.1.27mm,1.91mm,2.54mm,3.81mm,5.08mm, 5.08mm7.62 and 10.16mm . Calculate the penetration stress in Kilo pascal and plot the stress versus penetration depth curve. The CBR at the specified density is determined from a graph of CBR versus unit weight. The bearing ratio reported for the soil is normally the one at 2.54mm penetration. Bearing ration using corrected stress value taken from the stress penetration curve for 2.54mm and 5.08mm penetration. The CBR is then calculated using eq.3 and data obtained used for analysis in next section.

$$C.B.R. = (PT/PS)\ X\ 100 \quad \text{----------Equation 3}$$

Where PT = Test load corresponding to the chosen penetration from the load penetration,

PS = Standard load for the same penetration taken from the table above

3.6 Morphological Characterization

A JCM-6000plus Scanning Electron Microscope was utilized to characterize the sample that was taken from the site and the lab. With improved resolution, more depth of field, longer working distances, and better surface sensitivity, enhanced image was captured. More additionally, the analysis of surface area is done using a Horriba surface area analyzer with model number SA9603 (USA) with the degassing time of at 200 ^{o} C for 1 hr. The SSA sample was incinerated using electrical furnaces at temperatures ranging from 0-850 ^{o} C and complete silicate analysis done to determine the main components of SSA and EBCS, the. A top open-source image analysis program Fiji ImageJ used to characterize surfaces. The plugins used with topographical image obtained. The input was 8-bit and 32-bit; the pixel values correspond to the z-coordinate of the distance from a surface. ImageJ plugins are created to level and evaluate surface roughness statistics. To distinguish between waviness and roughness and evaluate the structure at various wavelengths, Gaussian and mean filtering method was used to remove noise in the picture surface.

4. Results and Discussion

4.1 Major Elemental Oxide analysis

Table 4 presents the complete silicate analysis of the SSA and the EBCS. As can be seen from the table the main components of SSA were SiO_2, Al_2O_3, P_2O_5, Fe_2O_3, MgO and CaO. The Primary oxides SiO_2, $Al2O_3$ and Fe2O3 utilized in pozzolanic and Hydraulic reaction or in both contributed for the cementitious property of SSA. The specification ASTM C618-15 or AASHTO M 295-11 Standard defines Class C ash as having a sum of the oxides (SiO_2+ Al_2O_3+ Fe_2O_3) of 50% or greater[44]. Class C ash is predominantly hydraulic with some pozzolanic properties. There is a strong relationship exists between the sum of the oxides and CaO content. However, fly ash properties, such as the ability to mitigate ASR or sulfate attack, are more strongly correlated with CaO content and, therefore, CaO content is commonly considered a better measure of fly ash performance[27, 41]. From this we can conclude that SSA as having a sum of the oxides (SiO_2+ Al_2O_3+ Fe_2O_3) 63.42% and CaO content of 4.64 % suggest that SSA can perform pozzolanic and hydraulic reaction with the aluminosilicates present in small cohesive soil particles over an extended length of time. The higher the concentration of calcium the faster the pozzolanic reaction[46]. This implied that the SSA could be applied to improve the properties of cohesive soil and can be ASCM. Long-term efficiency of the pozzolanic response is anticipated since it may last for a considerable amount of time[47]. Calcium silicate gel is created as a result of the interaction between clay minerals in EBCS and SSA[48]. The gel strengthens the soil by filling the pores and acting as a glue between the soil particles[49].

Table 4: Major and Minor oxide compositions (wt. %) of SSA and EBCS from silicate analysis

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
SSA	37.94	17.32	8.16	4.64	7.44	2.72	2.64	0.24	12.16	0.24	0.38	5.4
Soil	59.5	14.54	6.76	1.68	1.7	1.52	0.54	0.12	0<0.01	0.33	6.13	8.58

4.2 Mechanical Strength Analysis

4.2.1 Plasticity Index

The SSA samples were more finely divided and non-plastic (NP) than the soil. Figure 7 shows how the SSA affected the soil sample's PI. The PI of 0 % SSA additive was found to be 60.2 %. However, it began to decline at 4 %, 6 %, 8 % and 10 % SSA additive to 42.4%, 23%, 18.4% and 17.2% respectively. Cation exchange and flocculation - agglomeration happen quickly after stabilization[48]. Because of the flocculation that agglomeration causes, the composition of clay soils was altered. To produce bigger particles, the clay granules frequently group together due to the SSA cementitious property. Therefore, the soil's liquid limit reduced, plastic limit increased, and plasticity index decreased. Due to this it is anticipated its workability will increase, and its strength and deformation characteristics will improve in line for the effect of SSA addition[50]. Thus, this result indicates that the additive of SSA could improve the characteristics of soft subgrade soil by lowering water affinity.

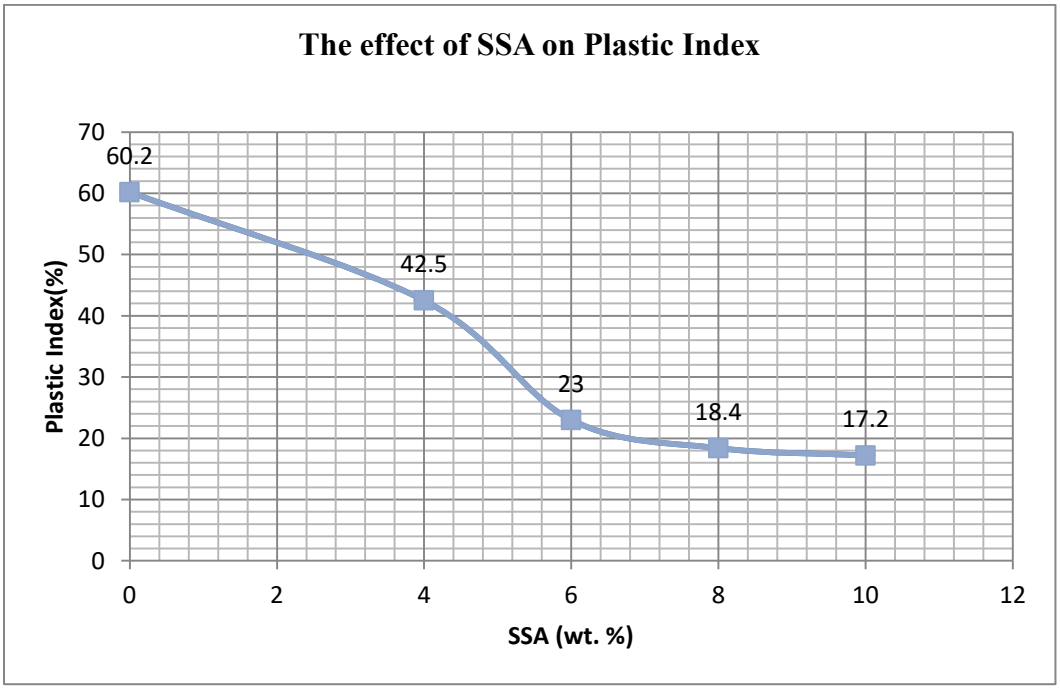


Figure 7: Plastic Index (PI) Vs SSA

4.2.2 Compaction Characteristics

The study employed SSA at concentrations ranging from 4% to 10% of the dry soil weight. Using typical compaction energies, the moisture density correlations of the soil samples were compressed for different SSA addition percentages. The soil sample with 0% SSA had a MDD of 1.30 g/cc and an OMC of 25.4%. As seen on fig.8 the MDD increased with addition of SSA 4%, 6%, and 8% SSA to 1.43 g/cc, 1.50 g/cc, 1.52 g/cc and decreased to 1.51 g/cc with 10% SSA addition.

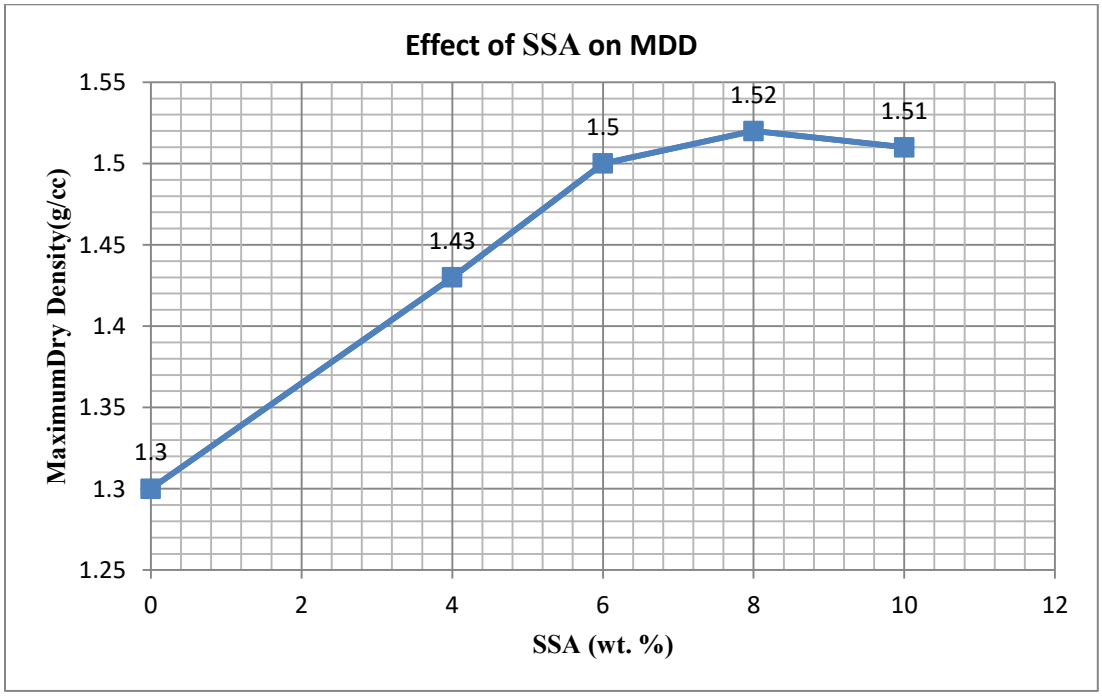


Figure 8 : Relationship between MDD Vs SSA

Due to SSA having a lower specific surface area than the soil samples, the dry density increased and the moisture content decreased as a result SSA addition to EBCS. MDD was also increased due to the fact that the fine particle of the SSA filled the pores within the soil sample causing it to be more compact and denser. Further addition of SSA beyond 8% (i.e. 10 % of SSA) lessened

the MDD.As seen on fig.9 the OMC reduced with addition of SSA 4%, 6%, 8% and 10% SSA to 19.8%, 18.80%, 17.70% and 16.23 % respectively.

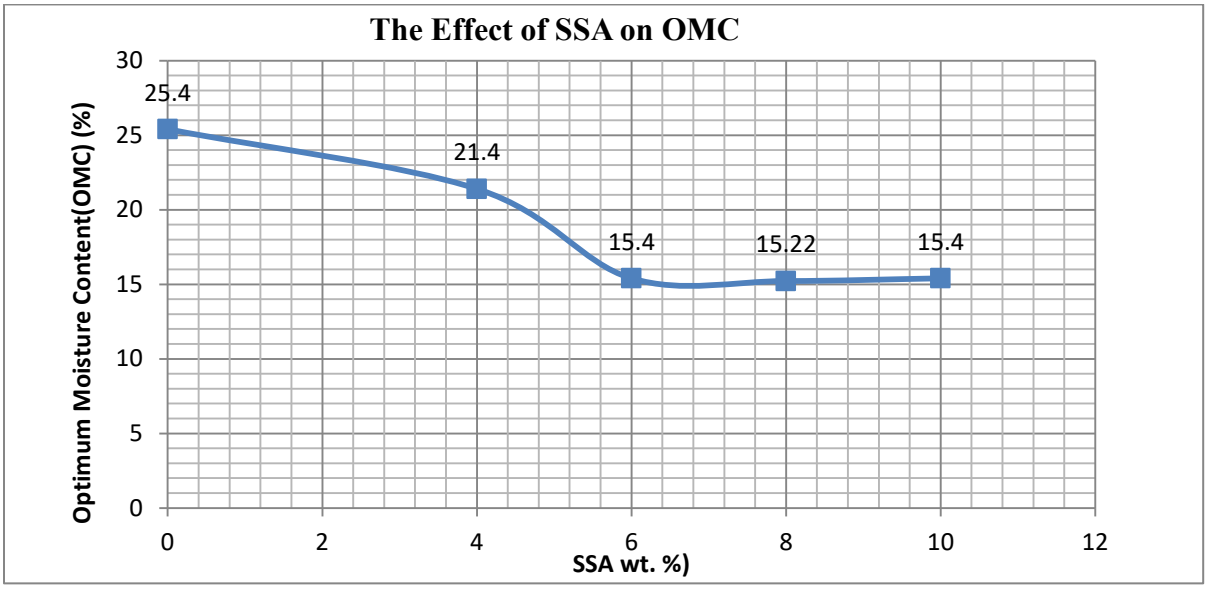


Figure 9: Relationship between OMC Vs SSA

This outcome can be attributed to SSA, which, when SSA reached 8%, either filled holes within soil particles or was filled with clods. The ideal samples to use as sub-grade materials have high values for dry density and low values for moisture content. Condensed clods are converted into soil particles in each unit volume of SSA when the amount of SSA additive reaches the maximum threshold, for all samples, the highest result for MDD was 1.52g/cc at 8% SSA corresponding OMC is 17.70% at 8% SSA. As addition of SSA was introduced, the compaction curves generally followed a pattern of increasing MDD values and a corresponding decline in OMC. Both MDD and OMC changed as a result of the stabilized mixes' composition being altered. The reduced optimal moisture content is due to the reduction in surface area of soil-SSA composite**.**

4.2.3 California Bearing Ratio (CBR)

Results showed that CBR values increased as the fraction of SSA addition, as illustrated in Fig. 10 The CBR values was 2.2 % for EBCS, the CBR values increased to 5.2%, 6.6% and 8.4% respectively, with SSA additives of 4%, 6%, 8%, and began to lower beyond 10%. Based on the

results, it is reasonable to conclude that SSA additive may effectively enhance subgrade soil conditions. This increase in strength could be brought about by the SSA's cementing abilities, capacity to change the absorbed water films, improved cohesiveness with the cementing agent, or the addition of internal friction. The graphic of fig.10 shows that the SSA addition of 8% produced the best results, followed by 6%, and both are categorized as subgrades for road construction because they are higher than the levels specified in the specification.

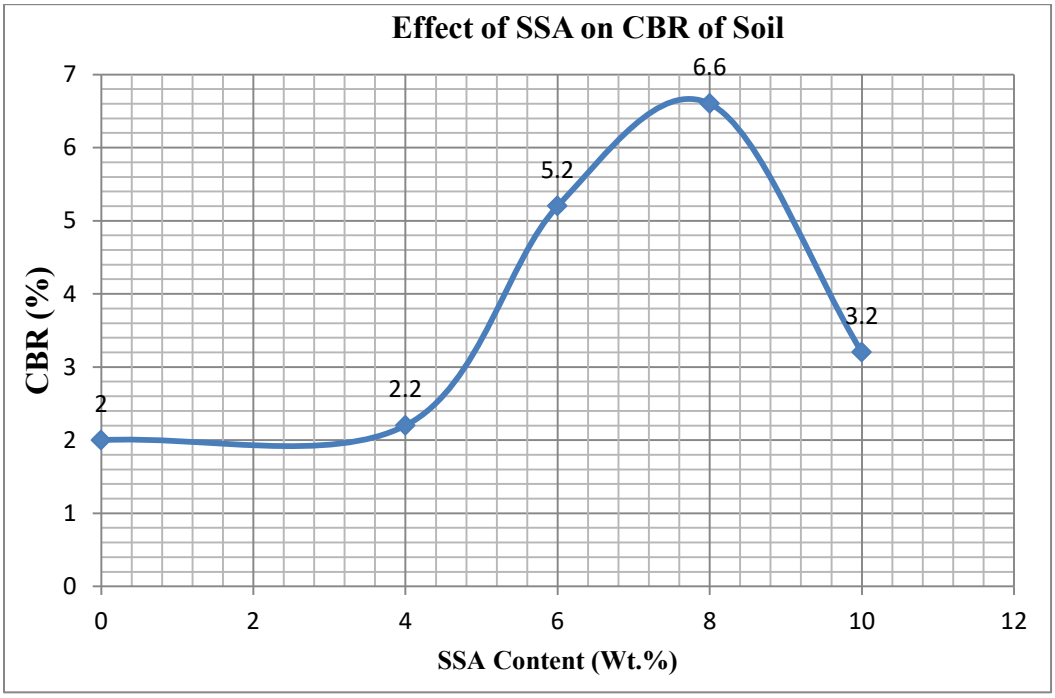


Figure 10: Relationship between CBR Vs SSA

4.3 Analysis of Microscopic Surface Morphology

The study programmed focuses on identifying variations in the microstructure of SSA, EBCS and Soil-SSA composite during laboratory consolidation. The diversity in SSA, EBCS and Soil-SSA composite fabric has been extensively studied using SEM, although quantitative and qualitative discussions have been made about particle orientation. This study used the Image analysis-based algorithm Image J to calculate the particle orientation and porosity of soil samples. Geometrical reference patterns, textbook micrographs, and high-quality photos were

used to verify the code's dependability. We used the Fig 11 SEM image of SSA, EBCS & Soil-SSA composite for the analysis of microstructure.

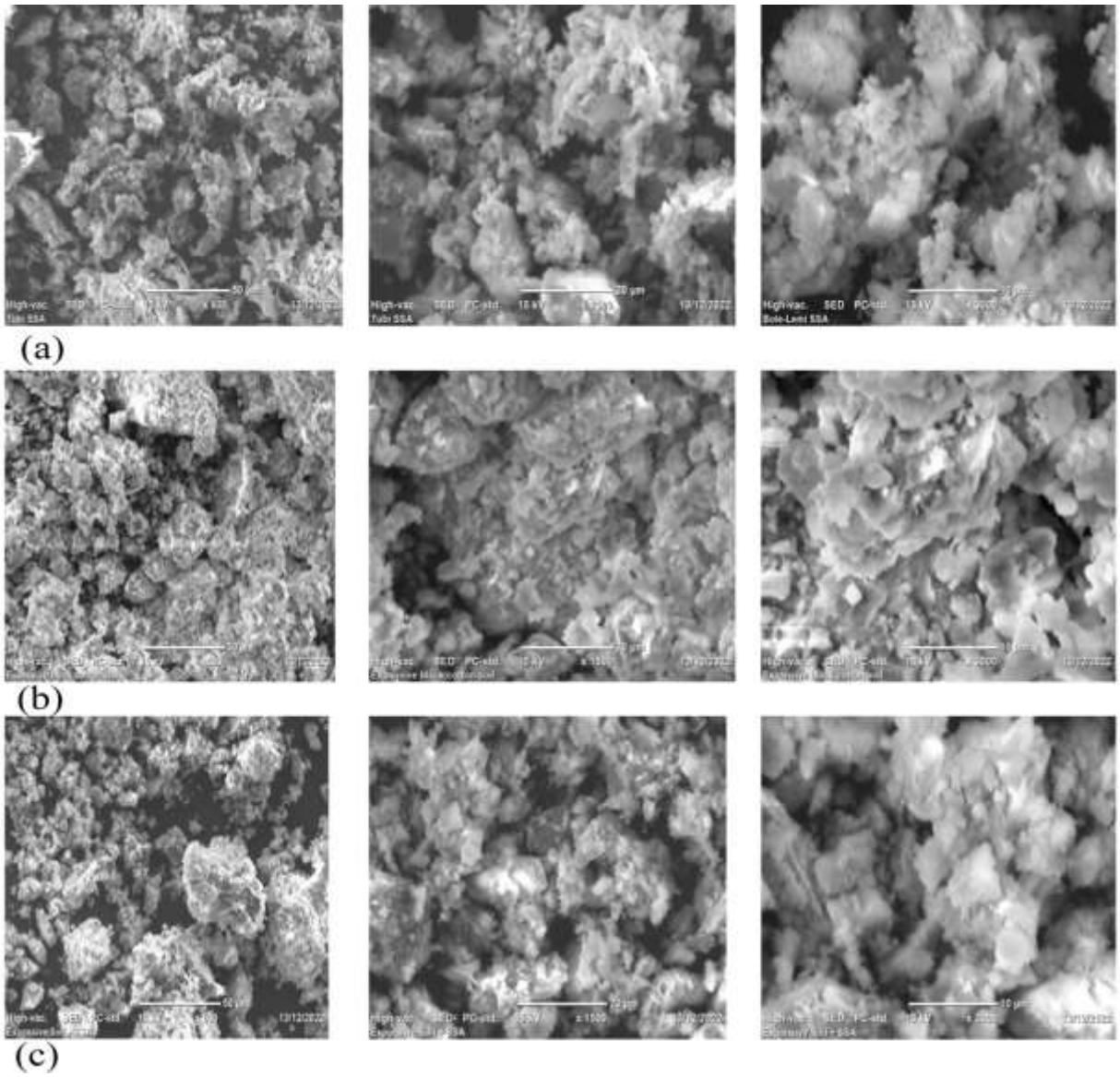


Figure 11: SEM image at different Magnifications for SSA (a), EBCS (b) & Soil-SSA composite(c) for the analysis of microstructure using Image J.

4.3.1 Specific Surface area analysis

The analysis of surface area was done using a BET surface area analyzer and FIJI Image SurfCharJ plugin to quantify the texture of the photos taken from SEM**.** Results of BET surface

area analyzer for EBCS and soil-SSA composite showed significant reduction. Surface area measurement for EBCS was 168.422m^2/gm and reduced to145.646 m^2/gm after treating with SSA. Result of Image analysis showed SSA has a surface area of 135.8865 μm^2 /unit volume of image pixels, EBCS has Surface area of 182.6692μm^2/ unit volume of image pixels and Soil-SSA composite has 158.316 µm2/ unit volume of image pixels.

Horiba Instruments, Inc.
SA-9600 Series Surface Area Analyzer

Analysis Report
Feb/09/2023

Customer	: Bereket Mulugeta	Operator ID	: SARA
Description	: Different Experiment	Analysis Date	: Feb/08/2023
Filename	: thomas.sa2	Analysis Time	: 16:37:48

Condition Settings

Room Temp	: 28.0 (°C)	Atm. Pres	: 700.0 (mm)
Gas Used	: Nitrogen	Gas Conc	: 0.300, 0.000, 0.000 %

	Channel: 1		Channel: 2		Channel: 3	
Sample Name	EBCS+SSA		EBCS			
Tube Number	1		2		0	
Tare Weight	10.1170	(gm)	10.1340	(gm)	0.0000	(gm)
Sample Weight	10.2930	(gm)	10.3150	(gm)	1.0000	(gm)
Degas Temp.	200	(°C)	200	(°C)	0	(°C)
Degas Time	60	(min)	30	(min)	0	(min)
Surface Area (M^2/gm)	145.646		168.422		-1.#IO	
Slope	134.610		113.352		-1.#IO	
Intercept	1.148		0.805		-1.#IO	
Vm	0.007		0.009		-1.#IO	
BET Const	118.233		141.865		-1.#IO	
Pearson Coef	1.000		1.000		0.000	
X[1] - 0.269	37.448		31.418		1.#IO	
X[2] - 0.179	25.211		20.991		1.#IO	
X[3] - 0.045	7.227		5.955		1.#IO	

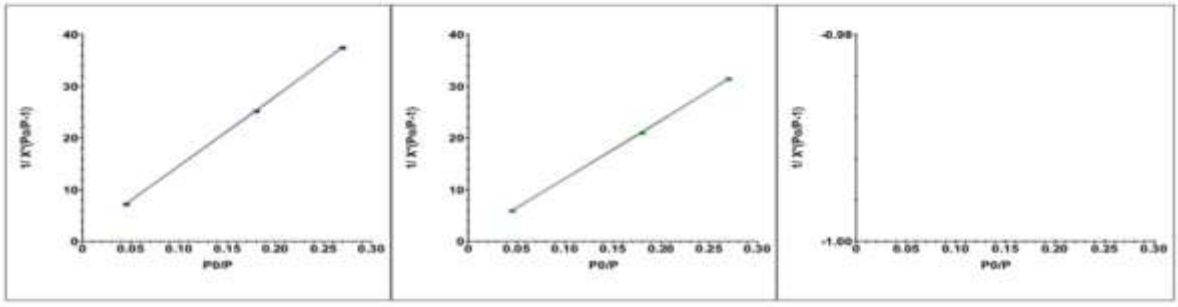


Figure 12: Surface area analysis sheet for soil-SSA composite and EBCS

Due to their microscopic size, clay minerals are difficult to notice with the naked eye. Scientific research use SEM pictures because they are not impacted by gravity forces but are by surface forces. Clays have a significant specific surface area ratio because of their form, which is comparable to that of plates. As a result, inter-particle forces and particle interaction increase

with water and dissolved ions. Clay eventually absorbs more water as a result of an interaction between the electrical charge on it and the water dipole[8]. For clay's physical processes, the precise surface area is essential since it directly impacts the material's surface characteristics. The specific surface area of soil particles affects the rate of infiltration, overland flow, contact area, absorption, adsorption, speed of overland flow , swelling and shrinking and many other physical and chemical processes , all affecting the wettability of soil particles. The reduced OMC content in the soil-SSA composite is due to the reduction in surface area and this study reveals that additive SSA is the main cause of the surface area reduction in EBCS.

4.3.2 Void Analaysis

This section intends to provide a computational tool developed to analyze porosity on the basis of SEM and image analyzing methodologies, which will help quantify the soil microstructure voids. The picture processed in order to find and identify the pores. The image is first converted to an 8-bit grayscale file with a pixel value range of 0-255. Then, using the adjust function, the picture contrast and brightness are modified. A median filter is then used to smooth out the grayscale distribution, and the image is further filtered using the value chosen for the color threshold for recognizing pores. The binary picture often has a lot of tiny dots, such as white dots inside the pores and black dots against the background, due to the impact of contaminants and image noise. The removal of these dots is another benefit of the pore area restriction. Additionally, the dataset is made to have the same pixel density and size, i.e., the pictures should have been captured at the same magnification. By using the scale bar dimension, this provides consistency when translating the pixel size into micrometers. The pores appear as black on a white background in a binary SEM image[51]. The Pores Analysis allows getting information regarding the number of detected pores[52].

To define the porosity of the image taken from SEM ,first information regarding the number of detected pores counted, as the number of pixels included in the areas recognized as pores value (Value=0), over the total amount of pixels (0-255) contained in the image. As seen on Table .5 the number of detected pores for EBCS is 1477, number of detected pores for Soil-SSA composite is 1349 and number of detected pores for SSA is 1299. Reduced porosity values for

Soil-SSA composite advocated that the addition of SSA reduced the void detected. The Pores focuses on the amount of pores identified but not their perimeter, area and shape. The beneficial influence of SSA reduced porosity of EBCS. In this case, ingress of water to the soil-SSA composite minimized. The results of the analysis can be used to draw correlations between the soil fabric and its mechanical and hydraulic behavior. This micro level void modification of EBCS with additive SSA increased macroscopic level performance characteristics (CBR, MDD, OMC and PI) to the soil-SSA composites.

Table 5: Void Analysis data

SSA		Soil		Soil-SSA Composite		SSA		Soil		Soil-SSA Composite	
V	C	V	C	V	C	V	C	V	C	V	C
0	1299	0	1477	0	1349	128	8687	128	8570	128	7808
1	209	1	235	1	208	129	8833	129	8531	129	7741
2	232	2	311	2	207	130	8907	130	8820	130	7722
3	247	3	372	3	263	131	9129	131	8860	131	7947
4	189	4	381	4	238	132	8841	132	9019	132	7811
5	206	5	367	5	195	133	8740	133	8893	133	7985
6	205	6	312	6	132	134	8874	134	9014	134	7960
7	167	7	327	7	143	135	8864	135	9362	135	8000
8	139	8	302	8	130	136	8765	136	9300	136	8004
9	129	9	292	9	120	137	9010	137	9391	137	8394
10	112	10	320	10	98	138	8993	138	9590	138	8244
11	132	11	354	11	91	139	8968	139	9748	139	8470
12	106	12	441	12	102	140	9119	140	9916	140	8327
13	100	13	565	13	77	141	9205	141	9694	141	8267
14	89	14	563	14	69	142	9339	142	9825	142	8286
15	96	15	633	15	68	143	9359	143	10037	143	8260
16	103	16	759	16	70	144	9360	144	10001	144	8313
17	98	17	781	17	53	145	9438	145	10161	145	8301
18	97	18	766	18	43	146	9421	146	10368	146	8225
19	123	19	756	19	49	147	9583	147	10383	147	8332
20	131	20	766	20	35	148	9508	148	10565	148	8006
21	110	21	708	21	31	149	9559	149	10557	149	8308
22	149	22	736	22	37	150	9469	150	10501	150	8366
23	178	23	708	23	37	151	9703	151	10659	151	8386
24	161	24	794	24	30	152	9701	152	10860	152	8350
25	195	25	813	25	26	153	9837	153	10840	153	8528
26	243	26	824	26	23	154	9684	154	10899	154	8175

SSA		Soil		Soil-SSA Composite		SSA		Soil		Soil-SSA Composite	
V	C	V	C	V	C	V	C	V	C	V	C
27	274	27	887	27	23	155	9719	155	11019	155	8459
28	391	28	908	28	17	156	9721	156	11092	156	8451
29	1355	29	957	29	26	157	10001	157	10971	157	8463
30	7025	30	996	30	61	158	9791	158	11024	158	8512
31	19177	31	979	31	222	159	9776	159	11102	159	8430
32	20294	32	1027	32	657	160	9608	160	11157	160	8479
33	10705	33	1090	33	1063	161	9476	161	11329	161	8406
34	9455	34	1131	34	1635	162	9638	162	11087	162	8448
35	6122	35	1326	35	2733	163	9477	163	11393	163	8431
36	4747	36	1228	36	3279	164	9184	164	11223	164	8372
37	4195	37	1241	37	3352	165	9281	165	11107	165	8431
38	3684	38	1270	38	3162	166	9314	166	11332	166	8267
39	3315	39	1287	39	3270	167	9269	167	10870	167	8280
40	2999	40	1247	40	3192	168	9164	168	11103	168	8133
41	2929	41	1297	41	3370	169	9139	169	10803	169	7938
42	2704	42	1296	42	3330	170	9257	170	10741	170	8011
43	2665	43	1286	43	3538	171	9259	171	10586	171	7988
44	2714	44	1300	44	3547	172	8970	172	10492	172	8123
45	2780	45	1279	45	3516	173	9172	173	10438	173	7974
46	2865	46	1180	46	3518	174	8843	174	10221	174	8046
47	2857	47	1290	47	3624	175	8859	175	10033	175	7908
48	2920	48	1233	48	3732	176	8942	176	9848	176	7721
49	3177	49	1194	49	3656	177	8937	177	9793	177	7750
50	3233	50	1279	50	3776	178	8534	178	9641	178	7552
51	3314	51	1325	51	3757	179	8389	179	9586	179	7520
52	3442	52	1276	52	3804	180	8199	180	9035	180	7422
53	3659	53	1402	53	3846	181	7968	181	9138	181	7291
54	3791	54	1482	54	3926	182	7681	182	8972	182	7193
55	3825	55	1419	55	4014	183	7301	183	8972	183	7247
56	4025	56	1650	56	4120	184	6923	184	8627	184	7018
57	4105	57	1601	57	4265	185	6800	185	8577	185	6785
58	4240	58	1680	58	4185	186	6328	186	8292	186	6762
59	4463	59	1797	59	4205	187	6143	187	8166	187	6834
60	4393	60	1899	60	4279	188	5713	188	8055	188	6561
61	4194	61	1931	61	4388	189	5356	189	7966	189	6358
62	4425	62	2089	62	4187	190	5271	190	7580	190	6348
63	4572	63	2233	63	4273	191	4964	191	7458	191	6284
64	4600	64	2340	64	4173	192	4669	192	7154	192	6268

SSA		Soil		Soil-SSA Composite		SSA		Soil		Soil-SSA Composite	
V	C	V	C	V	C	V	C	V	C	V	C
65	4682	65	2401	65	4174	193	4397	193	7000	193	6209
66	4697	66	2533	66	4444	194	4118	194	6887	194	6116
67	4875	67	2553	67	4325	195	3860	195	6870	195	5936
68	4963	68	2694	68	4431	196	3690	196	6557	196	5848
69	5071	69	2915	69	4585	197	3408	197	6326	197	5906
70	5288	70	2992	70	4535	198	3158	198	6321	198	5733
71	5407	71	3027	71	4662	199	2991	199	6060	199	5592
72	5268	72	3134	72	4776	200	2943	200	6037	200	5510
73	5422	73	3247	73	4703	201	2731	201	5884	201	5372
74	5590	74	3217	74	4828	202	2670	202	5752	202	5240
75	5666	75	3217	75	4876	203	2471	203	5335	203	5158
76	5803	76	3310	76	4896	204	2394	204	5181	204	5125
77	5909	77	3349	77	4984	205	2325	205	5020	205	4969
78	6045	78	3172	78	5050	206	2267	206	4908	206	4895
79	5965	79	3414	79	5081	207	2219	207	4700	207	4839
80	6047	80	3477	80	5278	208	2045	208	4690	208	4591
81	5892	81	3478	81	5240	209	1910	209	4586	209	4507
82	5775	82	3422	82	5423	210	1818	210	4425	210	4373
83	5729	83	3526	83	5479	211	1713	211	4153	211	4391
84	5684	84	3686	84	5534	212	1705	212	4134	212	4186
85	5575	85	3778	85	5747	213	1675	213	3808	213	4012
86	5361	86	3850	86	5761	214	1537	214	3832	214	3935
87	5701	87	3968	87	5753	215	1460	215	3644	215	3891
88	5661	88	4079	88	5909	216	1408	216	3559	216	3828
89	5693	89	4225	89	5695	217	1215	217	3459	217	3642
90	5794	90	4176	90	5861	218	1223	218	3321	218	3655
91	5763	91	4362	91	5998	219	1117	219	3103	219	3415
92	5815	92	4513	92	5740	220	1028	220	2997	220	3333
93	5938	93	4511	93	6015	221	1021	221	2863	221	3268
94	5820	94	4573	94	6004	222	920	222	2756	222	3134
95	5713	95	4612	95	6138	223	893	223	2699	223	2993
96	5956	96	4740	96	6078	224	856	224	2545	224	2902
97	5845	97	4969	97	6054	225	777	225	2406	225	2725
98	5819	98	5003	98	6114	226	757	226	2438	226	2544
99	5854	99	5022	99	6174	227	626	227	2298	227	2455
100	5995	100	5108	100	6211	228	595	228	2281	228	2421
101	5910	101	5272	101	6182	229	557	229	2129	229	2225
102	5715	102	5384	102	6299	230	496	230	2159	230	2116

SSA		Soil		Soil-SSA Composite		SSA		Soil		Soil-SSA Composite	
V	C	V	C	V	C	V	C	V	C	V	C
103	5783	103	5434	103	6118	231	513	231	2112	231	2045
104	5855	104	5490	104	6345	232	434	232	2085	232	1869
105	5801	105	5474	105	6306	233	405	233	2014	233	1847
106	5889	106	5558	106	6316	234	394	234	1974	234	1730
107	5873	107	5538	107	6486	235	385	235	1946	235	1669
108	6091	108	5674	108	6619	236	358	236	1878	236	1537
109	6210	109	5673	109	6589	237	320	237	1922	237	1566
110	6411	110	5717	110	6603	238	361	238	1905	238	1528
111	6466	111	5757	111	6701	239	310	239	1814	239	1522
112	6617	112	5981	112	6856	240	306	240	1712	240	1526
113	6709	113	6096	113	6798	241	342	241	1651	241	1503
114	6849	114	6184	114	6882	242	359	242	1644	242	1471
115	7007	115	6152	115	7030	243	368	243	1514	243	1430
116	7310	116	6400	116	7073	244	355	244	1560	244	1432
117	7394	117	6485	117	7097	245	408	245	1473	245	1408
118	7567	118	6691	118	7233	246	388	246	1477	246	1441
119	7604	119	6965	119	7403	247	433	247	1406	247	1454
120	7855	120	7248	120	7500	248	446	248	1597	248	1542
121	7865	121	7307	121	7455	249	500	249	1544	249	1771
122	8140	122	7514	122	7611	250	580	250	1567	250	1899
123	8312	123	7530	123	7674	251	669	251	1679	251	1965
124	8444	124	7842	124	7615	252	818	252	1777	252	2359
125	8379	125	8079	125	7558	253	968	253	1932	253	2461
126	8387	126	8292	126	7674	254	905	254	2161	254	2842
127	8623	127	8417	127	7614	255	4527	255	6584	255	13175

4.3.3 Histogram Analaysis

Histogram in Fig.12 shows brightness value of pixels in Image taken from SEM, the vertical axis is the frequency of how many pixels are (counts) and the horizontal axis indicates the brightness level (0-255) of the pixels. The histogram function is then used to evaluate the distribution of the elements, according to their characteristics.

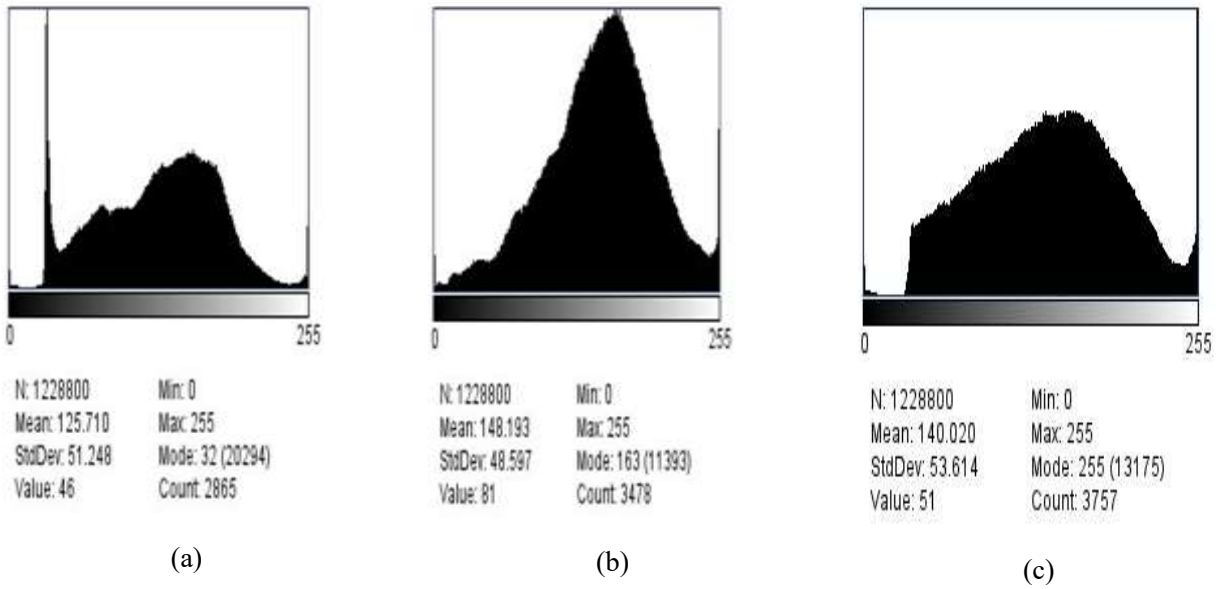


Figure 13: Histogram of SSA (a), EBCS (b) & Soil-SSA composite(c)

The histogram function is used to evaluate the distribution of the elements according to their characteristics in addition to Pores Analysis. Fig 12 (a) histogram of SSA the total number of pixels analyzed are 1,228,800 and have average mean particle size 125.710, standard deviation from the mean value 51.24 and modal value of 32 and has frequency of 20294.The lower average mean particle size and lower modal value of SSA indicates less roughness of SSA. Histogram of EBCS Fig 12(b) has total number of pixels value analyzed 1,228,800 and has average mean particle size of 148.193, standard deviation from the mean value 48.597 and has mode of 163 and frequency of 11393. The Higher average means particle size and higher modal value of EBCS indicates high roughness of EBCS Compared to both SSA and Soil-SSA Composite. Histogram of Soil-SSA composite Fig 12 (c) has total number of pixels value analyzed 1,228,800 and has average mean particle size 140.020, standard deviation from the mean 53.614 and has mode 255 and frequency of 13,175. The Lower average means particle size of Soil-SSA Composite compared to EBCS revels the reduction of average particle size which in turn reduce the roughness parameters but Higher modal value of Soil-SSA Composite compared to SSA and EBCS may seems to indicate high roughness of Soil-SSA Composite relative to SSA and EBCS but closer look at fig 15(c) Interactive 3D-Surface plot of soil-SSA composite the pictures

reveals characteristically rough surface of closely oriented particles peak and particle density which is due flocculation and agglomeration of small particle of SSA with EBCS. Thus, in return this close packing of particle reduced the surface roughness parameters.

4.3.4 Qualitative 3D-Surface plot & Particle plot profile Analysis

The mechanical responsiveness of soil and composite materials is greatly influenced by the texture of the soil surface; it influences the depth, speed, direction, absorption, and adsorption of overland flow. Accurate identification and tracking of particle shape and location are crucial for connecting micro and macro soil behaviors. In this approach, the SEM micrographs were assessed by ImageJ to generate the particle orientation of SSA, EBCS and soil-SSA composite. Fig. 13(a), (b) & Fig. 14 (a), (b), (c) & (d) illustrate particle surfaces plot and plot profile of SSA, soil-SSA composite and EBCS in greyscale respectively. A closer look at the pictures reveals characteristically rough surface of differently oriented particles peak and particle density.

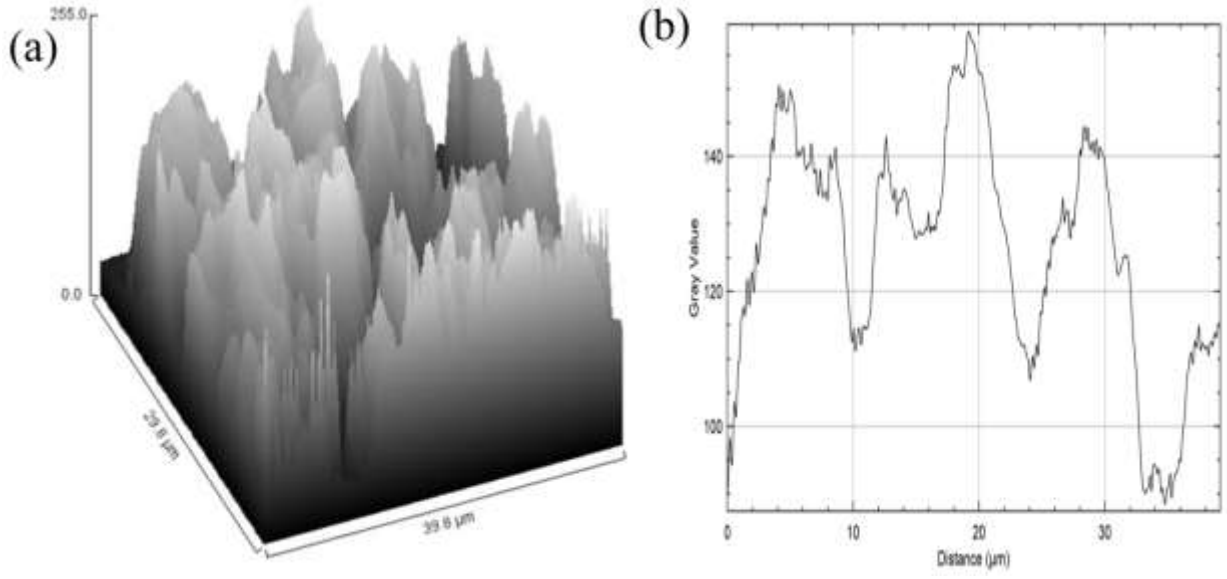


Figure 14: 3-D Surface plot of SSA (a) and Plot Profile of SSA (b)

The plot profile shows the frequency distributions that explain the frequencies of intensity values

occurring within images. The histograms show frequency of every gray level and these help in detecting issues regarding image acquisition[33]. The particles of EBCS are irregularly shaped and more rough compared to particles of SSA and stabilize soil-SSA composites as seen on 3-D surface plot and plot profile on fig 13 & fig 14**.**A closer look at surface plot and plot profile of EBCS fig.14 *(c) & (d)* reveals seems to exhibit larger roughness compared to stabilized soil-SSA composite ((*fig.14 a & b*) and additive SSA on *fig 13 a & b*.

The soil-SSA composite fabrics have what appears to be a dense surface. The histogram on the soil-SSA composite in Figure 12(c) has mode 255 and frequency of 13175 reveal that some of the small particles in the SSA are loosely aggregated to big particles in stabilized soil-SSA composite. This distinguishes the morphologies of the soil-SSA composite from those of the EBCS. SSA application to EBCS, results in the development of white lumps on the surface as can be seen marked on plot profile by red on fig 14(b), the SSA stabilizer application also led the EBCS structures to flocculate, particularly as a consequence of an increase in calcium ions in SSA, further demonstrating the presence of CSH and CAH[31].

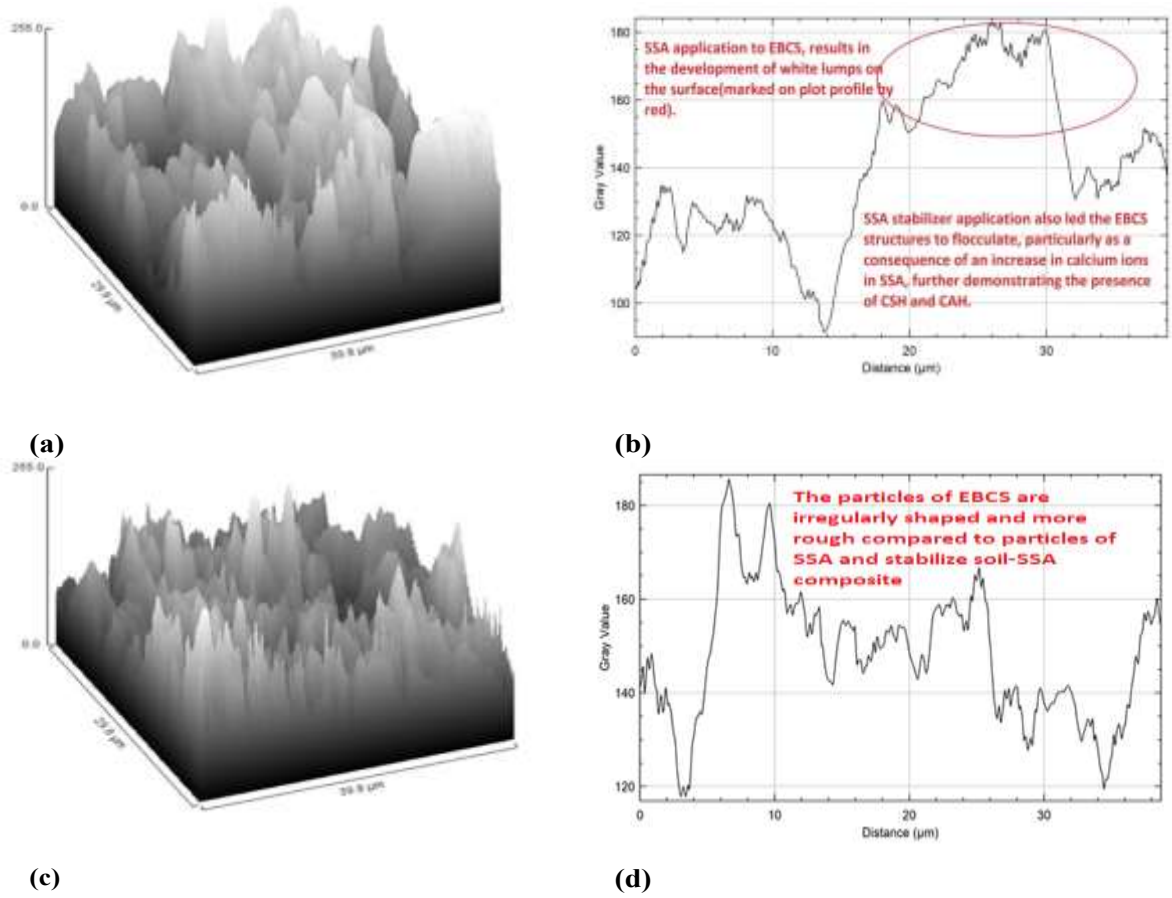


Figure 15: 3-D Surface plot of Soil-SSA composite (a), Plot Profile of Soil-SSA composite (b), and 3-D Surface plot of EBCS(c) and Plot Profile EBCS (d).

4.3.5 Qualitative 3D-interactive Image Analysis

ImageJ's 3-D interactive tool displays the relative surface topology of SSA, EBCS and soil-SSA composite membranes using SEM micrographs. Brightest locations are considered the top-most membrane surface while darkest locations are considered deepest[33]. Figs 15 and 16 evaluate 3-D interactive surface structures for SSA, EBCS and Stabilized soil-SSA composite. A systematic analysis was conducted to analyze grain size intensity and distribution in SSA, EBCS, and Soil-SSA composites. The area of integration is a crucial parameter in evaluating surface profile plots. 3-D interactive images reveal significant differences waviness of the surface area, average pixel intensity, particle orientation and grain size distance, revealing heterogeneity in surface roughness across all material**.** The 3-D interactive Image differences with respect to morphology

of surface are the results of variations in material characteristics[53]. 3-D images produced from membrane surfaces compute the depth of structures, demonstrating topography.

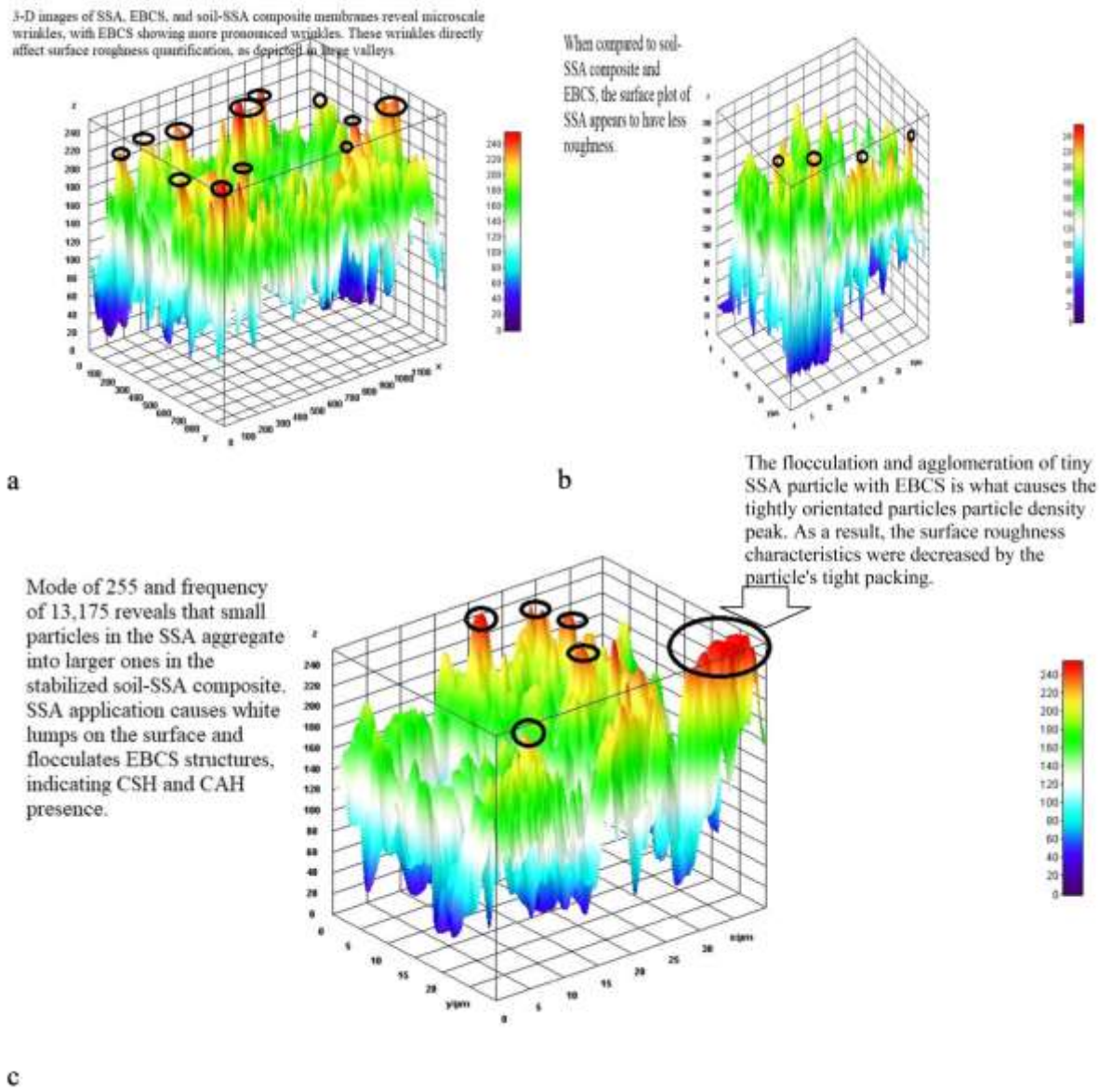


Figure 16: Interactive 3D-Surface plot of EBCS(a) , SSA(b) and soil-SSA composite (c)

The 3-D images for SSA, EBCS and soil-SSA composite membranes show wrinkles and the

wrinkles seem to be more pronounced in EBCS compared to the other. It seems that the large valleys illustrated in the images are microscale wrinkles. The quantification of surface roughness affected by this surface wrinkles directly. In case of physical stabilization, soil performance is improved without altering the chemistry, whereas in case of chemical stabilization, reactions occur in the soil matrix leading to better bonding and stability [48]. As can be seen on fig 15 (c)Interactive 3D-Surface plot of Stabilized soil-SSA composite , Soil stabilization process essentially unified SSA particles with EBCS which leads to modification of Soil-SSA Composite fabric and texture that enables it to achieve enhanced strength and durability due to agglomeration and flocculation[54].

The chemical theory involved in the reaction between chemical admixtures, silicate and aluminate of the expansive soils is complex. The primary factors include cation exchange, flocculation and agglomeration, pozzolanic reaction and carbonation [55]. The reaction mechanisms can be further classified into two distinct groups: modification for plasticity reduction and solidification. Modification may be a reversible process but solidification results in irreversible changes in the soil characteristics. Modification results through flocculation and cation exchange activity, whereas solidification results through pozzolanic reaction. These reactions contribute to physical, chemical, mineralogical and microstructural changes in the soil-SSA composite[48]. From this we can conclude that SSA as having a sum of the oxides (SiO_2+ Al_2O_3+ Fe_2O_3) 63.42% and Satisfy class C ash suggest that SSA can perform pozzolanic and hydraulic reaction which is responsible for modification for plasticity and solidification of Soil-SSA composite.

Most color blinded individuals cannot distinguish between red and green hues, while less frequently between blue and yellow hues. Red-green or blue-yellow deficiency may not be entirely blind to both colors. An interactive 3-D image is provided to assist color-blind readers in Fig 16. With different light look ups figures.

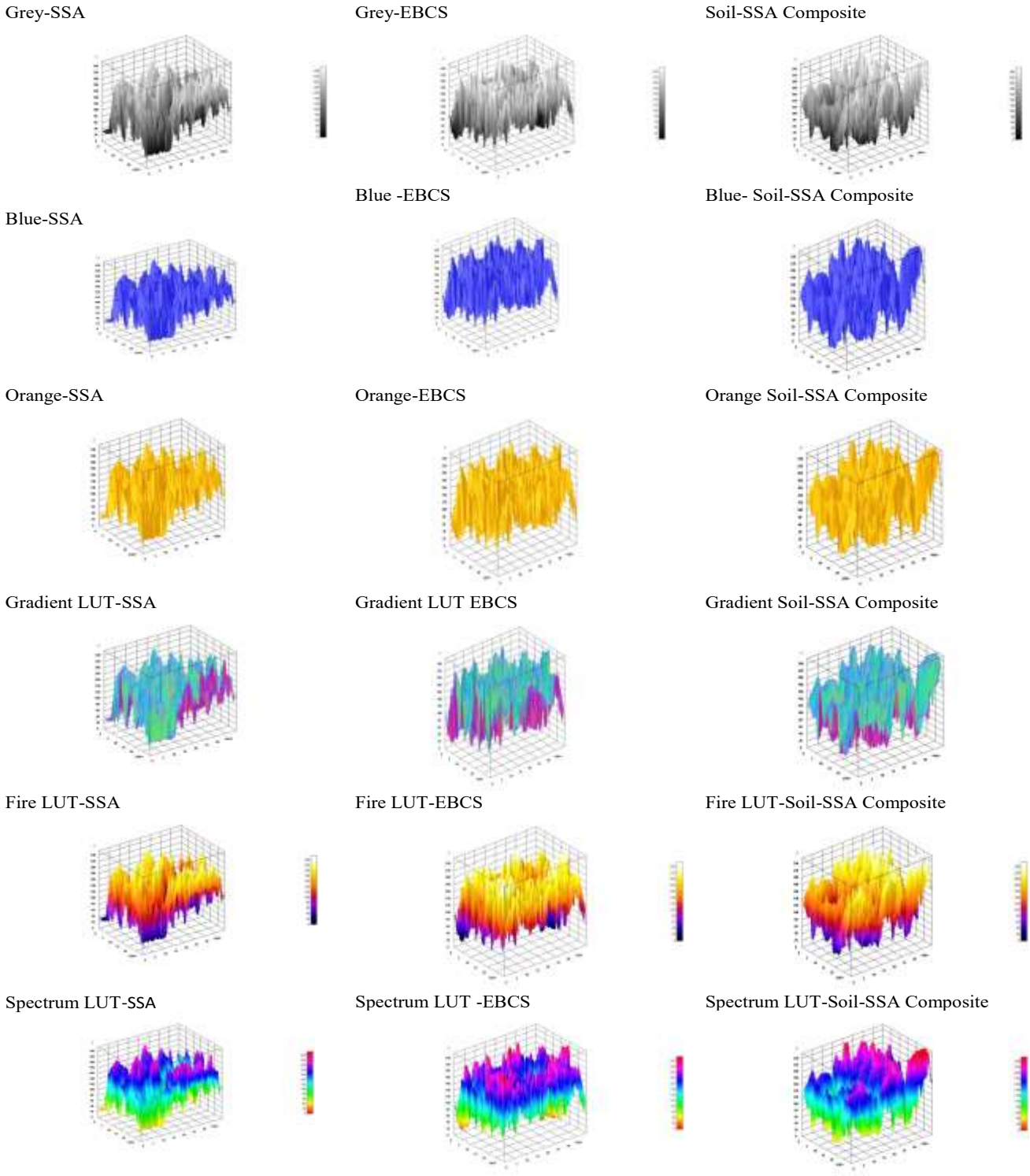


Figure 17: Interactive 3D-Surface profile of SSA, EBCS and Soil-SSA Composite with different LUT

5. Conclusions and Recommendation

5.1 Conclusions

SiO2, Al2O3, P2O5, Fe2O3, MgO, and CaO make up the majority of SSA. The cementitious property of SSA is contributed by the major oxides (SiO2, Al2O3, and Fe2O3) content 63.42% and CaO 4.64%. SSA satisfies Class C ash having mostly hydraulic and some pozzolanic qualities, according to the ASTM C618-15 Standard. The interaction of clay minerals in EBCS and SSA results in the formation of calcium silicate gel, which strengthens the soil by plugging holes and serving as glue between soil particles.

The plasticity index of 0% SSA additive was 60.2%, while at 4%, 6%, 8%, and 10%, it declined to 42.4%, 23%, 18.4%, and 17.2% respectively. The soil sample with 0% SSA had a maximum dry density of 1.30 g/cc and an OMC of 25.4%. With SSA addition, the MDD increased to 1.43 g/cc, 1.50 g/cc, and 1.52 g/cc, while the OMC decreased to 19.8%, 18.80%, 17.70%, and 16.23%, respectively. CBR values of EBCS was 2.2% and increased with SSA fraction, reaching 5.13%, 6.6% and 8.4% with 4%, 6%, 8% additives respectively, but decreased beyond 10%.

The results of the experiment showed significant reduction in surface area for soil-SSA composite, EBCS measuring was 168.422m^2/gm and Soil-SSA composite reduced to145.646 m^2/gm after treatment with SSA. The surface area of SSA was found to be 135.8865 μm^2 /unit volume of image pixels, while EBCS had 182.6692μm^2/ unit volume and Soil-SSA composite has 158.316 µm2/ unit volume of image pixels. The reduced OMC content in the soil-SSA composite is due to the reduction in surface area, with additive SSA being the main cause of the reduction in Soil-SSA composite.

The porosity of SEM images is determined by counting the number of detected pores. EBCS has 1477, Soil-SSA composite has 1349, and SSA has 1299 detected pores. The addition of SSA reduced void, minimizing water ingress to the soil-SSA composite. This micro-level void modification increased macroscopic performance characteristics, such as CBR, MDD, OMC, LL,

PL and PI, in soil-SSA composites. The results can be used to correlate soil fabric and mechanical and hydraulic behavior.

ImageJ's 3-D interactive tool displays analysis reveals heterogeneity in surface roughness across all materials, with significant differences in waviness, average pixel intensity, particle orientation, and grain size distance. The images show wrinkles, with EBCS showing more pronounced wrinkles, affecting surface roughness quantification. EBCS particles are irregularly shaped and rougher than those of stabilized soil-SSA composite and SSA. The histogram function evaluates element distributions and pore analysis. The soil-SSA composite fabric has a dense surface. SSA application to EBCS leads to white lumps on the surface and flocculation, indicating the presence of CSH and CAH.

5.2 Recommendations

The CBR value decreases with additional increases of SSA over 8%, as shown by the data analysis above. This may be related to a loss in stiffness (resistance to deformation).Therefore, I urge more research on the stiffness parameter of stabilized expansive black cotton soil.

Although there can be some ambiguity in the link between the qualitative and quantitative analyses, it is important to note that measuring surface roughness might have improved understanding of the results. It is suggested that more future studies use area roughness parameters to measure the amount of surface roughness.

By assessing the properties of the crack network, image analysis approach has a major potential to analyze cracking soils in geotechnical engineering. In the current study, detailed information regarding the surface morphology of soil was obtained using the image analysis procedure. Future research on drying-induced shrinkage and cracking mechanisms is advised.

Reference

[1] L. TAYE, "ASPHALT ROAD PAVEMENT REHABILITATION AND MAINTENANCE CASE STUDY IN ADDIS ABABA CITY ROADS," *Thesis*, no. August, p. 39, 2019, [Online]. Available: www.biu.ac.il

[2] E. Engineeringin, "PERFORMANCE EVALUATION OF KOTEBE WASTE WATER TREATMENT STABLIZATION PONDS IN ADDIS ABABA , ETHIOPIA," 2020.

[3] H. F. Yohannes, "Assessment on The Performance of AAWSA Controlled Sewerage System - The Case of Arada Sub city," no. December, p. 107, 2019.

[4] H. Tu, "Prediction of the Variation of Swelling Pressure and 1-D Heave of Expansive Soils With Respect To Suction," *PhD Thesis, Univ. Ottawa, Canada*, no. July, 2015.

[5] S. Y. Aga, "Physical stabilization of expansive subgrade soil using locally produced geogrid material," *SN Appl. Sci.*, vol. 3, no. 5, pp. 1–8, 2021, doi: 10.1007/s42452-021-04560-1.

[6] B. Omer Siddig Mustafa Hamza and M. Mohamed Eltayeb Zumrawi, "Characterization and Treatment of Expansive Subgrade Soils in Sudan in Civil Engineering," *https://www.researchgate.net/publication/339507773_Characterization_and_Treatment_of_Expansive_Subgrade_soils_in_Sudan*, no. July, doi: http://dx.doi.org/10.13140/RG.2.2.27302.27201.

[7] C. C. Ikeagwuani and D. C. Nwonu, "Emerging trends in expansive soil stabilisation: A review," *J. Rock Mech. Geotech. Eng.*, vol. 11, no. 2, pp. 423–440, 2019, doi: 10.1016/j.jrmge.2018.08.013.

[8] M. M. Mortland and W. D. Kemper, "Specific surface," *Methods Soil Anal. Part 1 Phys. Mineral. Prop. Incl. Stat. Meas. Sampl.*, vol. 9, no. 9, pp. 532–544, 2015, doi: 10.2134/agronmonogr9.1.c42.

[9] E. N. and A. Dinku, "Investigation on the effects of combining lime and sodium silicate

for expansive subgrade stabilization," *Zede J.*, vol. 31, no. 0, pp. 33–44, 2014.

[10] U. Bantayehu, "Performance , Problems and Remedial Measures for Roads Constructed on Expansive Soil in Ethiopia – A Review," *Civ. Environ. Res.*, vol. 9, no. 5, pp. 28–37, 2017.

[11] M. M. E. Zumrawi, "Construction Problems of Light Structures Founded on Expansive Soils in Sudan," *Int. J. Sci. Res.*, vol. 4, pp. 2319–7064, 2013, [Online]. Available: www.ijsr.net

[12] African Development Fund, "Addis Ababa Sewerage Project Phase 1." 1995. [Online]. Available: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/ADF-BD-IF-96-13-EN-SCANNEDIMAGE.143.PDF

[13] P. Athulya and R. Chandran, "Stabilization of Subgrade Soil using Additives - A Case Study," vol. 3, no. 29, pp. 1–4, 2015.

[14] A. I. Limited, "Black Cotton Soil in Highway Construction," vol. 10, pp. 144–148, 2020.

[15] B. V. S. Prasad and B. Ganesh, "An Experimental Study on Soil Stabilization with Water Resistance," vol. 21, no. 4, pp. 32–41, 2019, doi: 10.9790/0661-2104023241.

[16] A. Asmamaw, "Experimenting on the Geotechnical properties of Bahir Dar Black cotton soil stabilized with quarry dust," *Int. J. Eng.*, pp. 165–174, 2021.

[17] S. Negash, "' Stabilizing expansive subgrade soil on a selected road section in eastern part of Ethiopia in Somalia region Jigjiga-Tuli ' A Thesis Submitted to the School of Earth Science Presented in partial fulfillment of the requirements for the degree of Master o," 2021.

[18] C. C. Ikeagwuani and D. C. Nwonu, "Journal of Rock Mechanics and Geotechnical Engineering Emerging trends in expansive soil stabilisation : A review," *J. Rock Mech. Geotech. Eng.*, vol. 11, no. 2, pp. 423–440, 2019, doi: 10.1016/j.jrmge.2018.08.013.

[19] M. Y. Trushinskii, "Electrochemical soil stabilization method," *Soil Mech. Found. Eng.*, vol. 30, no. 2, pp. 61–65, 1993, doi: 10.1007/BF01782910.

[20] R. Saffari, G. Habibagahi, E. Nikooee, and A. Niazi, "Biological Stabilization of a Swelling Fine-Grained Soil: The Role of Microstructural Changes in the Shear Behavior," *Iran. J. Sci. Technol. - Trans. Civ. Eng.*, vol. 41, no. 4, pp. 405–414, 2017, doi: 10.1007/s40996-017-0066-z.

[21] J. Reddy and B. J. S. Varaprasad, "Sustainable Improvement of Expansive Clays Using Xanthan Gum as a Biopolymer," vol. 5, no. 9, pp. 1893–1903, 2019.

[22] A. Soltani, R. Raeesi, and B. C. O'Kelly, "Cyclic swell-shrink behaviour of an expansive soil treated with a sulfonated oil," *Proc. Inst. Civ. Eng. Gr. Improv.*, vol. 175, no. 3, pp. 166–179, 2022, doi: 10.1680/jgrim.19.00084.

[23] O. Hjelmar, "Disposal strategies for municipal solid waste incineration residues," *J. Hazard. Mater.*, vol. 47, no. 1–3, pp. 345–368, 1996, doi: 10.1016/0304-3894(95)00111-5.

[24] K. Ma and A. S. Hassan, "Enhancement of soil engineering properties with sewage sludge ash," *MOJ Ecol. Environ. Sci.*, vol. 5, no. 5, pp. 230–236, 2020, doi: http://dx.doi.org/10.15406/mojes/2020.05.00198.

[25] O. Access, "Sewage sludge reuse in concrete industry : a review Sewage sludge reuse in concrete industry : a review", doi: 10.1088/1755-1315/779/1/012010.

[26] "Use of Supplementary Cementitious Materials (SCMs) in Concrete Mixtures," p. 16001.

[27] D. Lin, K. Lin, H. Luo, D. Lin, and K. Lin, "A Comparison between Sludge Ash and Fly Ash on the Improvement in Soft Soil A Comparison between Sludge Ash and Fly Ash on the Improvement in Soft Soil," vol. 2247, 2012, doi: 10.1080/10473289.2007.10465294.

[28] M. A. Tantawy, E. M. Abdalla, and M. A. Abdelzaher, "Evaluation of the Pozzolanic

Activity of Sewage Sludge Ash," vol. 2012, no. iv, 2012, doi: 10.5402/2012/487037.

[29] T. Karayildirim, J. Yanik, M. Yuksel, and H. Bockhorn, "Characterisation of products from pyrolysis of waste sludges," *Fuel*, vol. 85, no. 10–11, pp. 1498–1508, 2006, doi: 10.1016/j.fuel.2005.12.002.

[30] M. Mirzababaei, S. Yasrobi, and A. Al-Rawas, "Effect of polymers on swelling potential of expansive soils," *Proc. Inst. Civ. Eng. Gr. Improv.*, vol. 162, no. 3, pp. 111–119, 2009, doi: 10.1680/grim.2009.162.3.111.

[31] R. K. Etim, D. U. Ekpo, U. B. Ebong, and I. N. Usanga, "Influence of Periwinkle Shell Ash on the Strength Properties of Cement-Stabilized Lateritic Soil," *Int. J. Pavement Res. Technol.*, vol. 15, no. 5, pp. 1062–1078, 2022, doi: 10.1007/s42947-021-00072-8.

[32] F. Mendoza and R. Lu, *Chapter 2 Basics of Image Analysis*, no. April. 2016. doi: 10.1007/978-1-4939-2836-1.

[33] D. Sinkhonde, A. Rimbarngaye, B. Kone, and T. C. Herring, "Representativity of morphological measurements and 2-d shape descriptors on mineral admixtures," *Results Eng.*, vol. 13, no. November 2021, p. 100368, 2022, doi: 10.1016/j.rineng.2022.100368.

[34] Rishi Kumari and Narinder Rana, "Particle Size and Shape Analysis using Imagej with Customized Tools for Segmentation of Particles," *Int. J. Eng. Res.*, vol. V4, no. 11, pp. 247–250, 2015, doi: 10.17577/ijertv4is110211.

[35] D. Sinkhonde, A. Rimbarngaye, and B. Kone, "A multi-image analysis suitable to characterise structural parameters of mineral and chemical admixtures for sustainable construction," *Clean. Eng. Technol.*, vol. 11, no. October, p. 100566, 2022, doi: 10.1016/j.clet.2022.100566.

[36] E. Abbate, P. Bruni, and M. Sagri, "Geology of Ethiopia," *Choice Rev. Online*, vol. 53, no. 02, pp. 53-0795-53–0795, 2015.

[37] T. A. Engidasew and A. Abay, "Assessment and Evaluation of Volcanic Rocks Used as

Construction Materials in the City of Addis Ababa," *Momona Ethiop. J. Sci.*, vol. 8, no. 2, p. 193, 2016, doi: 10.4314/mejs.v8i2.7.

[38] ع. ع. نعمان, "خرائط على العراق العامة المكتبات مواقع تعريف Google Earth," □□ □ □□□ □ □□ □ □□ □ □□□ □□ □□□□□□□□□ □□□□□□□□□ □. p. 75, 2018. doi: 10.34279/0923-009-001-004.

[39] D. Preparation and D. Soil, "Dry Preparation of Disturbed Soil and Soil Aggregate Samples for Test," no. 4, pp. 89–90, 2007.

[40] I. Density, "MOISTURE-DENSITY RELATIONS OF SOILS: USING AASHTO T 99 and AASHTO T 180," vol. 180, no. October, pp. 1–8, 2007.

[41] E. Preparation, S. Preparation, P. Produced, A. Mixtures, and C. Procedure, "WSDOT Errata to FOP for AASHTO T 312," no. January 2021, pp. 1–8, 2018.

[42] G. E. Bureau, "Test Method for Liquid Limit, Plastic Limit, and Plasticity Index," *Dep. Transp.*, no. August, pp. 1–16, 2015, [Online]. Available: https://www.dot.ny.gov/divisions/engineering/technical-services/technical-services-repository/GTM-7b.pdf

[43] AASHTO T-193, "Standard Method of Test for The California Bearing Ratio," vol. 99, pp. 580–585, 2007, doi: 10.1520/d1883-07.

[44] P. Suraneni, L. Burris, C. R. Shearer, and R. D. Hooton, "ASTM C618 fly ash specification: Comparison with other specifications, shortcomings, and solutions," *ACI Mater. J.*, vol. 118, no. 1, pp. 157–167, 2021, doi: 10.14359/51725994.

[45] C. F. Ash, "SUPPLEMENTARY CEMENTITIOUS Best Practices for Concrete Pavements," no. February, pp. 1–7, 2016.

[46] E. Silitonga, Z. Matondang, M. Fadilla, J. Tampubolon, E. Sinaga, and Suhairiani, "Effect of the available amount of CaO in Pozzolanic Binders on enhancing physical characteristic of concrete," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 420, no. 1, 2018, doi:

10.1088/1757-899X/420/1/012011.

[47] O. M. Sierra, J. Payá, J. Monzó, M. V. Borrachero, L. Soriano, and J. Quiñonez, "Characterization and Reactivity of Natural Pozzolans from Guatemala," *Appl. Sci.*, vol. 12, no. 21, 2022, doi: 10.3390/app122111145.

[48] D. Barman and S. K. Dash, "Stabilization of expansive soils using chemical additives: A review," *J. Rock Mech. Geotech. Eng.*, vol. 14, no. 4, pp. 1319–1342, 2022, doi: 10.1016/j.jrmge.2022.02.011.

[49] N. Ural, "The significance of scanning electron microscopy (SEM) analysis on the microstructure of improved clay: An overview," *Open Geosci.*, vol. 13, no. 1, pp. 197–218, 2021, doi: 10.1515/geo-2020-0145.

[50] Ashok kumar T, "Development of Rapid Characterization Methods and Stabilization of Expansive Soil," no. January, 2020.

[51] C. Liu, B. Shi, J. Zhou, and C. Tang, "Quantification and characterization of microporosity by image processing, geometric measurement and statistical methods: Application on SEM images of clay materials," *Appl. Clay Sci.*, vol. 54, no. 1, pp. 97–106, 2011, doi: 10.1016/j.clay.2011.07.022.

[52] G. Di Remigio, I. Rocchi, and V. Zania, "New method for a SEM-based quantitative microstructural clay analysis - MiCA," *Appl. Clay Sci.*, vol. 214, no. September, p. 106248, 2021, doi: 10.1016/j.clay.2021.106248.

[53] C. C. Nwaeju, F. O. Edoziuno, A. A. Adediran, T. J. Tuaweri, and M. Saravana Kumar, "Grain characteristics and mechanical properties of as-cast Cu-10%Al alloy: Effects of alloying additions," *Results Eng.*, vol. 12, no. October, p. 100295, 2021, doi: 10.1016/j.rineng.2021.100295.

[54] A. R. Estabragh, H. Rafatjo, and A. A. Javadi, "Treatment of an expansive soil by mechanical and chemical techniques," *Geosynth. Int.*, vol. 21, no. 3, pp. 233–243, 2014,

doi: 10.1680/gein.14.00011.

[55] S. Deka, “Performance enhancement of expansive soil by application of fly ash and lime,” no. June, 2011, [Online]. Available: http://14.139.196.25/handle/123456789/199%0Ahttp://14.139.196.25/bitstream/handle/123456789/199/TH-1044_02610403.pdf?sequence=1&isAllowed=y

Annex's: Laboratory Test Results

MOISTURE DENSITY RELATIONS OF THE SOIL

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

By; BEREKET MULUGETA NIGAT

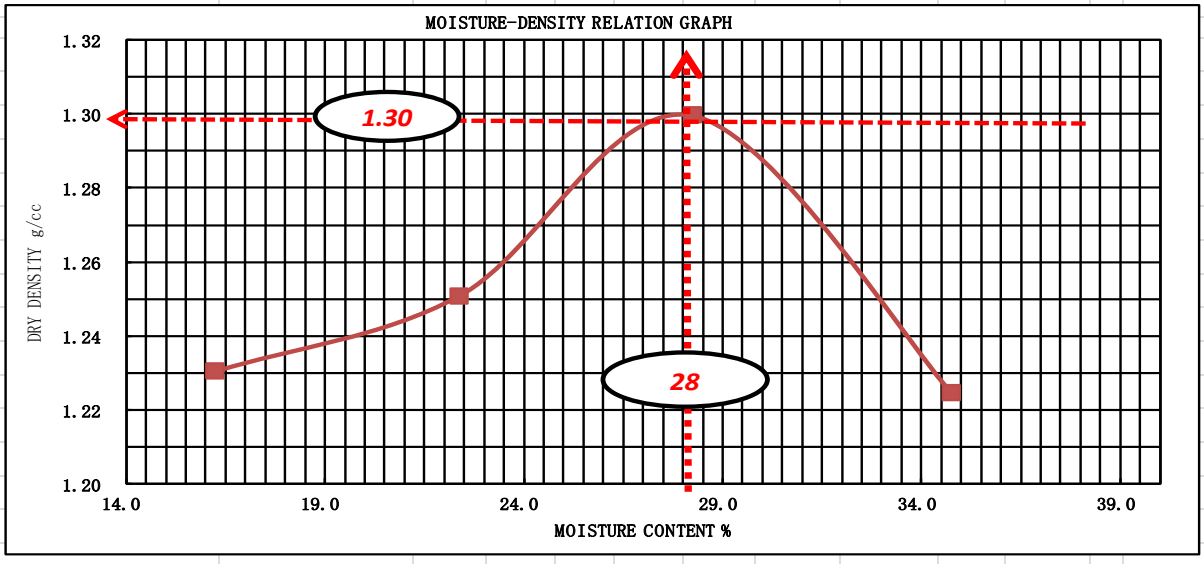
ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T 180-97, Method D

Location:	Kality Centeral Laboratory
Source:	Bole Arabsa Ayat 4
Material type:	Expansive Black Cotton Soil

Wt. mold+sample(g)	8000	8213	8502	8467		
Wt. of mold(g)	4962	4962	4962	4962		
Wt. of sample(g)	3038	3251	3540	3505		
Volume of mold(cm)^3	2124	2124	2124	2124		
Wet density (g/cc)	1.43	1.53	1.67	1.65		NMC
tare No	A.3	X.4	P.2	D.1		T.2
Wt. tare+sample(g)	336	329	345	408		372
Wt. tare+dry sample(g)	297	280	282	319		343
Wt. of water(g)	39	49	63	89		29
Wt. of tare(g)	57	61	59	63		61.0
Wt. of dry sample(g)	240	219	223	256		282.0
Moisture content(g/cc)	16.3	22.4	28.3	34.8		10.3
Dry density(g/cc)	1.23	1.25	1.30	1.22		

DIA. Of mould(mm)	Rammer Wt(kg)	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.30	28	5



CALIFORNIA BEARING RATIO TEST

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

By; BEREKET MULUGETA NIGAT
ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T 193-99

Location:	Kality Centeral Laboratory	**Ring factor**	*40.21*
Source:	Bole Arabsa Ayat 4	**Height of specimen**	116.43
Material type:	Expansive Black Cotton Soil	**Penetration piston area**	1.935cm 2

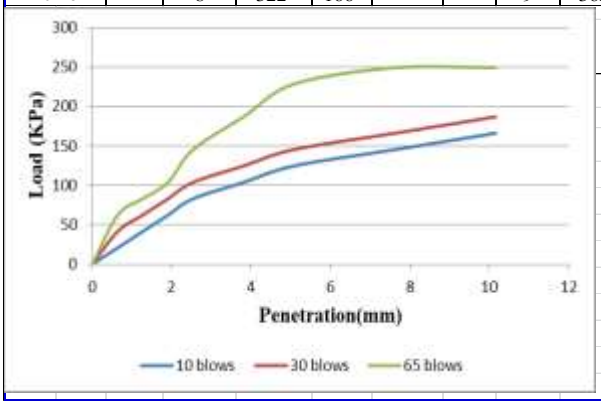
Mould No.	C		C		C	
No. of layers	5		5		5	
No. of blows per layer	10		30		65	
CONDITION OF SAMPLE	**Before soaking**	**After soaking**	**Before soaking**	**After soaking**	**Before soaking**	**After soaking**
Wt.of wet sample+mould	9364	9664	9573	9855	9871	10145
Wt.of mould	6341	6341	6275	6275	6106	6106
Wt.of wet sample	3023	3323	3298	3580	3765	4039
Volume of mould	2124	2124	2124	2124	2124	2124
Wet unit weight	1.42	1.56	1.55	1.69	1.77	1.90
Can No.	X.2	R.3	G.9	D.7	T.2	P.13
Wt.wet sample + can	408	383	417	391	410	383
Wt.dry sample +can	328	305	335	312	331	307
Wt.of water	80	78	82	79	79	76
Wt.of can	57	61	59	63	61	62
Wt.dry sample	271	244	276	249	270	245
% Moisture content	29.5	32	29.7	31.7	29.3	31
Dry unit weight	1.10	1.18	1.20	1.28	1.37	1.45

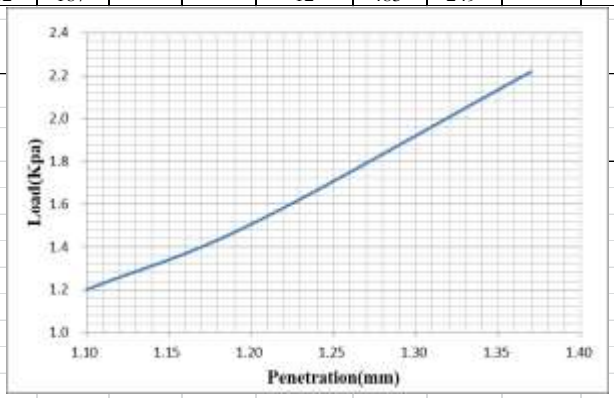
SWELL DATA

Initial height of sample(mm)	**Elapse time (day)**	**Mould 1**			**Mould 2**			**Mould 3**		
socked day of month		**gauge reading**	**swell**		**gauge reading**	**swell**		**gauge reading**	**swell**	
			mm	**%**		**mm**	**%**		**mm**	**%**
12/7/2021	0	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
12/8/2021	1	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
12/9/2021	2	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
12/10/2021	3	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
12/11/2021	4	10.0	10.00	***8.59***	10.0	10.00	***8.59***	10.0	10.00	***8.59***

CBR DATA

Penetration (mm)	Std load (KPa)	mould 1					mould 2					mould 3				
		Gauge reading	Test load		corr.CBR		Gauge readin	Test load		corr.CBR		Gauge reading	Test load		corr.CBR	
			N	KPa	KPa	%		N	KPa	KPa	%		N	KPa	KPa	%
0.64		1	40	21			2	80	42			3	121	62		
1.27		2	80	42			3	121	62			4	161	83		
1.91		3	121	62			4	161	83			5	201	104		
2.54	6900	4	161	83	83	***1.2***	5	201	104	104	***1.5***	7	281	145	145	***2.1***
3.81		5	201	104			6	241	125			9	362	187		
5.08	10300	6	241	125	125	***1.2***	7	281	145	145	***1.4***	11	442	229	229	***2.2***
7.62		7	281	145			8	322	166			12	483	249		
10.16		8	322	166			9	362	187			12	483	249		





PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

By; BEREKET MULUGETA NIGAT

ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T89,T90

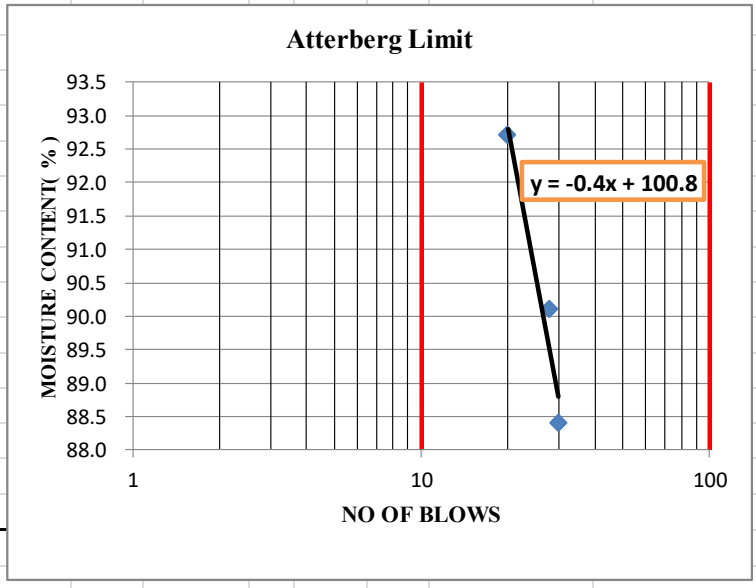
Test Location:	Kality Centeral Laboratory
Sample Source	Bole Arabsa Ayat 4
Material type:	Expansive Black Cotton Soil

	LIQUID LIMIT				PLASTIC LIMIT	
Container number	5H	3A	50		30	70
Number of blows	30	28	20			
Wt.of Container +Wet soil(g)	33.35	31.19	29.88		21.80	21.89
Wt.of Container +Dry soil(g)	25.07	23.09	23.3		20.63	20.51
Wt.of water (g)	8.28	8.1	6.58		1.17	1.38
Wt.of Container weight (g)	15.7	14.1	16.2		16.77	15.94
Wt.of Dry soil (g)	9.37	8.99	7.1		3.86	4.57
Moisture content %	88.4	90.1	92.7		30.3	30.2
				Average %	30.3	

SIEVE ANALYSIS			
Sieve size	Wt.Ret.	%Ret	%Pass
No.10			
No.40	5	1.0	99.0
No.200	3	0.6	98.4
Pan	0		
Wash Lost			
Total	500.0		

Summary If LL or PL cannot be do, PI = NP;If PL >= LL, PI = NP

Liquid Limit :	91.1
Plasticity Limit:	30.3
Plasticity Index:	60.8



PLASTIC LIMIT AND PLASTICITY INDEX

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

By; BEREKET MULUGETA NIGAT

ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T89,T90

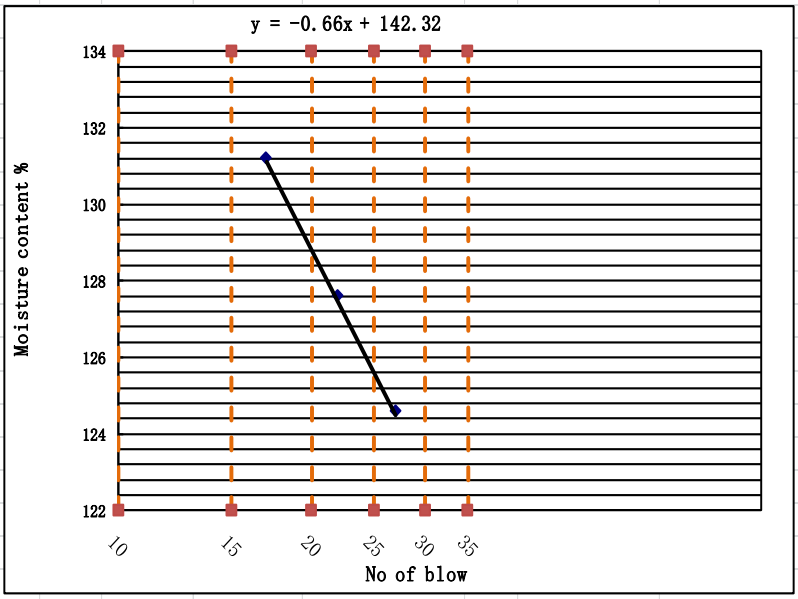
Location:	Kality Centeral Laboratory
Source:	Bole Arabsa Ayat 4
Material type:	sewerage sludge

	LIQUID LIMIT				PLASTIC LIMIT	
Container number	C-17	C-50	C-56		D-8	D-40
Number of blows	27	22	17			
Wt.of Container +Wet soil(g)	29.44	31.51	33.63		21.48	21.45
Wt.of Container +Dry soil(g)	21.13	22.76	23.96		18.25	18.82
Wt.of water (g)	8.31	8.75	9.67		3.23	2.63
Wt.of Container weight (g)	14.46	15.9	16.59		14.74	15.9
Wt.of Dry soil (g)	6.67	6.86	7.37		3.51	2.92
Moisture content %	124.6	127.6	131.2		92.0	90.1
				Average %	91.1	

SIEVE ANALYSIS			
Sieve size	Wt.Ret.	%Ret	%Pass
No.10			
No.40			
No.200			
Pan			
Wash Lost			
Total	500.0		

Summary: If LL or PL cannot be do, PI = NP;If PL >= LL, PI = NP

Liquid Limit :	127.8
Plasticity Limit:	91.1
Plasticity Index:	36.8



Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

By; BEREKET MULUGETA NIGAT

ADDIS ABABA INSTITUTE OF THECHNOLOGY

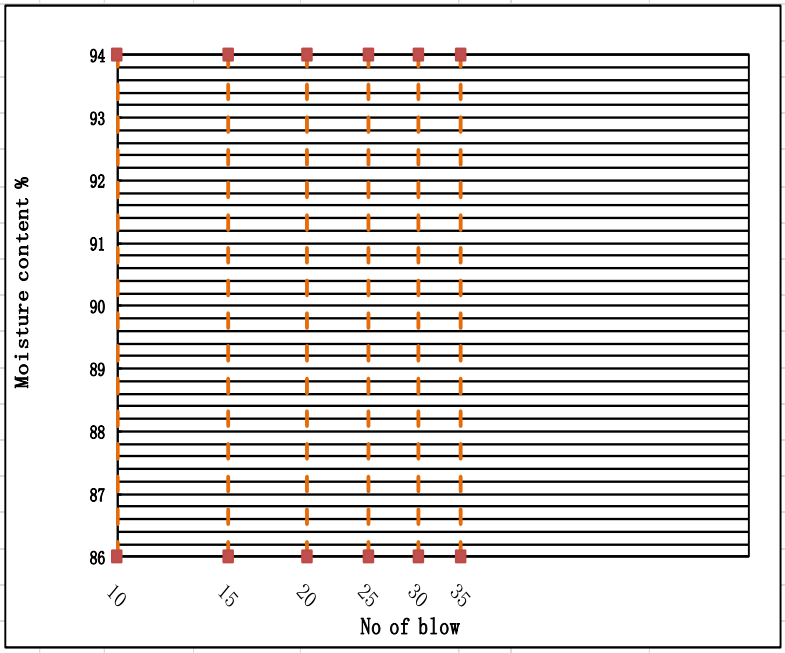
TEST METHOD : AASHTO T89,T90

Location:	Kality Centeral Laboratory
Source:	Kotebe Treatment Plant
Material type:	SSA

	LIQUID LIMIT				PLASTIC LIMIT	
Container number	C-21	C-32	C-18		D.05	D-10
Number of blows						
Wt.of Container +Wet soil(g)						
Wt.of Container +Dry soil(g)	N.P				N.P	
Wt.of water (g)						
Wt.of Container weight (g)						
Wt.of Dry soil (g)						
Moisture content %						
				Average %		

SIEVE ANALYSIS			
Sieve size	Wt.Ret.	%Ret	%Pass
No.10			
No.40			
No.200			
Pan			
Wash Lost			
Total	500.0		

Summary If LL or PL cannot be do,
PI = NP;If PL >= LL, PI = NP



MOISTURE DENSITY RELATIONS OF THE SOIL

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

By; BEREKET MULUGETA NIGAT

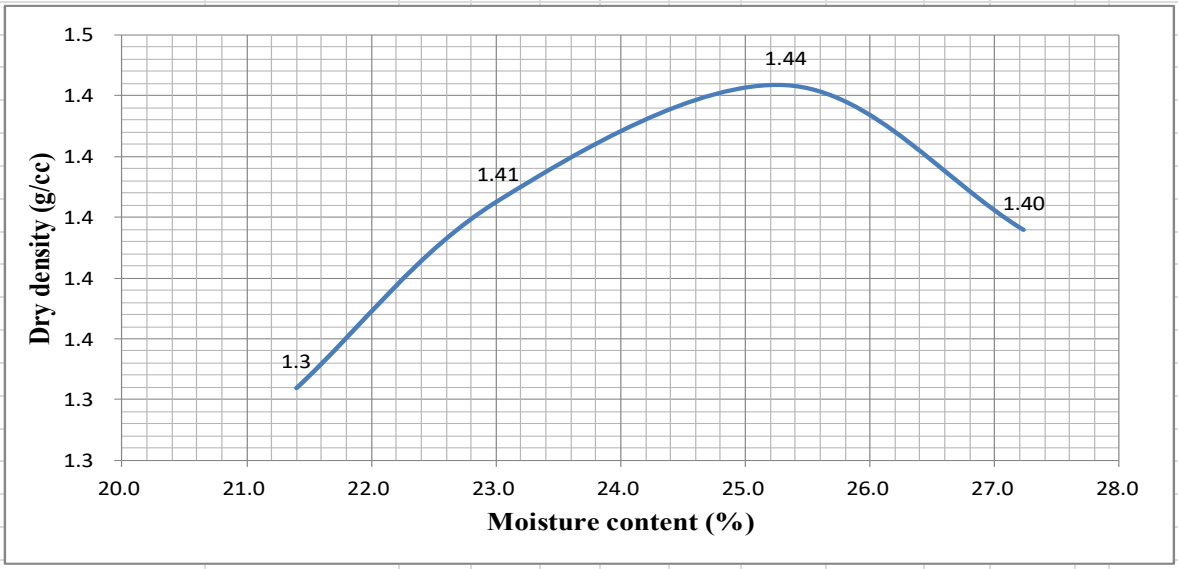
ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T 180-97, Method D

Location:	Kality Lab.
Source:	Bole Arabsa Ayat
Material type:	Soil-SSA Composite(4% SSA proportion)

Wt. mold+sample(g)	8386	8593	8763	8693		
Wt. of mold(g)	4921	4921	4921	4921		
Wt. of sample(g)	3465	3672	3842	3772		
Volume of mold(cm)^3	2124	2124	2124	2124		
Wt. density (g/cc)	1.63	1.73	1.81	1.78		NMC
tare No	T-7	Y-3	B-2	B		B.3
Wt. tare+sample(g)	342	365	345	329		469
Wt. tare+dry sample(g)	290	307	286	271		429
Wt. of water(g)	52	58	59	58		40
Wt. of tare(g)	47	55	53	58		87.0
Wt. of dry sample(g)	243	252	233	213		342.0
Moisture content(g/cc)	21.4	23.0	25.3	27.2		11.7
Dry density(g/cc)	1.34	1.41	1.44	1.40		

DIA. Of mould(mm)	Rammer Wt(kg)	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.44	25.4	5



CALIFORNIA BEARING RATIO TEST

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

By:BEREKET MULUGETA NIGAT
ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T 193-99

Location:	Kality Lab.	**Ring factor**	40.21
Source:	Bole Arabsa Ayat	**Height of specimen**	116.43
Material type:	Soil-SSA Composite(4% SSA proportion)	**Penetration piston area**	1.935cm 2

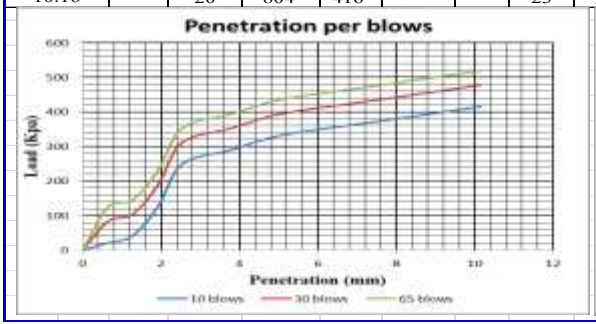
Mould No.	16		15		18	
No. of layers	5		5		5	
No. of blows per layer	10		30		65	
CONDITION OF SAMPLE	Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample+mould	9531	9981	9845	10313	10326	10737
Wt.of mould	6224	6224	6266	6266	6306	6306
Wt.of wet sample	3307	3757	3579	4047	4020	4431
Volume of mould	2124	2124	2124	2124	2124	2124
Wet unit weight	1.56	1.77	1.69	1.91	1.89	2.09
Can No.	17	R.3	T-3	D.7	B	P.13
Wt.wet sample + can	380	383	305	391	345	383
Wt.dry sample +can	325	305	253	312	285	307
Wt.of water	55	78	52	79	60	76
Wt.of can	115	61	54	63	56	62
Wt.dry sample	210	244	199	249	229	245
% Moisture content	26.2	32	26.1	31.7	26.2	31
Dry unit weight	1.24	1.34	1.34	1.45	1.50	1.60

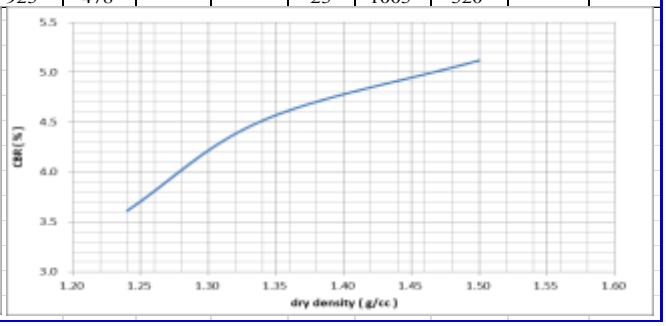
SWELL DATA

Initial height of sample(mm)	Elapse time (day)	Mould 1			Mould 2			mould 3		
socked day of month		gauge reading	swell		gauge reading	swell		gauge reading	swell	
			mm	%		mm	%		mm	%
1/17/2022	0	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/18/2022	1	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/19/2022	2	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/20/2022	3	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/21/2022	4	9.6	9.60	8.25	9.2	9.20	7.90	8.9	8.90	7.64

CBR DATA

Penetration (mm)	Std load (KPa)	mould 1					mould 2					mould 3				
		Gauge reading	test load		corr.CBR		Gauge readin	test load		corr.CBR		Gauge readin	test load		corr.CBR	
			N	KPa	KPa	%		N	KPa	KPa	%		N	KPa	KPa	%
0.64		1	40	21			4	161	83			6	241	125		
1.27		2	80	42			5	201	104			7	281	145		
1.91		6	241	125			9	362	187			11	442	229		
2.54	6900	12	483	249	249	*3.6*	15	603	312	312	*4.5*	17	684	353	353	*5.1*
3.81		14	563	291			17	684	353			19	764	395		
5.08	10300	16	643	332	332	*3.2*	19	764	395	395	*3.8*	21	844	436	436	*4.2*
7.62		18	724	374			21	844	436			23	925	478		
10.16		20	804	416			23	925	478			25	1005	520		





PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

By:BEREKET MULUGETA NIGAT

ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T89,T90

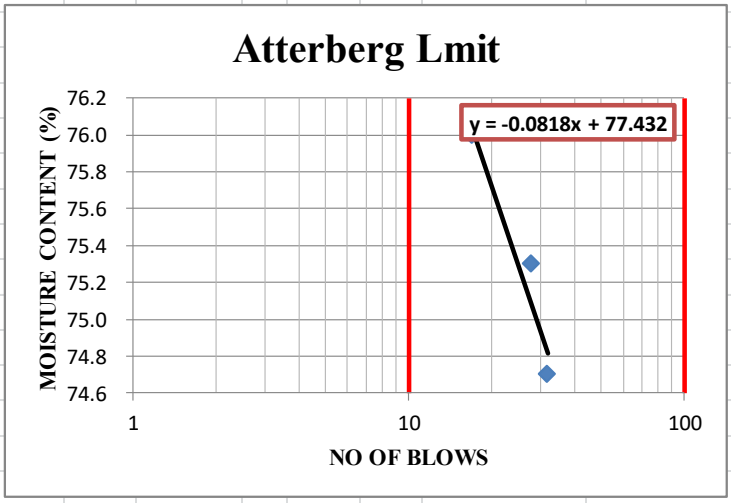
Lab Location	Kality Lab.
Sample Source	Bole Arabsa Ayat
Material type	Soil-SSA Composite(4% SSA proportion)

	LIQUID LIMIT				PLASTIC LIMIT	
Container number	K	L	Z		13	15A
Number of blows	32	28	17			
Wt.of Container +Wet soil(g)	33.93	33.87	33.76		21.38	20.32
Wt.of Container +Dry soil(g)	26.48	27.07	26.37		20.16	19.24
Wt.of water (g)	7.45	6.8	7.39		1.22	1.08
Wt.of Container weight (g)	16.51	18.04	16.65		16.45	15.95
Wt.of Dry soil (g)	9.97	9.03	9.72		3.71	3.29
Moisture content %	74.7	75.3	76.0		32.9	32.8
				Average %	32.9	

SIEVE ANALYSIS			
Sieve size	Wt.Ret.	%Ret	%Pass
No.10			
No.40			
No.200			
Pan			
Wash Lost			
Total	500.0		

Summary: If LL or PL cannot be do, PI = NP;If PL >= LL, PI = NP

Liquid Limit :	75.5
Plasticity Limit:	32.9
Plasticity Index:	42.6



MOISTURE DENSITY RELATIONS OF THE SOIL

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

By; BEREKET MULUGETA NIGAT

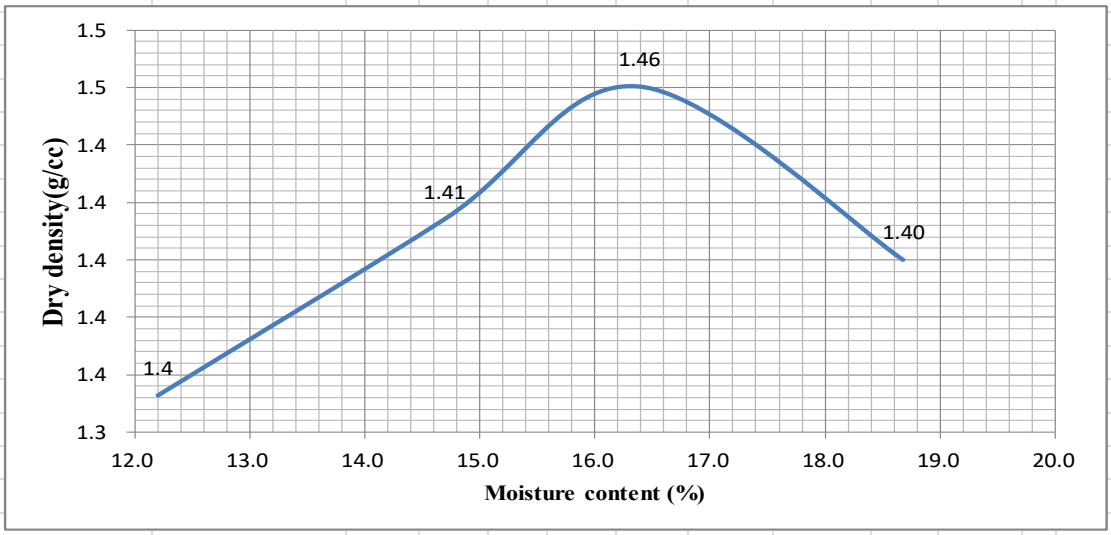
ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T 180-97, Method D

Location:	Kality Lab.
Source:	Bole Arabsa Ayat
Material type:	Soil-SSA Composite (6 % SSA proprtion)

Wet mold+sample(g)	8148	8369	8534	8453		
Wet of mold(g)	4924	4924	4924	4924		
Wet of sample(g)	3224	3445	3610	3529		
Volume of mold(cm)^3	2124	2124	2124	2124		
Wet density (g/cc)	1.52	1.62	1.70	1.66		NMC
tare No	2	T-18	B-2	C-02		20
Wet tare+sample(g)	345	337	464	361		470
Wet tare+dry sample(g)	314	301	406	313		455
Wet of water(g)	31	36	58	48		15
Wet of tare(g)	60	56	52	56		104.0
Wet of dry sample(g)	254	245	354	257		351.0
Moisture content(g/cc)	12.2	14.7	16.4	18.7		4.3
Dry density(g/cc)	1.35	1.41	1.46	1.40		

DIA. Of mould(mm)	Rammer Wt(kg)	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.46	16.4	5



CALIFORNIA BEARING RATIO TEST

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

By; BEREKET MULUGETA NIGAT
ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T 193-99

Location:	Kality Lab.	**Ring factor**	*40.21*
Source:	Bole Arabsa Ayat	**Height of specimen**	116.43
Material type:	Soil-SSA Composite (6 % SSA proprtion)	**Penetration piston area**	1.935cm 2

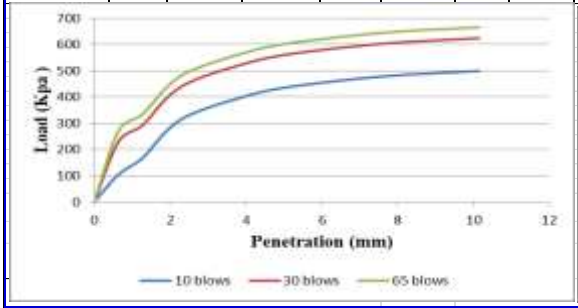
Mould No.	16		15		18	
No. of layers	5		5		5	
No. of blows per layer	10		30		65	
CONDITION OF SAMPLE	Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample+mould	9745	10127	9830	10185	10093	10425
Wt.of mould	6603	6603	6439	6439	6306	6306
Wt.of wet sample	3142	3524	3391	3746	3787	4119
Volume of mould	2124	2124	2124	2124	2124	2124
Wet unit weight	1.48	1.66	1.60	1.76	1.78	1.94
Can No.	17	R.3	T-3	D.7	B	P.13
Wt.wet sample + can	305	422	377	455	351	432
Wt.dry sample +can	268	363	329	392	307	374
Wt.of water	37	59	48	63	44	58
Wt.of can	55	63	53	70	53	69
Wt.dry sample	213	300	276	322	254	305
% Moisture content	17.4	19.7	17.4	19.6	17.3	19
Dry unit weight	1.26	1.39	1.36	1.47	1.52	1.63

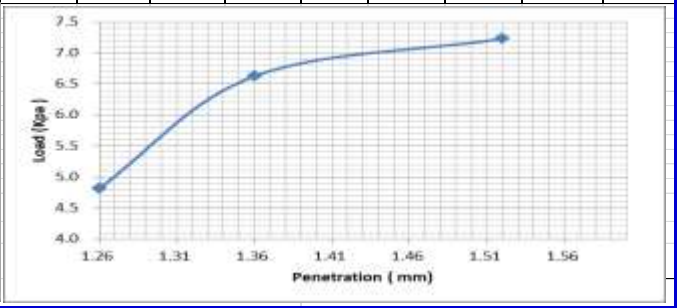
SWELL DATA

Initial height of sample(mm)	Elapse time (day)	Mould 1			Mould 2			mould 3		
socked day of month		gauge reading	swell		gauge reading	swell		gauge reading	swell	
			mm	%		mm	%		mm	%
1/17/2022	0	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/18/2022	1	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/19/2022	2	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/20/2022	3	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/21/2022	4	8.0	8.00	6.87	7.0	7.00	6.01	7.0	7.00	6.01

CBR DATA

Penetration (mm)	Std load (KPa)	mould 1					mould 2					mould 3				
		Gauge reading	test load		corr.CBR		Gauge readin	test load		corr.CBR		Gauge readin	test load		corr.CBR	
			N	KPa	KPa	%		N	KPa	KPa	%		N	KPa	KPa	%
0.64		5	201	104			11	442	229			13	523	270		
1.27		8	322	166			14	563	291			16	643	332		
1.91		13	523	270			19	764	395			21	844	436		
2.54	6900	16	643	332	332	*4.8*	22	885	457	457	*6.6*	24	965	499	499	*7.2*
3.81		19	764	395			25	1005	520			27	1086	561		
5.08	10300	21	844	436	436	*4.2*	27	1086	561	561	*5.4*	29	1166	603	603	*5.9*
7.62		23	925	478			29	1166	603			31	1247	644		
10.16		24	965	499			30	1206	623			32	1287	665		





PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

By; BEREKET MULUGETA NIGAT

ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T89,T90

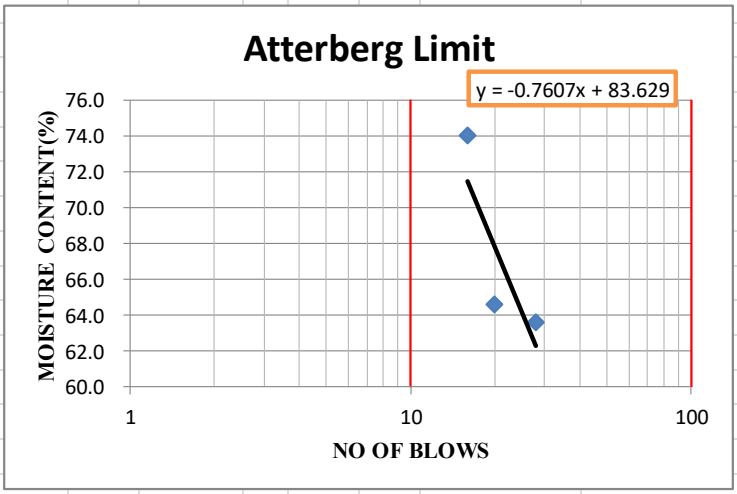
Location:	Kality Lab.
Source:	Bole Arabsa Ayat
Material type:	Soil-SSA Composite (6 % SSA proprtion)

	LIQUID LIMIT				PLASTIC LIMIT	
Container number	R	19	6A		13	15A
Number of blows	28	20	16			
Wt.of Container +Wet soil(g)	35.81	36.85	38.28		22.36	24.30
Wt.of Container +Dry soil(g)	28.09	29.20	29.72		21.13	21.77
Wt.of water (g)	7.72	7.65	8.56		1.23	2.53
Wt.of Container weight (g)	15.96	17.36	18.16		14.7	16.43
Wt.of Dry soil (g)	12.13	11.84	11.56		6.43	5.34
Moisture content %	63.6	64.6	74.0		19.1	47.4
				Average %	33.3	

SIEVE ANALYSIS			
Sieve size	Wt.Ret.	%Ret	%Pass
No.10			
No.40			
No.200			
Pan			
Wash Lost			
Total	500.0		

Summary: If LL or PL cannot be do, PI = NP;If PL >= LL, PI = NP

Liquid Limit :	64.0
Plasticity Limit:	33.3
Plasticity Index:	30.7



MOISTURE DENSITY RELATIONS OF THE SOIL

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

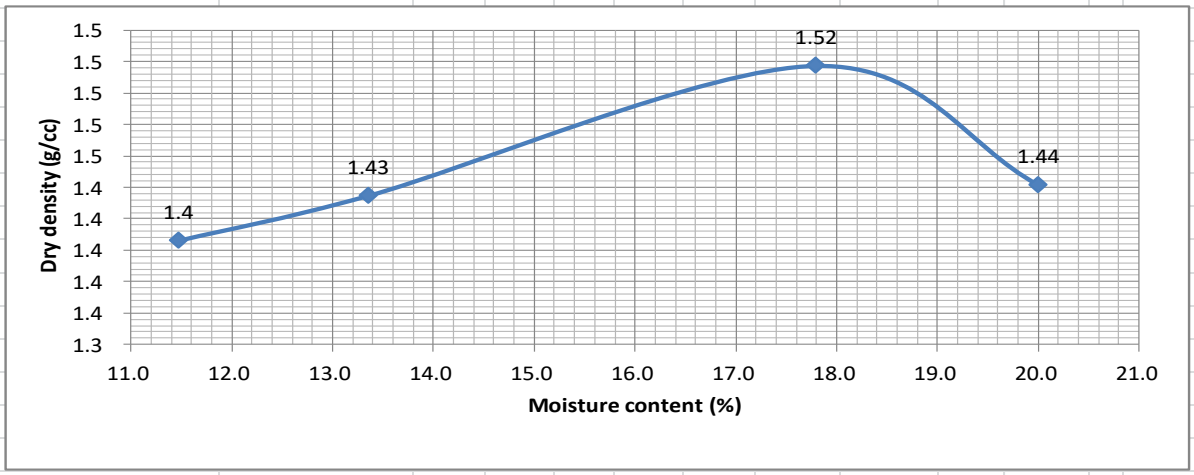
By: BEREKET MULUGETA NIGAT
ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T 180-97, Method D

Location:	Kality Lab.
Source:	Bole Arabsa Ayat
Material type:	Soil-SSA Composite(8% SSA proprtion)

Wet mold+sample(g)	8253	8378	8720	8598		
Wet of mold(g)	4924	4924	4924	4924		
Wet of sample(g)	3329	3454	3796	3674		
Volume of mold(cm)^3	2124	2124	2124	2124		
Wet density (g/cc)	1.57	1.63	1.79	1.73		NMC
tare No	R-2	C-1	p	B-26		B-10
Wet tare+sample(g)	332	370	345	310		436
Wet tare+dry sample(g)	304	333	303	268		412
Wet of water(g)	28	37	42	42		24
Wet of tare(g)	60	56	67	58		52.0
Wet of dry sample(g)	244	277	236	210		360.0
Moisture content(g/cc)	11.5	13.4	17.8	20.0		6.7
Dry density(g/cc)	1.41	1.43	1.52	1.44		

DIA. Of mould(mm)	Rammer Wt(kg)	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.52	17.8	5



CALIFORNIA BEARING RATIO TEST

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

By; BEREKET MULUGETA NIGAT
ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T 193-99

Location:	Kality Lab.	**Ring factor**	*40.21*
Source:	Bole Arabsa Ayat	**Height of specimen**	116.43
Material type:	Soil-SSA Composite(8% SSA proprtion)	**Penetration piston area**	1.935cm 2

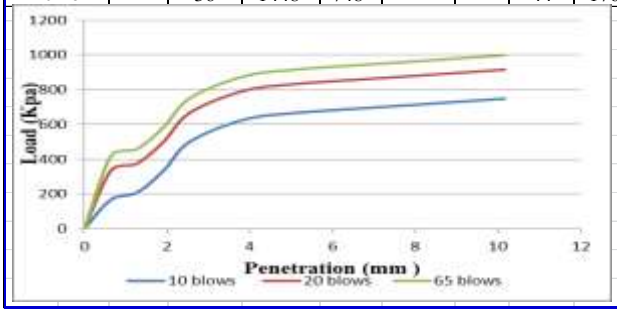
Mould No.	17		R-10		2	
No. of layers	5		5		5	
No. of blows per layer	10		30		65	
CONDITION OF SAMPLE	Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample+mould	9421	9803	9584	9939	10103	10431
Wt.of mould	6254	6254	6175	6175	6215	6215
Wt.of wet sample	3167	3549	3409	3764	3888	4216
Volume of mould	2124	2124	2124	2124	2124	2124
Wet unit weight	1.49	1.67	1.60	1.77	1.83	1.98
Can No.	9	R.3	20	D.7	T18	P.13
Wt.wet sample + can	363	455	346	415	302	428
Wt.dry sample +can	321	392	312	359	267	371
Wt.of water	42	63	34	56	35	57
Wt.of can	67	55	103	58	56	61
Wt.dry sample	254	337	209	301	211	310
% Moisture content	16.5	18.7	16.3	18.6	16.6	18.4
Dry unit weight	1.28	1.41	1.38	1.49	1.57	1.67

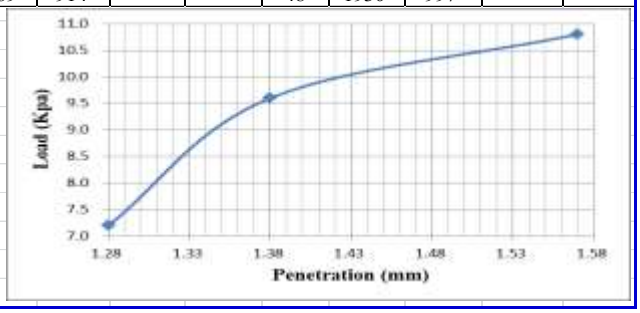
SWELL DATA

Initial height of sample(mm)	Elapse time (day)	Mould 1			Mould 2			mould 3		
socked day of month		gauge reading	swell		gauge reading	swell		gauge reading	swell	
			mm	%		mm	%		mm	%
1/17/2022	0	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/18/2022	1	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/19/2022	2	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/20/2022	3	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/21/2022	4	3.6	3.60	*3.09*	7.9	2.50	*2.15*	2.0	2.00	*1.72*

CBR DATA

Penetration (mm)	Std load (KPa)	mould 1					mould 2					mould 3				
		Gauge reading	test load		corr.CBR		Gauge readin	test load		corr.CBR		Gauge readin	test load		corr.CBR	
			N	KPa	KPa	%		N	KPa	KPa	%		N	KPa	KPa	%
0.64		8	322	166			16	643	332			20	804	416		
1.27		10	402	208			18	724	374			22	885	457		
1.91		16	643	332			24	965	499			28	1126	582		
2.54	6900	24	965	499	499	*7.2*	32	1287	665	665	*9.6*	36	1448	748	748	*10.8*
3.81		30	1206	623			38	1528	790			42	1689	873		
5.08	10300	32	1287	665	665	*6.5*	40	1608	831	831	*8.1*	44	1769	914	914	*8.9*
7.62		34	1367	707			42	1689	873			46	1850	956		
10.16		36	1448	748			44	1769	914			48	1930	997		





PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

By; BEREKET MULUGETA NIGAT

ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T89,T90

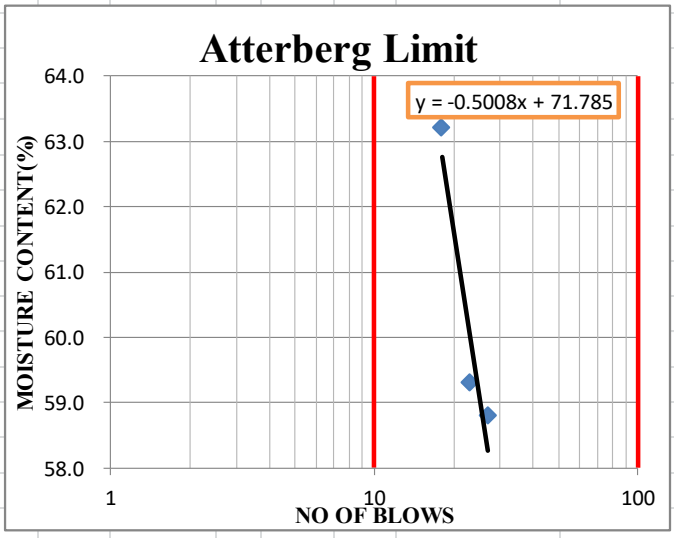
Location:	Kality Lab.
Source:	Bole Arabsa Ayat
Material type:	Soil-SSA Composite(8% SSA proprtion)

	LIQUID LIMIT				PLASTIC LIMIT	
Container number	T	M	O		E	4
Number of blows	18	23	27			
Wt.of Container +Wet soil(g)	31.53	36.7	30.9		25.62	24.43
Wt.of Container +Dry soil(g)	25.4	28.95	24.61		22.97	22.19
Wt.of water (g)	6.13	7.75	6.29		2.65	2.24
Wt.of Container weight (g)	15.7	15.87	13.91		16.43	16.79
Wt.of Dry soil (g)	9.7	13.08	10.7		6.54	5.4
Moisture content %	63.2	59.3	58.8		40.5	41.5
				Average %	41.0	

SIEVE ANALYSIS			
Sieve size	Wt.Ret.	%Ret	%Pass
No.10			
No.40			
No.200			
Pan			
Wash Lost			
Total	500.0		

Summary: If LL or PL cannot be do, PI = NP;If PL >= LL, PI = NP

Liquid Limit :	59.3
Plasticity Limit:	41.0
Plasticity Index:	18.3



MOISTURE DENSITY RELATIONS OF THE SOIL

Msc Thesis on Investigating the mechanisms of expansive black cotton soil stabilization with sewage sludge ash using experimental & image analysis methods.

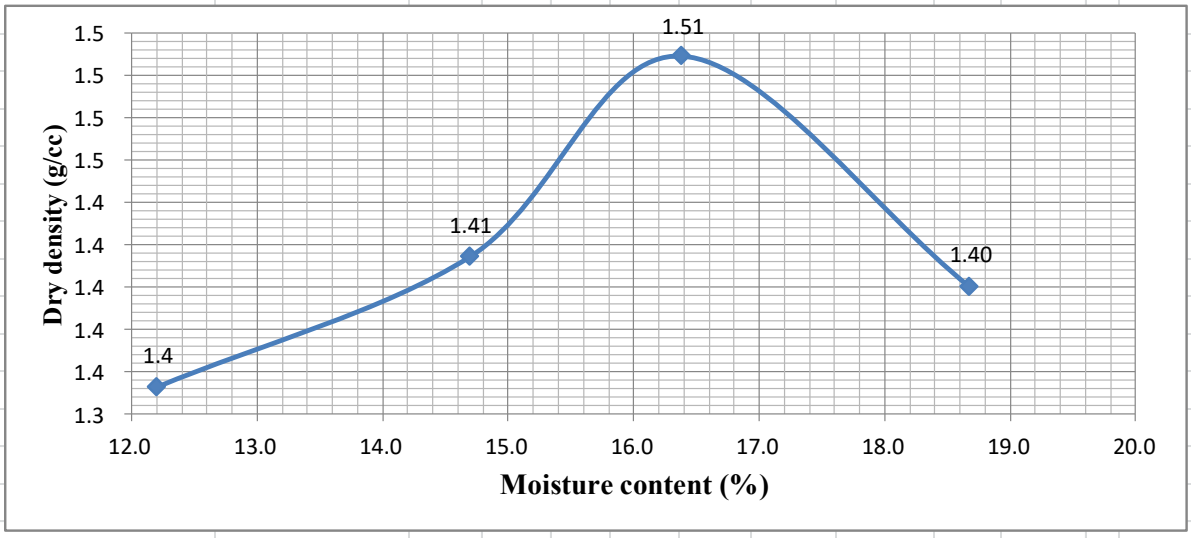
By:BEREKET MULUGETA NIGAT
ADDIS ABABA INSTITUTE OF THECHNOLOGY

TEST METHOD : AASHTO T 180-97, Method D

Location:	Kality Lab.
Source:	Bole Arabsa Ayat
Material type:	Soil-SSA Composite (10% SSA)

Wet mold+sample(g)	8148	8369	8654	8453		
Wet of mold(g)	4924	4924	4924	4924		
Wet of sample(g)	3224	3445	3730	3529		
Volume of mold(cm)^3	2124	2124	2124	2124		
Wet density (g/cc)	1.52	1.62	1.76	1.66		NMC
tare No	2	T-18	B-2	C-02		20
Wet tare+sample(g)	345	337	464	361		470
Wet tare+dry sample(g)	314	301	406	313		455
Wet of water(g)	31	36	58	48		15
Wet of tare(g)	60	56	52	56		104.0
Wet of dry sample(g)	254	245	354	257		351.0
Moisture content(g/cc)	12.2	14.7	16.4	18.7		4.3
Dry density(g/cc)	1.35	1.41	1.51	1.40		

DIA. Of mould(mm)	Rammer Wt(kg)	Blows/layer	Max.dry density(g/cc)	O.M.C(%)	No.of layers
152.4	4.5	56	1.51	16.4	5



CALIFORNIA BEARING RATIO TEST

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By:BEREKET MULUGETA NIGAT
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TEST METHOD : AASHTO T 193-99

Location:	Kality Lab.	**Ring factor**	*40.21*
Source:	Bole Arabsa Ayat	**Height of specimen**	116.43
Material type:	Soil-SSA Composite (10% SSA)	**Penetration piston area**	1.935cm 2

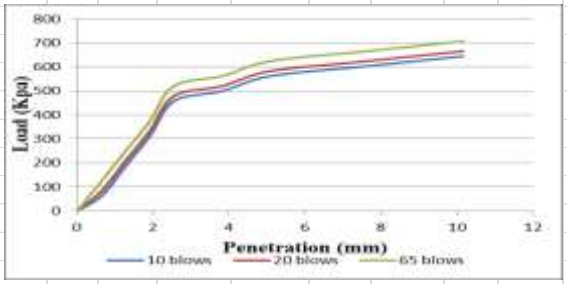
Mould No.	16		15		18	
No. of layers	5		5		5	
No. of blows per layer	10		30		65	
CONDITION OF SAMPLE	Before soaking	After soaking	Before soaking	After soaking	Before soaking	After soaking
Wt.of wet sample+mould	9745	10127	9830	10185	10093	10425
Wt.of mould	6603	6603	6439	6439	6306	6306
Wt.of wet sample	3142	3524	3391	3746	3787	4119
Volume of mould	2124	2124	2124	2124	2124	2124
Wet unit weight	1.48	1.66	1.60	1.76	1.78	1.94
Can No.	17	R.3	T-3	D.7	B	P.13
Wt.wet sample + can	305	422	377	455	351	432
Wt.dry sample +can	268	363	329	392	307	374
Wt.of water	37	59	48	63	44	58
Wt.of can	55	63	53	70	53	69
Wt.dry sample	213	300	276	322	254	305
% Moisture content	17.4	19.7	17.4	19.6	17.3	19
Dry unit weight	1.26	1.39	1.36	1.47	1.52	1.63

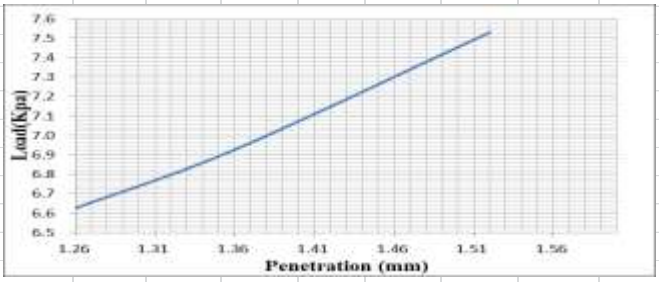
SWELL DATA

Initial height of sample(mm)	Elapse time (day)	Mould 1			Mould 2			mould 3		
socked day of month		gauge reading	swell		gauge reading	swell		gauge reading	swell	
			mm	%		mm	%		mm	%
1/17/2022	0	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/18/2022	1	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/19/2022	2	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/20/2022	3	0.0	0.00	0.00	0.0	0.00	0.00	0.0	0.00	0.00
1/21/2022	4	*2.0*	*2.00*	*1.72*	*10.0*	*2.00*	*1.72*	*2.0*	*2.00*	*1.72*

CBR DATA

Penetration (mm)	Std load (KPa)	mould 1					mould 2					mould 3				
		Gauge reading	test load		corr.CBR		Gauge readin	test load		corr.CBR		Gauge readin	test load		corr.CBR	
			N	KPa	KPa	%		N	KPa	KPa	%		N	KPa	KPa	%
0.64		3	121	62			4	161	83			6	241	125		
1.27		9	362	187			10	402	208			12	483	249		
1.91		15	603	312			16	643	332			18	724	374		
2.54	6900	22	885	457	457	6.6	23	925	478	478	6.9	25	1005	520	520	7.5
3.81		24	965	499			25	1005	520			27	1086	561		
5.08	10300	27	1086	561	561	5.4	28	1126	582	582	5.6	30	1206	623	623	6.1
7.62		29	1166	603			30	1206	623			32	1287	665		
10.16		31	1247	644			32	1287	665			34	1367	707		





PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

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TEST METHOD : AASHTO T89,T90

Location:	Kality Lab.
Source:	Bole Arabsa Ayat
Material type:	Soil-SSA Composite (10% SSA)

	LIQUID LIMIT				PLASTIC LIMIT	
Container number	R	19	6A		13	15A
Number of blows	19	22	28			
Wt.of Container +Wet soil(g)	35.76	36.55	36.28		22.16	23.93
Wt.of Container +Dry soil(g)	28.09	29.20	29.72		19.90	21.77
Wt.of water (g)	7.67	7.35	6.56		2.26	2.16
Wt.of Container weight (g)	15.96	17.36	18.16		14.7	16.43
Wt.of Dry soil (g)	12.13	11.84	11.56		5.2	5.34
Moisture content %	63.2	62.1	56.7		43.5	40.4
				Average %	42.0	

SIEVE ANALYSIS			
Sieve size	Wt.Ret.	%Ret	%Pass
No.10			
No.40			
No.200			
Pan			
Wash Lost			
Total	500.0		

Summary: If LL or PL cannot be do, PI = NP;If PL >= LL, PI = NP

Liquid Limit :	59.4
Plasticity Limit:	42.0
Plasticity Index:	17.5