**ADDIS ABABA UNIVERSITY**

**School of Graduate Studies**

**Addis Ababa Institute of Technology**

**School of Civil and Environmental Engineering**

# POTENTIAL USE OF RICE HUSK ASH AS WORETA EXPANSIVE SOIL STABILIZER

**By: Chalachew Admas**

**Advisor: Dr.-Ing. Samuel Tadesse**

**A thesis submitted to the school of graduate studies of Addis Ababa University in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering**

**(Geotechnical Engineering)**

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**ADDIS ABABA UNIVERSITY**

**SCHOOL OF GRADUATE STUDIES SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**

This is to certify that the thesis prepared by Chalachew Admas entitled **"Potential Use of Rice Husk Ash as Woreta Expansive Soil Stabilizer"** submitted in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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# DECLARATION

I hereby declare that the thesis entitled **Potential Use of Rice Husk Ash as Woreta Expansive Soil Stabilizer** has been carried out by me under the supervision of Dr.-Ing. Samuel Tadesse, during the year 2020 as part of Master of Science Program in Geotechnical engineering. I further declare that this work has not been submitted to any other University or institution for the award of any degree. All quotations and their sources are specifically acknowledged by means of references.

**Chalachew Admas**

Signature: __________________

Place and date of submission: School of Graduate Studies, Addis Ababa University

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## ABSTRACT

Expansive soils cause serious problem in the civil engineering practice due to swell and shrinkage upon wetting and drying. In Woreta this soil is the dominant and extends to very deep depth. In this study, the potential use and the effectiveness of expansive soils stabilization using rice husk ash are evaluated. Rice husk ash is the most locally available agricultural waste material in Woreta and it is an attractive pozzolanic. According to the chemical content test the main component of the rice husk ash is silica and its amount is about 76%, which is the element that governs the reactivity of the ash. The effectiveness of this ash in soil stabilization is tested in the laboratory by conducting laboratory tests like compaction, California bearing ratio, unconfined compressive strength, Atterberg limit, specific gravity, and free swell on uncured and 7 days cured samples with a different percentage of ash (5%, 10%, 15% and 20% of soil dry weight) with and without the amendment of 4% lime. The results obtained, indicates that the use of rice husk ash in soil stabilization generally increase strength and decrease swelling potentials. The liquid limit, plasticity index, maximum dry density, specific gravity, and free Swell properties had been decreased with the addition of rice husk ash, while the OMC increased. The UCS test results indicated that the treated soil increases by 23% and 67% for uncured and by 49% and 119% for 7 days cured sample in strength over that of the virgin soil with the addition of 5% and 10% rice husk ash respectively. Also, the combination of rice husk ash with 4% lime enormously increase the UCS value for both cured and uncured samples. Others parameters found to be improved are the CBR value and it increased from 1.2% to a maximum of 2% for uncured and 2.4% for 7 days cured with the addition of 10% rice husk ash alone and around 17% for uncured and 22% for 7 days cured with the addition of 10% rice husk ash amended with 4% lime. Nonetheless, both the UCS and CBR of treated expansive soil reduced slightly when the rice husk ash content was greater than 10%, which indicates that the optimum amount to achieve the highest strength is around 10% rice husk ash content. Both UCS and CBR values increase significantly due to the presence of curing.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| AAiT | Addis Ababa Institutes of Technology |
| AASHTO | American Association of Highway and Transportation Officials |
| ASTM | American Society for Testing and Materials |
| BS | British Standard |
| CBR | California Bearing Ratio |
| DTU | Debre Tabor University |
| ERA | Ethiopian Roads Authority |
| FDOT | Florida Department of Transportation |
| FDREMWR | Federal Democratic Republic of Ethiopia Minister of Water Resources |
| FS | Free swell |
| IPMS | Improving productivity and market success |
| LL | Liquid Limit |
| MDD | Maximum Dry Density |
| OMC | Optimum Moisture Content |
| PI | Plastic Index |
| PL | Plastic Limit |
| RHA | Rise husk ash |
| SL | Shrinkage Limit |
| UCS | Unconfined compressive strength |
| USCS | Unified Soil Classification System |

**Units**

| | |
|---|---|
| % | Percentage |
| kPa | Kilo Pascal |
| g/cm3 | Gram per centimeter cube |
| gm | Gram |
| kg | Kilo gram |
| kN | Kilo Newton |
| kN/m2 | Kilo Newton per meter square |
| mm | Millimeter |

# Chapter 1 INTRODUCTION

Expansive soils are clay soils with high plasticity and show massive volume change when exposed to the fluctuations of moisture content, and also causes significant damage to civil engineering works by cyclically shrinking and swelling within the active zone, which is defined as the depth in the soil to which periodic changes of moisture occurs. These soils typically contain Smectite clay minerals such as montmorillonite that attract and absorb water. Expansive soils undergo extra volume change by absorbing water between the specific microstructural structures and the magnitude of volume change is dependent on the mineralogical composition of the expansive soil and the variations of soil moisture content. These soils are found in arid and semi-arid areas of tropical and temperate climatic zones, in countries such as; the United States, Canada, Australia, Africa, India, China, Israel, etc. (Puppala, Punthutaecha, & Vanapalli (2006) where annual evapotranspiration is more than the precipitation (Jones & Holtz, 1973).

The problem of expansive soils is widespread in many parts of Ethiopia and throughout the world. Foundations constructed on such soils are exposed to large uplifting forces caused by the swelling. Swell pressures contribute to lifting and heave movements of structures in both vertical and lateral directions and cause: -

- ✓ Lifting, heaving, and shrinkage cracking of sidewalks, and transport roads,
- ✓ Swelling and cracking of foundations and floor slabs in a residential building,
- ✓ Jammed doors and windows collapse, and
- ✓ Ground movements and damages to underground structures like a ruptured pipeline.

These damages cost great budgets for the worth of maintenance, repair, and replacement of engineering structures, buildings, pipelines, roads, and pavements.

There are several methods to reduce the expansion potential and minimizing damages caused by expansive soil such as;

- ➢ Pre-wetting of the expansive soil before placing the foundation,
- ➢ Replacing expansive soil with the non-expansive material,
- ➢ Increasing the depth of footings to transfer loads of building to more stable soils,
- ➢ Reinforcing all concrete foundation elements and making thicker slabs,

- Drainage control in regions with high water tables by employing a sub-drain system or French drain, and
- Changing the clay mineralogy by adding chemical material (stabilization) such as; lime, silica fume, fly ash, amorphous silica, enzymes, cation exchange products, emulsions, acids, and polymers, (Zumrawi, 2016).

Soil stabilization is the method of enhancing the strength, volume stability, and durability of the soil and its aim is increasing strength and resistance to softening by water through bonding the soil particles together and it is widely used in road and foundation construction. Broadly, it refers to any chemical or mechanical treatment given to a mass of soil to improve or maintain its engineering properties.

Woreta is a town located in the South Gondar zone of the Amhara region east of Lake Tana about 55 kilometers from the regional capital, Bahir dar. This town has 110 55' N in latitude and 370 42'E in longitude with an average elevation of 1,828 meters above sea level. It's the administrative center of Fogera Woreda. This town is one of the fastest-growing towns in the Amhara region starting from the selection in one of the investment areas and the planning of connecting the dry port to the railway through it. Also in the rice production of Ethiopia, a relatively great percentage of the production is produced in this area due to this the first rice research institution is established in October 2018 in this town with the major mission of applying china production methods of rice to produce the great number of tons of paddy per hectares and ordering the country within the most rice-producing country of the world in the future few years. Therefore, rice husk ash is the most locally available agricultural waste material in this area which is resulted from the burning of rice husk.

The effectiveness of this ash in soil stabilization is tested in the laboratory by conducting tests like compaction, California bearing ratio, unconfined compressive strength, Atterberg limit, specific gravity, and free swell on uncured and 7 days cured samples with a different percentage of ash (5%, 10%, 15% and 20% of soil dry weight) with and without the amendment of 4% lime. The main aim of the paper is to investigate the use of rice husk ash which is a locally available agricultural waste to stabilize the expansive soil.

## 1.1 Statement of The Problem

A relatively large area of Woreta town covered with expansive soils. In most road and building structures, these soils have created persistent challenges and a relatively common problem. On the other hand, access road construction in the road sector increases due to the rapid growth of this city, which means that the demands for subgrade materials increase, but there is a lack of nearby land available to allow excavation for fill materials of subgrade construction. Moreover, replacement techniques, and stabilization using conventional stabilizing agents are extremely expensive, thus increasing construction costs. Even if shipping large amounts of construction materials has a negative environmental effect and is not a sustainable practice. In this situation, stabilizations of expansive soil using locally available agricultural wastes is one of the most approaches to overcome this problem. Based on the available literature, the use of locally available high silica content agricultural waste material in soil stabilization will considerably reduce the construction costs by improving the engineering properties of the soil. Also, reduces the environmental hazards it causes and the area of open land needed for its disposal.

Woreta is one of the main rice productions area of Ethiopia. Therefore, RHA is the most locally available high silica content agricultural waste material in Woreta. Unfortunately, limited studies have been conducted in which rice husk ash could be used to enhance expansive soil properties in the world and there are no studies in Woreta so far. However, more investigations are essential in order to have a better understanding of the geotechnical properties of expansive soil improved with the RHA which necessitates this research's on "potential use of rice husk ash as Woreta expansive soil stabilizer."

## 1.2 Research Questions

1. How can the lack of selected building materials in Woreta be resolved?
2. How can a locally available agricultural waste material like "rice husk" which is producing in high potential is used as a stabilizing agent for expansive soils found in Woreta?
3. What are the physical and mechanical properties of soil stabilized by using rice husk ash?
4. How much is the optimum amount of rice husk ash required for stabilizing expansive soil found in Woreta?

## 1.3 Objective of The Study

### 1.3.1 General objectives

Several goals are expected to be achieved in this study. However, the main objective of the study is investigating the potential use of rice husk ash to stabilize the expansive soil found in Woreta.

### 1.3.2 Specific objective

The above general objective is achieved by performing the following specific objectives: -

- ✓ Investigating an alternative method to solve the paucity of available nearby lands to allow excavate fill materials for making subgrade.
- ✓ Characterizing a rice husk ash and evaluating its effectiveness in reducing swell and shrink behaviors of expansive soil found in Woreta.
- ✓ Investigating the engineering properties of expansive soil found in Woreta stabilized with RHA by conducting various geotechnical laboratory tests.
- ✓ Determining the optimum amount of RHA required for stabilization of expansive soil found in Woreta.
- ✓ Show the possible applications of rice husk in construction industry,
- ✓ Provide an alternative solution for the disposal of agricultural wastes.

## 1.4 Scope of The Study

The scope of the research is to study how "Rice husk ash" can be effectively utilized in combination with expansive soil to get an improved quality of composite material which may be used in the various function of soil.

## 1.5 Significance of The Study

- Resolve the shortage of select material,
- Indicate the economical way of agricultural waste management system,
- Give information's to the rice research institute about the use of rice husk in construction industry.
- Reduce wastes and its environmental pollution,
- Reduce the area of open land needed for waste disposal,

## 1.6 Thesis Organization

The presentation of this thesis work is organized into five chapters. The first chapter provides a brief description of the thesis background, aim, scope, and methodology used. Chapter two presents a literature review on expansive soils, rice husk ash, and soil stabilization. The third Chapter briefly discusses the study area and the characterization of materials used for the study and the laboratory testing procedures followed. The fourth chapter consists of the test results obtained; analysis and discussions of results concerning the theoretical background and findings of previous studies. Chapter five presents conclusions and recommendations drawn from this research. Lastly but not list provide the reference used and appendix.

# Chapter 2 LITERATURE REVIEW

## 2.1 Introduction

This literature study aims to provide a basic platform for a better understanding of expansive soils as well as its problems associated with civil engineering works and also for a better understanding of soil stabilization using agricultural by-products.

The major emphasis is put on the following imperative range of subjects:

- Agricultural west and its engineering applications.
- Soil stabilization technic theory and practice.
- Expansive soils theory and practice.

Along with the identification of expansive soils and its problems, this chapter also places the theoretical, conceptual, and methodological background of the entire research established and linking each variable to theories and objectives of the study

## 2.2 Literature Review on Expansive Soils

Soil with clay content larger than 30% is classified as being clay. The term 'clay' refers to a naturally occurring material composed primarily of fine-grained minerals, high plasticity, and susceptible to volume changes in response to variations in moisture content which mean that due to the imbibing of absorbing water in rainy or wet seasons swell and shrink in their volume when water evaporates from them during summer or dry seasons (Sridharan & Prakash, 2016).

Expansive soil is one of the problematic clay soils that face many geotechnical engineers in the field due to changes in volume in relation to changes in water content (Lucian, 2008). Various name has evolved to describe the expansive clayey soil, including gumbo soils, buckshot soils, and black cotton soils (Sridharan & Prakash, 2016). The term cracking soil is also used for these soils as they tend to shrink and crack when devoid of water from them during summer or dry seasons. The alternate swelling and shrinkage of such soils in different seasons result in severe cracking of civil engineering structures. As the lightly loaded structures cannot counteract the swelling pressure caused by expansive soils, they are subjected to severe cracking and causing major problems for foundations, roads, sidewalks, pipelines, excavations, and industrial and agricultural operations. The types of problems that have caused the damage are diagonal cracks above doors and windows, pavement cracking, and heaving of floors (Magdi & Asim , 2017). Expansive soils contain clay minerals and the percentage of clay minerals in expansive soils can illustrate the potential of expansion (Lucian, 2008).

## 2.3 Formation of Expansive Soils

The constituents of the parent material during the early and intermediate stages of the weathering process determine the types of clay formed. The nature of the parent material is much more important during these stages than after intense weathering for a long period of time (Kassahun, 2013). Donaldson (1969) classified the parent materials that give rise to expansive soil are classified into two groups. The first group comprises the basic igneous rocks and the second group comprises sedimentary rocks that contain montmorillonite as a constituent, which breaks down physically to form expansive soil. The basic igneous rock group is low in silica and rich in a metallic base such as pyroxenes, amphiboles, biotitic, and olivine. Such rocks include the gabbro's, basalts, and volcanic glass. The sedimentary rock group includes shales and claystone, limestone and marls rich in magnesium (Teklu, 2003).

## 2.4 Clay Mineralogy and Their Characteristics

The mineralogy of soil particles is a major contributor in determining the shape and size of the particles, as well as the engineering properties of the soil. Clay minerals are very tiny crystalline substances evolved primarily from the chemical weathering of certain rock-forming minerals. Chemically they are a group of hydrous aluminum phyllosilicates or layer silicates plus other metallic ions. The nature and characteristics of minerals present in soil markedly affect the engineering properties of fine-grained soils. Due to this clay mineralogy is the fundamental factor controlling expansive soil behavior (Nelson & Miller, 1992). The three main groups of clay minerals are kaolinite, montmorillonite, and illite.

Kaolinite consists of repeating layers of one silica sheet and one alumina sheet. Because of the stacking of one layer of each of the two basic sheets, kaolinite is called a 1:1 clay mineral (Figure 2-1)**.** This basic layer is held together by hydrogen bonds since it is a very strong bond, it prevents hydration and expansion. They have low swelling and shrinkage responses to water content variation (Holtz R. , 1981)

Illite mineral is consists of a series of single octahedral sheets of aluminum sandwiched between two tetrahedral sheets of silicon due to this illite has a 2:1 clay mineral (Figure 2-1). That has the interlayers bonded together with a potassium atom. Illite tends to absorb more water than kaolinites and have higher swelling and shrinkage characteristics (Holtz R. , 1981).

Montmorillonite is another clay mineral and composed of two silica sheets and one alumina sheet and it is called a 2:1 clay mineral (Figure 2-1). Because of the bonding by van der Waal's forces between the tops of silica sheets is the week and there is a net negative charge deficiency in the octahedral sheet and exchangeable ions can enter and separate the layers. Thus montmorillonite crystals can be very small, but at the same time, they have a very strong attraction for water. Soils containing montmorillonite are very susceptible to swelling as they increase water content, and the swelling pressures developed can easily damage light structures and highway pavements (Holtz R. , 1981).

The structure diagrams of the above clay minerals are shown in Figure 2-1 below.

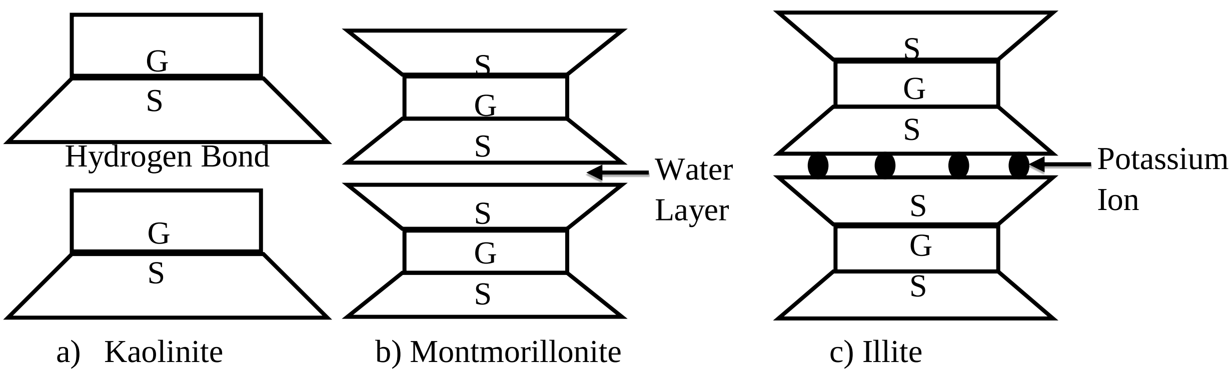



Figure 2-1 Idealized illustration of clay minerals redrawn from Mitchell and Soga (2005)

Clay soil containing montmorillonite is susceptible to swelling, with important engineering implications (Lancellotta, 1995).

## 2.5 Recognition of Expansive Soils

The first step in any geotechnical engineering project is identifying and describe the subsoil condition and it is important for the selection of appropriate sampling, testing, design, and methods of construction. The geotechnical methods of expansive soil identification can be broadly divided into filed and laboratory identification methods. Field techniques are usually based upon visual recognition whereas laboratory techniques include several specialized testes (Lancellotta, 1995). The main objective of this topic is to discuss different ways that are commonly used to identify expansive soils.

### 2.5.1 Field identification

The objective of the site visit should be to gain enough information about the history of the site. In addition to this, experienced geotechnical engineers are visually identifying potentially expansive soils. Some of the important method that indicates the potential for the expansiveness of a soil is the following: -

- They have mostly the color of black and gray,
- The appearance of cracking in nearby structures,
- A pattern of polygonal desiccation, or “shrinkage cracks” in the dry season and close down in the rainy season,
- Shiny appearance on cut surfaces,
- The wet samples of the soil are soft, cohesive, sticky and it will be relatively difficult to clean the soil from the hands,
- high dry strength and low wet strength (Lancellotta, 1995).

### 2.5.2 Laboratory identification

Some laboratory tests are available for the identification purposes of swelling soils. Identification of troublesome soil in the laboratory can be broadly classified into two categories namely, mineralogical identification and inferential testing methods (indirect and direct methods) (Sridharan & Prakash, 2016).

#### 2.5.2.1 Mineralogical identification methods

Chen (1975) opined that mineralogical identification can be useful in the evaluation of the material but is not sufficient in itself, which is for better and reliable results it should be used in combination. The fundamental factor controlling expansive soil behavior are clay mineralogy and it can be identified using a variety of techniques. The techniques that can be used are X-ray diffraction, chemical analysis, dye adsorption, differential thermal analysis, and Scanning electron microscopy.

The various methods of mineralogical identification are important in a research laboratory to explore the basic properties of clay, but it is not suitable for routine tests because it is time-consuming, requires expansive test equipment and, the results are interpreted by specially trained technicians (Al-Rawas & Mattheus, 2006).

#### 2.5.2.2 Indirect methods

These methods evaluate the swelling potential of expansive soils by using simple soil property tests. Such tests are easy to perform and should be included as routine tests in the investigation of expansive soil. These methods include the index property, potential volume change, and activity methods which are valuable tools in evaluating the swelling property (Chen, 1975).

Some of the various tests under these methods are: -

A. **Atterberg Limits**

Atterberg limits are water contents at boundaries that show characteristic engineering behaviors and it can yield significant information about the behavior of soils. Identification of expansive soil using Atterberg limits are the most popular and provide a wide acceptable means of rating. Expansive soils are strongly influenced by the variation of water content. Many classification schemes are available in the geotechnical engineering literature to recognize the soil expansivity based on the Atterberg limit of fine-grained soils (Lancellotta, 1995).

#### 2.5.2.3 Direct methods

This method is the most satisfactory and committed method of determining the swelling pressure and swelling potential of expansive soil and also provides the most valuable data by direct measurement and tests are simple to perform. Direct measurement of expansive soil can be made using a standard one – dimensional consolidometer (Kamil, 2011).

## 2.6 Distribution of Expansive Soils

Expansive soils are found in various parts of the world, especially in the semi-arid region of the tropical and temperate zones (Johnson, 1969) and cause damages for engineering structures because of swelling in the wet season and shrink in the dry season (Mishra, Dhawan, & Rao, 2008). Donaldson (1969) mentions that expansive soil found, some of them are Argentina, Australia, Burma, Canada, Cuba, Ethiopia, Ghana, India, Israel, Iran, Mexico, Morocco, Zimbabwe, South Africa, Spain, Turkey, U.S.A., Venezuela (Tefera & Leykun, 1999). In eastern Africa, expansive soils have been developed from the basaltic rocks of the Ethiopia plateau and they also occur extensively as alluvial deposits in southern Sudan ( (Taddesse, 1989). Many parts of Ethiopia are covered with expansive soils (Alene, 2010).

According to Fogera Woreda Office of Agriculture and Minister of water resource, the dominant soil type in Fogera plain is black clay soil (Vertisols) and extends in a very deep depth, heavy clay texture and high cation exchange capacity (IPMS, 2005; FDREMWR, 2009).

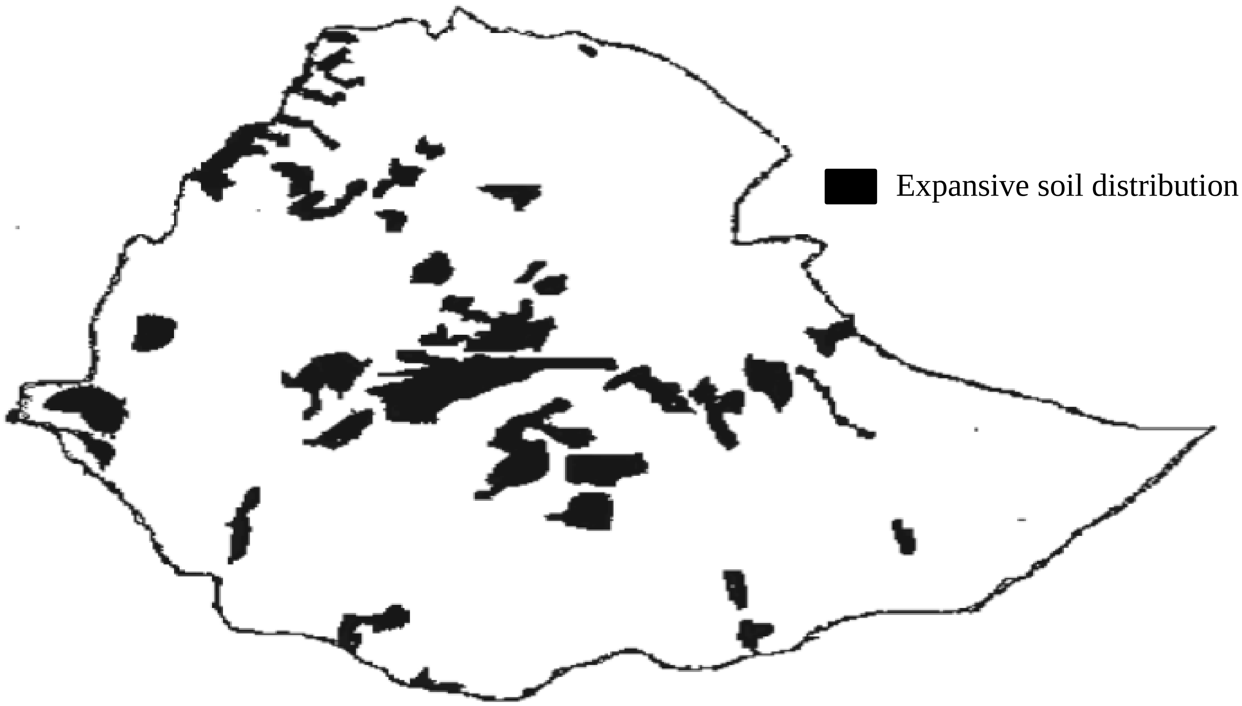



Figure 2-2 Distribution of expansive soil in Ethiopia (Tsegaw, 2003; Nigussie, 2011)

## 2.7 Classification of Expansive Soils

The purpose of an identification and classification system for expansive soils is to qualitatively characterize the potential swelling behavior and to forewarn the engineer in the planning stage about the problems associated with these soils (Elarabi, 2004). It is difficult to find a characterization and classification of expansive soils in national codes of practice; despite the fact, the expansive soils are widely distributed over almost all the geographical locations in the world. The parameters determined for the identification of expansive soil have been combined in different classification schemes. The classification system used is based on an indirect and direct prediction of swell potential as well as combinations to arrive at a final decision (Chen, 1975).

The relationship between the liquid limit and plasticity index (plasticity chart) plays a very significant role in classifying fine-grained engineering soils. Chen (1988) introduced a single index method for identifying expansive soils using only the plasticity index.

| Swelling Potential | Plasticity Index (%) |
|---|---|
| Low | 0-15 |
| Medium | 15-35 |
| High | 35-55 |
| Very High | 55 and above |

Table 2-1 Classification of expansive soil based on plasticity index (Chen, 1988)

According to their activities of soil also classified clays which are developed by Skempton (1953) by combing Atterberg limits and clay content (percent by weight finer than 2μ m) into a single parameter called activity. Skempton classified clays into three classes according to their activities as indicated in Table 2-2 blows.

Activity is defined as: Activity=$\frac{PI}{\text{Percent of clay} < 0.002\text{mm}}$

| Degree of activity | Activity |
|---|---|
| Low | <0.7 |
| Normal clay | 0.75-1.25 |
| Active Clay | >1.25 |

Table 2-2 Classification of expansive soil based on Skempton method

The free swell ratio is also one of the most commonly used simple tests to estimate the swelling potential of expansive clay. Sridharan & Prakash (2016) proposed a classification of expansive soils based on the free swell ratio, defined as the ratio of sediment volume of soil in distilled water to that in kerosene. Free swell ratio, in addition to predicting the degree of soil expansivity more realistically, giving information about identifying the dominant clay mineralogy of the soil (Table 2-3).

| FSR | Clay Type | Soil Expansivity | Dominant Clay Mineral type |
|---|---|---|---|
| 1 | Non-swelling | Negligible | Kaolinitic |
| 1.0 - 1.5 | Mixture of swelling and non-swelling | Low | Mixture of Kaolinitic and Montmorillonitic |
| 1.5 – 2.0 | Swelling | Moderate | Montmorillonitic |
| 2.0 – 4.0 | Swelling | High | Montmorillonitic |
| >4 | Swelling | Very High | Montmorillonitic |

Table 2-3 Classification of soils based on FSR (Sridharan & Prakash, 2016)

Generally, there are several classification methods of soils for engineering purposes, but the Unified Soil Classification System (USCS) and the method of the American Association of State Highway and Transportation (AASHTO) have substantial acceptance. Since the USCS and AASHTO systems are widely used, they are used to classify soils of the study area. Soils rated CM or CH by the USCS, and A-6 or A-7 by AASHTO can be considered potentially expansive soil (Nelson & Miller, 1992).

## 2.8 Problem Associated with Expansive Soil

Expansive soils raise challenges to civil engineers in general and geotechnical engineers in particular (Chen, 1975). They cause more damage to infrastructure founded on them, especially light buildings and pavements, than other natural disasters, including earthquakes and flooding, because of their potential to react to changes in moisture regime (Jones & Holtz, 1973). In the world-wide, these problems are known and reported in many places especially in the arid and semi-arid regions (Elarabi, 2004). Geotechnical engineers did not recognize damages associated with buildings found on expansive soils until the late 1930s. The U.S. Bureau of reclamation made the first recorded observation about soil heaving in 1938 (Chen, 1975). Since several researchers have conducted researches into expansive soils.

## 2.9 Literature Review on Soil Stabilization

Soils are the most widely used materials in civil engineering works. However, due to higher compressibility and poor bearing capacity the available soil at various locations may not be suitable for the requirements of particular construction and create significant problems for the pavements or structures when constructed on it. In these cases, contractors have four options:

(1) Find a new construction site
(2) Redesign the structure so it can be constructed on the poor soil
(3) Remove the poor soil and replace it with good soil
(4) Improve the engineering properties of the site soils

Options 1 and 2 tend to be impractical today, while in the past, option 3 has been the most commonly used method. However, this may cause several environmental and economic concerns specifically with regards to its transportation and disposal. In order to prevent this possible scenario, an alternative solution is through option 4 which is being used more often today and expected to dramatically increase in the future (Kalidas, 2014) and it is an attractive alternative to prevent the failure of geotechnical structures (Behak, 2017). Soil stabilization is a very old practice in use (Gupta, 2016) and it involves the use of stabilizing agents (binder materials) in weak soils to enhance its geotechnical properties such as durability, permeability, strength, and compressibility (Makusa, 2012); and make it permanently become suitable for construction and meet engineering design standards (Salahudeen & Akiije, 2014). Generally, the processes of soil stabilization involve analysis of the properties of a given soil, finding a specific economical method for modifying the soil, determining feasibility.

## 2.10 Type of Soil Stabilization

Soil stabilization can be done through a variety of methods (Makusa, 2012). All of these methods fall into two broad groups, namely; mechanical and chemical stabilization (Tefera & Leykun, 1999).

### 2.10.1 Mechanical stabilization

Under this category, soil stabilization can be achieved through the physical process by altering the physical nature of native soil particles by either induced vibration or compaction or by incorporating other physical properties such as barriers and nailing and also this practice does not require a chemical change of the soil (Makusa, 2012). Mechanical stabilization is not the main subject of this research and will not be further discussed.

### 2.10.2 Chemical stabilization

It is the oldest and most common method of soil stabilization to improve its volume stability, durability, permeability, strength, and stress-strain behavior. Under this category, soil stabilization depends mainly on chemical reactions between stabilizers and soil minerals to achieve the desired interests of engineers (Makusa, 2012). Chemical reactions such as hydration, ion exchange, pozzolanic reaction, flocculation, precipitation, polymerization, oxidation, and carbonation, occur between the soil and additives (Hans & Sibel, 1991).

Portland cement, lime, asphalt, calcium chloride, sodium chloride, and paper mill wastes are common chemical stabilization agents. The effectiveness of the additives depends on the soil conditions, stabilizer properties, and type of construction (i.e., houses, roads, etc.), and also the selection of a particular additive depends on costs, benefits, availability, and practicality of its application (Yesilbas, 2004). RHA may be used as a chemical stabilizer as it contains high silica content.

Strength gain is primarily due to the chemical reactions that occur between the stabilizer and soil particles. These chemical reactions occur in two phases, with both immediate and long-term benefits. The first phase of the chemical reaction involves immediate changes in soil texture and soil properties caused by cation exchange. According to Geiman (2005), practically all fine-grained soils undergo this rapid cation exchange and flocculation/agglomeration reactions when treated with calcium contain stabilizer in the presence of water. The second phase of the chemical reaction involves pozzolanic reactions within the stabilizer-soil mixture, resulting in strength gain over time.

Pozzolan means a broad class of silica and aluminous-based materials which in themselves, possess little or no cementitious value but finely disperse, and react with calcium hydroxide when coming in contact with water at normal temperature to form compounds possessing cementitious properties. The capacity of a pozzolan to react with calcium hydroxide and water is given by measuring its pozzolanic activity (Patrick, 2016).

## 2.11 Agro-industrial Waste and Its Engineering Application

There has been an increase in the generation of solid waste from agricultural, industrial, and domestic sources due to the rising population, urbanization, and living standards. These agro-industrial waste products include fly ash, carpet plastic waste, rubber tires, rice husk ash, textiles, silica fume, blast furnace slag, bagasse ash, and so on. In the field of geotechnical engineering, and construction materials recent research focuses on agro-industrial wastes being locally available and has disposal problems (Anupam, Kumar, & Ransinchung, 2013). Recycling of these wastes in concrete production (Shafigh, 2014) and soil stabilization might potentially reduce construction costs and enhance environmental sustainability (Sanewu, 2013).

### 2.11.1 Utilization of agricultural waste in soil stabilization

Several experiments and review studies are already documented by different authors in the worldwide in order to improve the properties of expansive soil using agricultural and industrial waste as a soil stabilizer. Some of them are pointed out here.

Madurwar (2013) reviews the application of various agro-waste for sustainable construction materials and come of agro-wastes have the potential to develop energy-efficient and cost-effective sustainable construction materials. From the various literature, it indicates that construction products produced from various agro-waste materials are relatively cheaper, durable, lightweight, and environmentally friendly than the conventional one.

Hasan (2016) studied the improvement of expansive soils using agricultural waste bagasse ash by the addition of lime on soil obtained from a road subgrade construction site in Queensland, Australia. The soil was classified as high plasticity clay (CH). On selected expansive soil samples with different lime-bagasse ash ratios the author conduct UCS and CBR tests. Compaction characteristics and index properties were also determined using the Atterberg limit test, moisture-density relations, and free swell tests. The conclusions and findings drawn from the study are with the increase of bagasse ash-lime content, the dry density slightly decreased and due to the non-plastic properties of bagasse ash its swelling decreases, also the UCS, CBR change with various curing time and additive contents, at 25% bagasse ash-lime content increased the unconfined compressive strength by 80%.

Anupam (2013) analyzed the performance of various agricultural and industrial waste materials in road construction are studied through laboratory investigation. The soil admixed with fly Ash, bottom ash, rice husk ash, and rice straw ash samples were cured up to 28 days before testing. Various tests, such as UCS, shrinkage limit, CBR, and triaxial test were carried out and the following conclusions have been drawn: -

- Admixing of FA, BA, RHA, and RSA resulted in higher optimum moisture content and a reduced dry density as the dosages of stabilizers increased and was more pronounced for RHA mixed soil than of other stabilizers.
- Marked improvements in shrinkage limits have been noted for soils mixed with FA, BA, RHA, and RSA. This change was more pronounced with 30 percent RHA blending.
- Mixing of FA, BA, and RHA up to 25 percent and RSA up to 20 percent improved the CBR values of clay soil at all curing days. The CBR value of soil blended with 20 percent RSA was much higher than that of 25 percent FA, 25 percent BA, and 25 percent RHA admixing.
- Based on his study, all stabilizers viz. FA, BA, RHA, and RSA after 28 days of cure, reach their optimum strength. It is proposed that these can be used as an efficient soil stabilizer abundance.

### 2.11.2 Rice husk ash and its characteristics

Rice husk is an abundantly available and renewable agricultural waste product, generated from the accumulation of the outer covering of rice grains during the milling process and the previous research data suggests that 70 million tons of rice husk is generated per annum worldwide (Dwivedi, 2019) and it’s not suitable as animal feed because of its abrasive character and poor nutritive value (Boateng & Skeete, 1990). Its dumping pose serious environmental threats to the surrounding (Dwivedi, 2019) and it generates pollution, which has caused health problems to the inhabitants. RHA is a fine residue collected from the incineration of rice husk after the milling process. A rice mill turns the paddy plant into 78% rice and 22% rice husk, and when it is burnt, produces about 15-20% weight of ash (Behak, 2017). RHA is a non-cohesive material having a low specific gravity and contains about 86% - 98% silica amount of siliceous ash which is highly chemically reactive (Dwivedi, 2019). Since it behaves as a pozzolanic material, thus it can be used for the stabilization of expansive soil in road subgrade. Several studies have recognized RHA as an effective pozzolan (Sarkar, Alamgir, & Rokonuzzaman, 2012). The maximum percentage of siliceous material contained in rice husk ash showed that it has pozzolanic properties (Sherwood, 1993) similar to bagasse ash and hydrated lime.

### 2.11.3 Availability of rice husk ash in Ethiopia

To assess the potential of rice husk ash production in Ethiopia, it is imperative to evaluate the rice crop yield in the country. The production of rice in Ethiopia is a recent phenomenon, beginning at Fogera (Woreta) and Gambella Plains in the early 1970s, which is followed by its use as a food crop (Belayneh, 2017). But the area of rice production in the country has been increasing over the past few years. It is reported that the potential rice production area in Ethiopia is estimated to be about thirty million hectares (MoARD, 2010). Alemu (2015) studied the predominant rice-growing potential areas of the country. The conclusions drawn from his study are rice could suitably grow in: -

- West central highlands of Amhara region (Fogera, Gonder Zuria, Dembia, Takusa, and Achefer);
- North west lowland areas of Amhara and Benshangul regions (Jawi, Pawi, Metema, and Dangur);
- Gameblla regional state (Abobo and Etang Woredas)
- South and southwest lowlands of SNNPR (Beralee, Weyito, Omorate, Gura Ferda, and Menit);
- Somali region (Gode);
- South-western highlands of Oromia region (Illuababora, East and West Wellega, and Jimma zones)

Out of the total national rice production in 2008, 40 percent is produced in the Amhara regional state, 1.14 percent in the Tigray region, 0.41 percent in Benshangul-Gumz, 7.23 percent in Oromia, 1.55 percent in Gambella, 13.33 percent in Somalia, and 27.18 percent in Southern region (NRRDSE, 2009). According to MoA national rice development strategy (2020) the total area under rice production has increased from 10,000 ha in 2008 to over 63,000 ha in 2019, and also production has increased from 71,316 tons in 2008 to over 171,000 tons in 2019. This indicates that rice production in the country is boosting at a high rate and also the major production area is in Amhara regional state. This increment results high amount of rice husk ash.

### 2.11.4 Utilization of rice husk ash in engineering works

Omondi (2013) studied the cementitious properties of a mixture of RHA with building lime. They concluded that RHA greatly improves the compressive strength and consistency reduces. On the other side, the cost of concrete containing rice husks was found to be less than half the cost of an equivalent grade of concrete made using PPC cement. Also, Hough and bar ( (1956) reported the use of rice husk ash in the manufacture of building blocks as early as 1923. A large house had been constructed from these blocks and was reported to be in excellent condition thirty years later.

Dwivedi (2019) studied the development of hybrid metal matrix composite using the electromagnetic stir casting technique. RHA was used as primary reinforcement material, while B4C (boron carbide) was used as secondary reinforcement material. They concluded that tensile strength and hardness were enhanced significantly also environmental pollution can be reduced by using rice husk ash as reinforcement material in the development of green composite material.

Norsyahariati, Nazrin, and Abubakar (2017) made a study on the potential use of rice husk ash as partial cement replacement and throughout the testing scheme, the properties of original and mixed peat soil have been recognized, discussed, and analyzed. Compaction, Atterberg 's limit, CBR, UCS tests were carried out on soil samples and soil with stabilizers. The compaction parameters (MDD and OMC), cohesion value, and degree of internal friction angle of peat soil is found to be increased with an increment of rice husk ash. The optimum percentage of RHA in order to improve the properties of peat soil is 12% of RHA by weight.

Sharma (2008) conducted a series of laboratory tests to evaluate the influence of rice husk ash to treat expansive soil with various additive contents after 28 days of curing. They reported that the unconfined compressive strength increased with increasing lime content for given RHA contents. They noted that the presence of high silica content in RHA increases pozzolanic reaction and the resistance to the applied compressive load of the RHA-soil admixture.

Isah (2015 ), tends to evaluate the effect of rice husk ash on soft clay soil and it was found that on the addition of RHA the compaction characteristics of soft clay soil are improved and the optimum moisture content increases with an increase in the percentage of RHA. While Maximum dry density decreases with an increase in percentage addition of RHA. The study also shows that there is a slight improvement in CBR value with a percentage increase up to 10%. Other parameters found to be improved are the consistency limit as well as the ultimate bearing capacity of the clay soil with rice husk ash mixture. Therefore, RHA was found to be suitable as a stabilizing agent for soft soil improvement.

## 2.12 Research Gap

In this chapter, a comprehensive literature review on the behavior and modification techniques of expansive soils as well as the engineering properties of expansive soils treated with agricultural wastes was carried out and presented.

Little data is available on stabilization of Ethiopian expansive soils using different additives. However, no work has so far been carried out with regards to the stabilization of Woreta expansive soils using rice husk ash and its effect on the geotechnical properties of this soil. Therefore, the possible use of rice husk ash for stabilizing these soils has been explored in this study. Before recommending the use of rice husk ash for improving the properties of expansive soil, its effect on the basic engineering properties needs to be investigated thoroughly.

# Chapter 3 METHODOLOGY

## 3.1 Introduction

This chapter describes about sample preparation, laboratory tests, and the procedure adopted in this research. It can be noted that the testing setups and apparatus are described in detail for interpretation. Most of the laboratory tests employed for this investigation were conducted at Debre Tabor University (DTU), Addis Ababa University (AAiT), and ARCON design-build plc. soil laboratories.

## 3.2 Study Area

The study was conducted in Woreta town and it is located in the South Gondar zone of the Amhara region east of Lake Tana about 625 kilometers from Addis Ababa. Woreta road provides the primary access to rib irrigation projects (FDREMWR, 2009). This town has a latitude and longitude of 110 55' N 370 42'E with an average elevation of 1,828 meters above sea level. It is the administrative center of Fogera woreda and irrigation area of rib (FDREMWR, 2009). This town is one of the fastest-growing towns in the Amhara region starting from the selection to dry port and in one of the investment areas. In the rice production of Ethiopia, a relatively great percentage of the production are produced in this area due to this the first rice research institution is established in October 2018 in this town with a mission of applying china production methods of rice to produce a great number of tons of paddy per hectares and ordering the country within the most rice-producing country of the world in the future few years. Therefore, rice husk ash is the most locally available agricultural waste material.


Figure 3-1 Location map of the study area and sampling point

## 3.3 Materials

### 3.3.1 Expansive soil

The soil used in this study is grayish-black in color highly plastic clay soil which is collected from a site in the Amhara region Fogera Woreda Wereta city. The soil was collected by the method of disturbed sampling after removing the topsoil at 1.5m depth and transported in sacks to the laboratory. A little amount of the sample was sealed in a polythene bag for determining its natural moisture content. The collected soil sample was air-dried and pulverized into particles passing BS No. 4 sieve (4.75 mm aperture) before laboratory tests were conducted. The properties of the soil are addressed in the results section in Table 4-1.

### 3.3.2 Rice husk ash

The rice husk ash used in this study was prepared by collecting rice husk residue from the mill-house waste dump site in Wereta city. The Rice Husk was placed on a galvanized sheet and openly burnt. The burnt ash was heaped and left to cool for 24 hours, which is sufficient to turn most of the burnt ash into white ash (amorphous material) and then sieve this ash with 0.15mm aperture sieve to remove the dust particle. Also the chemical composition of RHA was tested in the Geological Survey of Ethiopia

## 3.4 Experimental Methodology

### 3.4.1 Methods of testing

The laboratory tests carried out first were on the natural soil which includes Atterberg limits, particle size distribution, CBR, compaction, and UCS for native soil in accordance with ASTM and AASHTO Standard. Specimen for UCS and CBR tests are prepared at the optimum moisture contents and maximum dry densities. In the second phase of the study, different percentages of RHA (5%, 10%, 15%, and 20%) are mixed with soil, and tests are carried out on uncured and seven days cured samples to observe the changes in the properties of soil such as specific gravity, free swell, maximum dry density, optimum moisture content, unconfined compressive strength, and CBR value of soil.

### 3.4.2 Sieve analysis

The purpose of sieve analysis is to determine the percentage of various grain sizes. The grain size distribution is used to determine the textural classification of soils (i.e., gravel, sand, silty clay, etc.) which in turn is useful in evaluating the engineering characteristics such as swelling potential, strength, permeability, and susceptibility to frost action (FDOT, 2000). For the determination of coarser and finer particles sieve and hydrometer analysis are conducted (ASTM D 422-98; ASTM D 1140-98).

### 3.4.3 Specific gravity

Specific gravity is the measure of the heaviness of the soil particles and it can be determined by using the density bottle method by changing the percentages of RHA (ASTM D 854-98). It is the ratio of the weight in air of a given volume of a material at a normal temperature to the weight in air of the same volume of distilled water at the same stated temperature. The specific gravity is used to find out the degree of saturation and unit weight of moist soil. Ultimately the unit weight of soil is used to determine pressure, settlement, and stability problem (FDOT, 2000).


Figure 3-2 Specific gravity test

### 3.4.4 Free swell

According to Holtz and Gibbs (1956), 10 $cm^3$ ($V_i$) of dry soil passing through a no. 40 sieve is poured into a 100 cm3 graduated cylinder filled with water. The volume of settled soil is measured after 24 hours which gives the value of $V_f$. The free swell value increases with the plasticity index. The authors proposed that soils with a free-swell value as low as 100 percent can cause damage to lightly loaded structures and soils with a free swell value below 50 percent seldom experience major volume change even under light loadings.

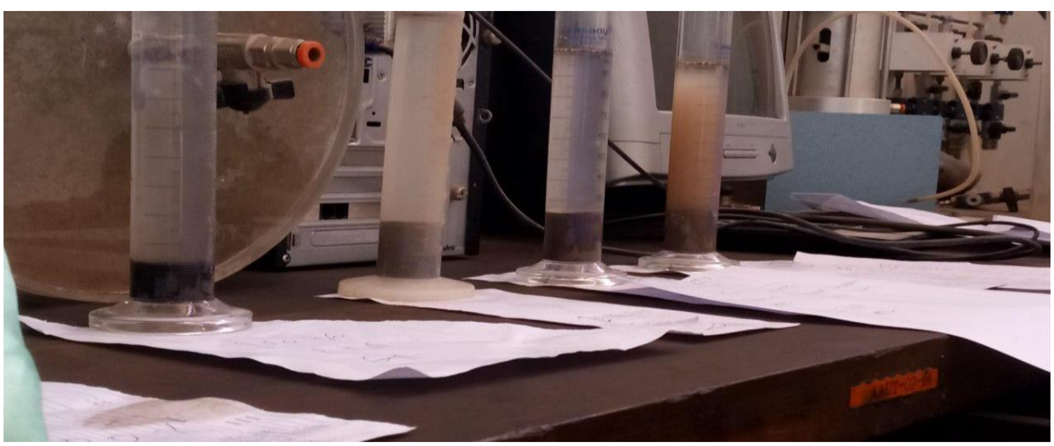


Figure 3-3 Free swell tests

### 3.4.5 Atterberg limit

As moisture contents increase, clay and silt soils go through four distinct states of consistency: solid, semi-solid, plastic, and liquid. Each stage exhibits significant differences in strength, consistency, and behavior. Atterberg limit tests accurately define the boundaries between these states using moisture contents at the points where the physical changes occur. The test values and derived indexes have direct applications in the foundation design of structures and in predicting the behavior of soils infills, embankments, and pavements (Lambe & Whitman, 2000).

The liquid limit of a soil is the moisture content, expressed as a percentage of the mass of the oven-dried soil, at the boundary between the liquid and plastic states of consistency (FDOT, 2000). The moisture content at this boundary is arbitrarily defined as the water content at which two halves of a soil cake will flow together, for a distance of 13 mm along the bottom of a groove of standard dimensions separating the two halves, when the cup of a standard liquid limit apparatus is dropped 25 times from a height of 10 mm at the rate of two drops per second. Plastic Limit is the moisture content, expressed as a percentage of the mass of the oven-dried soil under which the soil can be rolled into threads of 3mm in diameter without crumbling. In this water content soil changes from the plastic state to a semisolid state and soil transitions between brittle and plastic behavior. The liquid and plastic limit tests were conducted on samples passing 0.425 mm (no. 40) sieve; natural soils and soil mixed with (5, 10, 15, and 20%) RHA using Casagrande's apparatus (ASTM D 4318-98).

In this study, the additive content is defined by the ratio of the weight of an RHA to the dry weight of the soil, expressed as a percentage.

Figure 3-4 Atterberg limit tests

### 3.4.6 Shrinkage characteristics

In reviewing the literature on expansive soil, much attention has been focused by various investigators on the shrinkage properties. These tests are performed to determine the limits of a soil's tendency to lose volume during decreases in moisture content. Large changes in soil volume are important considerations for soils that are to be used as fill material for highways and railroads or for soils that are to support structural foundations. Unequal settlements resulting from such volume changes can result in cracks in structures or unevenness in roadbeds. The shrinkage limit and shrinkage ratio are particularly useful in analyzing soils that undergo large volume changes with changes in water content (FDOT, 2000). The shrinkage limit is defined as the smallest water content at which the soil is saturated or the maximum water content at which a reduction in the water content will not cause a decrease in the volume of the soil mass (Mariki, 2000). The shrinkage ratio and linear shrinkage are soil parameters that are often determined in conjunction with the shrinkage limit (Mariki, 2000). Shrinkage ratio indicates how much volume change may occur as a change in water content above the shrinkage limit takes place, and linear shrinkage gives an indication on the amount of axial strain that drying may cause to soil samples (FDOT, 2000). Tests shall be performed in accordance with ASTM D 427.

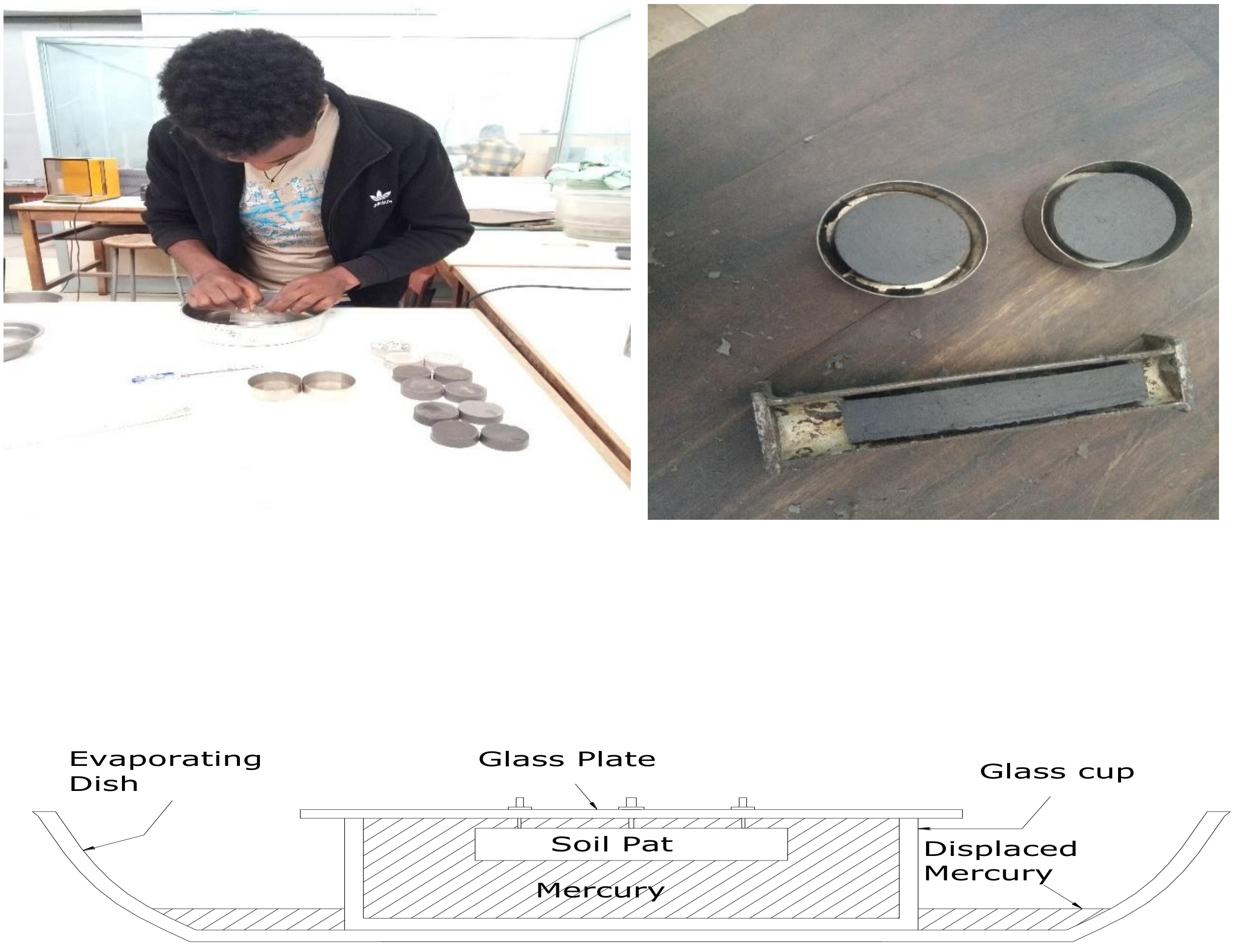



Figure 3-5 shrinkage limit test

### 3.4.7 Moisture content dry density relationship

Compaction tests were applied to the soil, as per ASTM D698-91 with the purpose of finding optimum moisture content in order to maximize its dry density which eventually decreases long-term compressibility, increases shear strength, and sometimes reduces permeability. The expansive soil was stabilized with varying percentages of rice husk ash (0%, 5%, 10%, 15%, and 20%) of its dry weight with and without 4% lime. For this test, stabilized soil was thoroughly mixed with an adequate amount of water and the wet sample was compacted in proctor mold in three equal layers using a standard proctor rammer of 2.5 kg. From the dry density and moisture content relationship, optimum moisture content (OMC) and maximum dry density (MDD) were determined for uncured and seven days cured samples. This was done to study the effect of rice husk ash content on OMC and MDD (Mariki, 2000).


Figure 3-6 Samples preparation for a compaction test

### 3.4.8 Unconfined compressive strength

UCS test is the most common and adaptable method of evaluating the strength of stabilized soil. It is the key test recommended for the determination of the amount of additive necessary to be used in the stabilization of soil (Singh & Singh, 1991). The test is carried out according to ASTM D2166-98a in a cylindrical specimen with dimensions of 38mm diameter 76 mm in length. In this test, the soil goes to failure by axial load only with no confining surrounding stresses (ASTM D 2166-98a).


Figure 3-7 Unconfined compression test

### 3.4.9 California bearing ratio

One of the essential parameters, used in the evaluation of soil subgrades for both rigid and flexible pavement design is the California bearing ratio. It is represented by the force applied by the plunger and the depth of its penetration into the specimen; it is intended to establish the relationship between force and penetration of the natural soil and the soil rice husk ash mixture and this test indirectly measures the shearing resistance of soil under the controlled condition of moisture and density. The CBR test is conducted for the natural and stabilized soil in accordance with ASTM D1883-99. To study the effect of the pozzolanic reaction of rice husk ash and lime on the CBR value of soil tests were conducted for uncured and 7 days cured soil samples. The samples are compacted in three layers with 56 blows from the 2.5kg rammer. One point CBR has been tested after being soaked in water for 96 hr, for each sample. The soaked condition simulates the behavior of subgrade under heavy rainfall or flooded situations. In this research, samples were compacted to an MDD at the OMC determined by standard Proctor tests (ASTM D1883-99).

# Chapter 4 RESULTS AND DISCUSSION

## 4.1 Properties of Material Used

### 4.1.1 Expansive soil

Representative soil samples were collected from two stations are tested in the soil mechanics laboratory of DTU; AAiT and ARCON Consulting Plc. for identification and determination of various properties of treated and untreated soil. The preliminary identification test indicated that the soil on both stations was grayish-black in color and its wet sample is soft, cohesive, sticky, difficult to clean from the hand, this indicates that the soil is highly plastic. The liquid limit of soil from stations one and two is 102.6% and 93.8% respectively. According to Daksanamurthy and Raman (2006) identification of expansive soil, these are the typical value for clay soils of very high swelling potentials. The particle size distribution curve shows that about 99.2 and 96.2 percent of the soil passes through the no. 200 sieve for sample points one and two respectively. Based on this result AASHTO soil classification system puts the soil under the A-7-5 group which is a material of poor engineering property to be used as sub-grade material and also according to USCS the soil is classified as CH clay with high plasticity.

On the other side according to Bowles (1992) soil having 0-7% CBR values are very poor subgrade materials. Hence, the soil was found to be highly plastic expansive clay with low bearing capacity when it is soaked and high swelling potential and fell below the standard recommendations for most geotechnical construction works especially highway construction to use this soil as subgrade material. Therefore, the soil requires initial modification and/or stabilization in order to get increased strength.

| Properties | Soil sample 1 (SP 1) | Soil Sample 2 (SP 2) | RHA |
|---|---|---|---|
| Natural moisture content (%) | 41.9 | 38.5 | 0 |
| Percent passing B.S Sieve # 200 | 99.2 | 96.2 | 70.78 |
| Liquid Limit (%) | 102.6 | 93.8 | Np |
| Plastic Limit (%) | 40.2 | 36.4 | Np |
| Plasticity Index (%) | 62.4 | 57.4 | Np |

| | | | |
|---|---|---|---|
| Group Index | 66.5 | 57.7 | - |
| Activity | 1.48 (Active) | 1.59 (Active) | - |
| AASHTO Classification | A-7-5 | A-7-5 | - |
| USCS | CH | CH | - |
| Maximum Dry Density (Mg/cm$^3$) | 1.23 | | 0.704 |
| Optimum Moisture Content (%) | 35 | | 65.7 |
| Unconfined Compressive Strength (KN/m$^2$) | 130.9 | | Impossible |
| Specific Gravity | 2.68 | 2.6 | 2.04 |
| Free swell (%) | 130 | 110 | 10 |
| Color | Grayish Black | Grayish Black | Gray |

Table 4-1 Geotechnical properties of the natural soil and rice husk ash

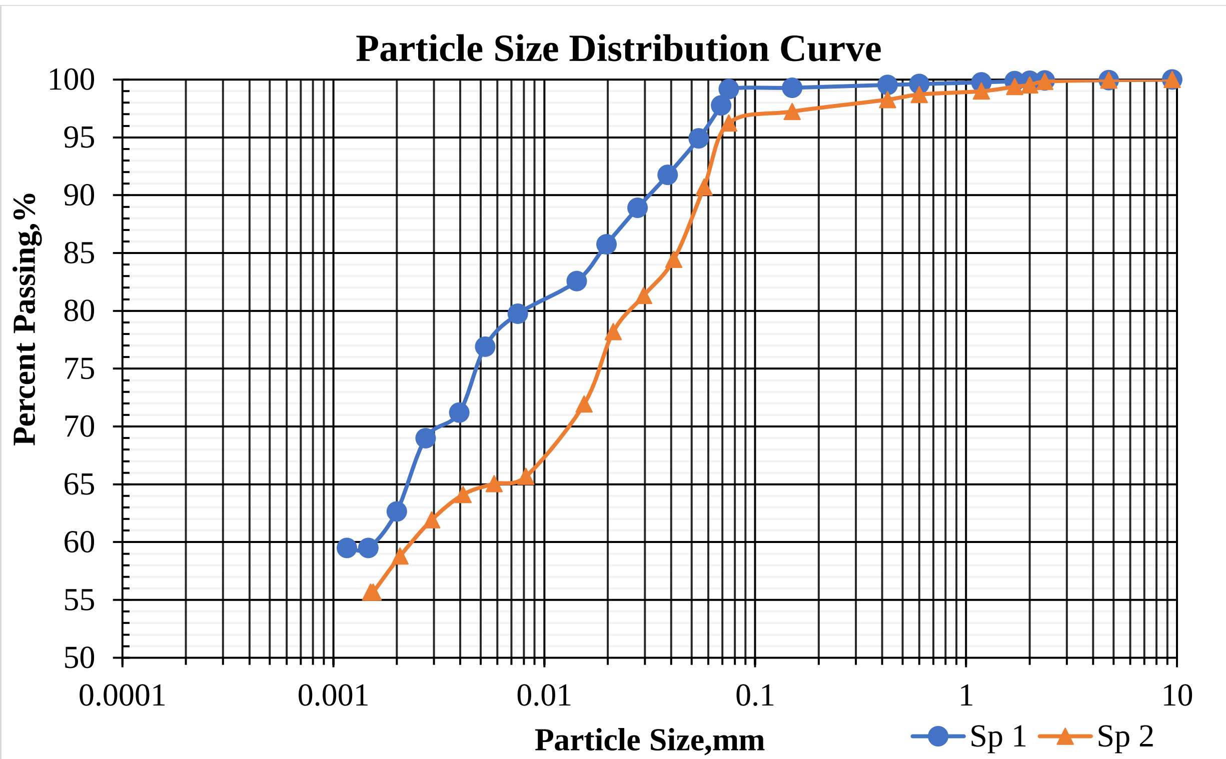



Figure 4-1 Particle size distribution curve of the expansive soil

From the two stations select sample one for taking soils for further works because based on the identification laboratory test result soils in sample one is slightly high expansive, more clay content, and poor engineering properties than soils in sample two.

### 4.1.2 Rice husk ash

The Rice Husk ash used in this study was prepared by collecting rice husk residue from the mill-house waste dump site in Woreta city and burn it to get the ash. It was lightweight, fine grayish ash with a specific gravity of 2.04, and its engineering properties are summarized in Table 4-1 above. Similarly, the chemical composition of RHA was tested in the Geological Survey of Ethiopia and shown in Table 4-2.

| Description | Symbol | Percentage composition (%) | Description | Symbol | Percentage composition (%) |
|---|---|---|---|---|---|
| Silica | $SiO_2$ | 75.5 | Potassium | $K_2O$ | 1.48 |
| Alumina | $Al_2O_3$ | 3.5 | Manganese | MnO | 0.12 |
| Iron | $Fe_2O_3$ | 0.88 | Phosphorus | $P_2O_5$ | 1.12 |
| Calcium | CaO | 2.2 | Titanium | TiO | 0.02 |
| Magnesium | MgO | 0.6 | Loss of ignition | LOI | 10.71 |
| Sodium | $Na_2O$ | <0.01 | Combined | $SiO_2 + Al_2O_3 + Fe_2O_3$ | 79.88 |

Table 4-2 Chemical composition of rice husk ash

The Table reveals that silica ($SiO_2$) is the main component of RHA. The requirement of ASTM C 618 for a combined $SiO_2 + Al_2O_3 + Fe_2O_3$ of more than 70% was satisfied and is generally regarded as a pozzolanic material. Thus, RHA is a suitable material for use as a pozzolan. Liu (2016) concluded that RHA had three-layered structures: inner, outer, and interface with interstitial and honeycombed pores, which were in fact, the major cause for the high chemical activity and large specific surface area of RHA, which meant that RHA had a certain reaction activity.

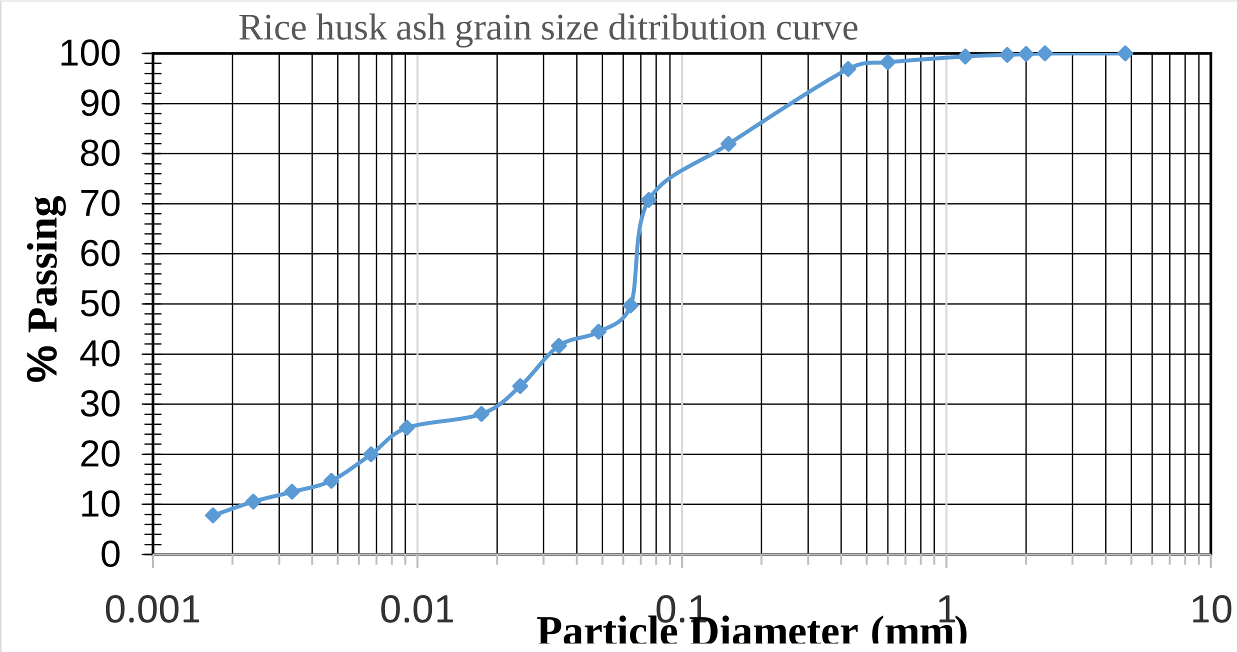


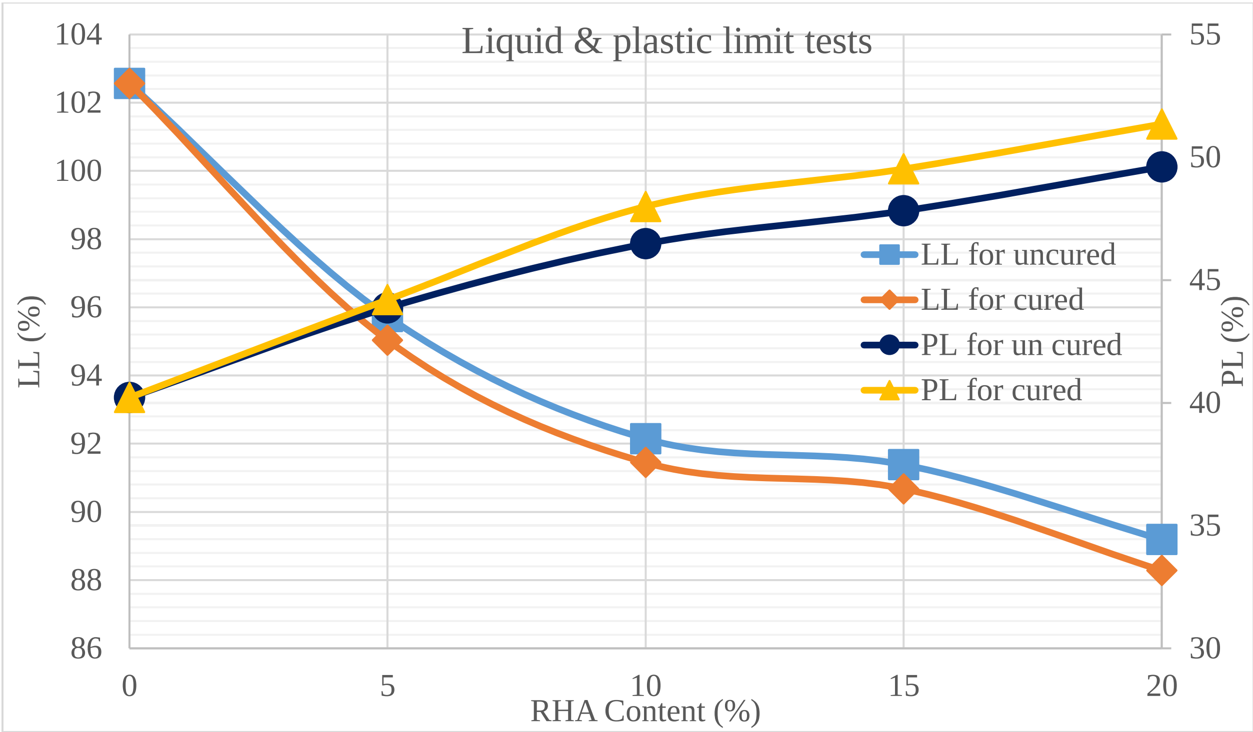

Figure 4-2 Particle size distribution curve of rice husk ash

As indicated in Figure 4-2 above the grain size of rice husk ash was courser than the expansive soil, this make an improvement in different parameters of stabilized soil.

## 4.2 Effects of Rice Husk Ash on the Consistency Limit

The consistency limit test in terms of liquid limit, plastic limit, and the plastic index was performed for natural and stabilized soils with different percentages of rice husk ash. The Influence of rice husk ash on the consistency limit of soils is shown in Figure 4-3 for both uncured and 7 days cured soil samples.

From the test results it is observed that liquid limit and plasticity index values are decreasing with increasing the percentage of RHA but the plastic limit was increase both for immediate and 7 days cured with increasing the percentage of RHA. These results are compatible with the findings of Muntohar & Hantoro (2000). This trend attributed to the replacement of the finer soil particles by the RHA with a consequent reduction in the clay content and also due to the flocculation and agglomeration of stabilized soil particle, which reduced clay's water affinity and surface area of clay particle (Alhassan, 2008) and this reduction was generally indicative of a reduction in the compressibility and swelling characteristics.



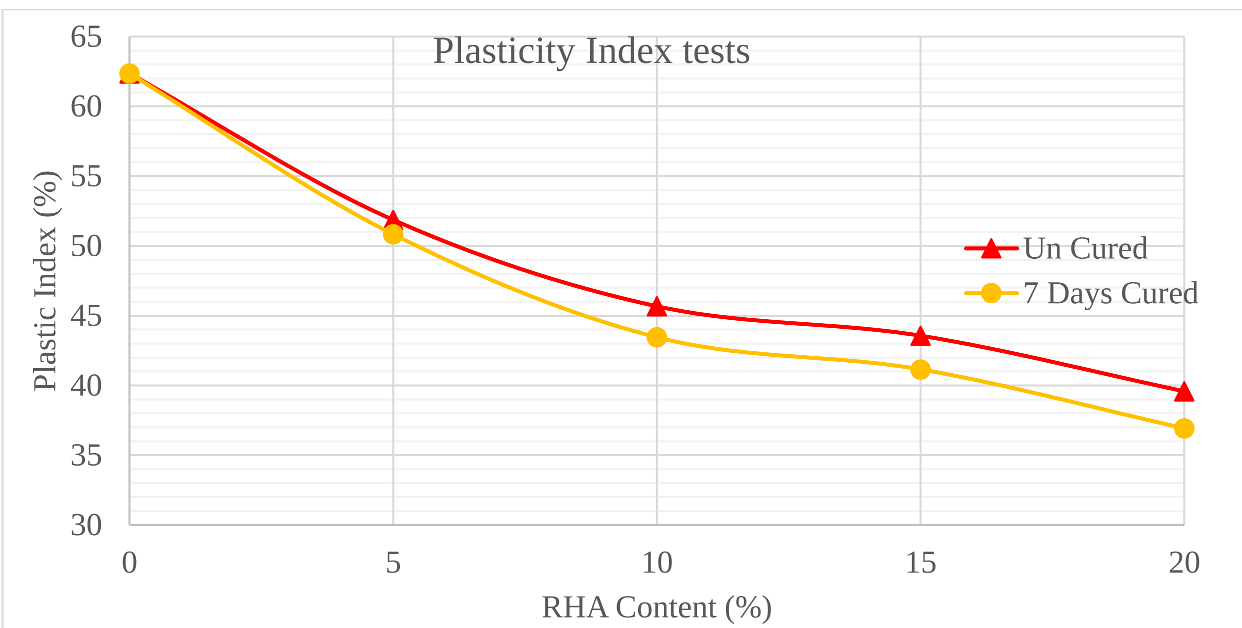




Figure 4-3 Effects of RHA on Atterberg limits

Test results of the plasticity index and liquid limit were plotted on the Casagrande plasticity chart to illustrate the changes in the plasticity of soil, as well as the particle size of soil fines Figure 4-4.

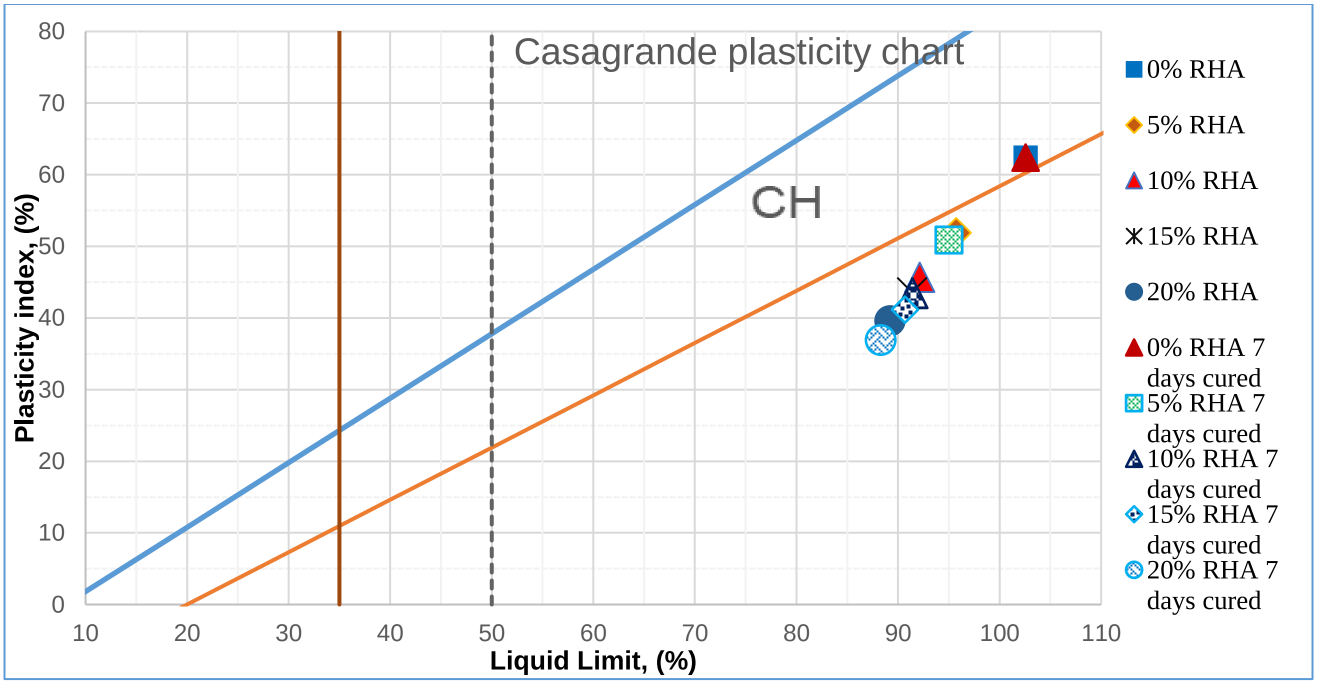
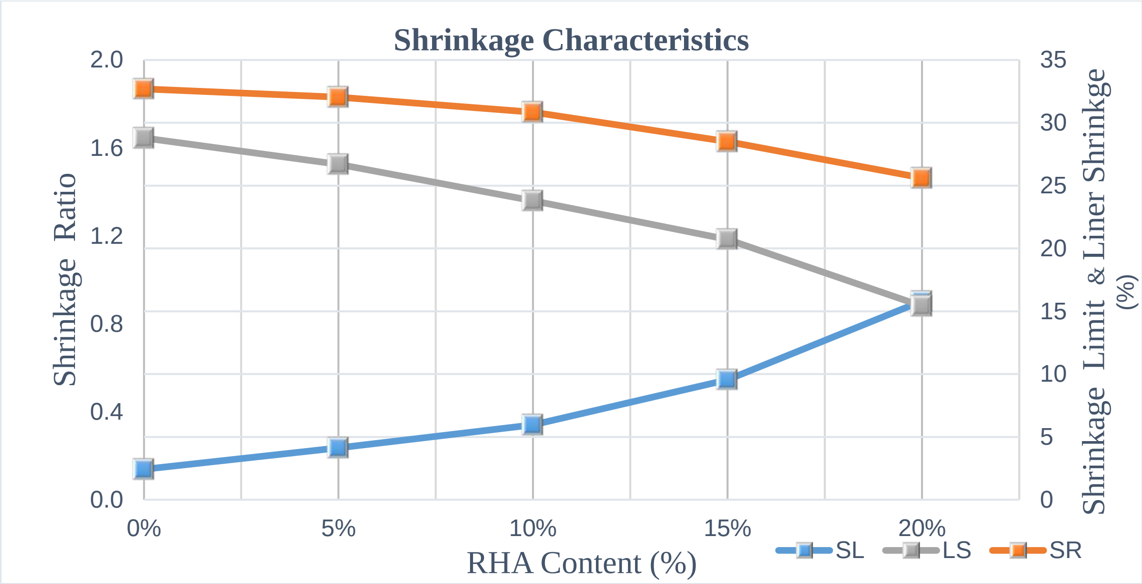



Figure 4-4 Plasticity chart for the RHA treated soils

From the chart, the untreated soil falls well above A-line but the stabilized samples moved below A-line which indicates that the soil class turns slightly toward silt size characteristics. Details of the Atterberg limit test results are shown in Appendix 1.

## 4.3 Effects of Rice Husk Ash on Shrinkage Characteristic

Variations of shrinkage characteristics of the treated expansive soil along with RHA content are presented in Figure 4-5. As shown in the figure below rice husk ash stabilizers showed improvements in reducing shrinkage characteristics of the treated expansive soil. The replacement of finer clay particles by relatively stronger and coarser particles could be the key factors resulting in considerable improvements in reducing shrinkage characteristics with the increase in the additive content. Therefore, this stabilizer provides positive impacts on the engineering characteristics of expansive soil in terms of shrinkage and cracking.



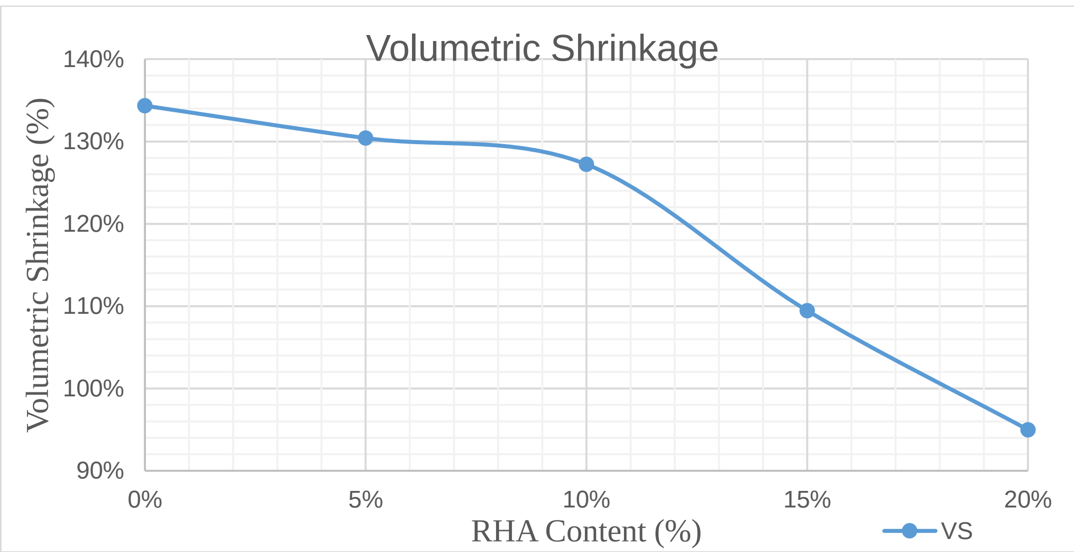




Figure 4-5 Shrinkage characteristics of RHA treated soils

## 4.4 Effects of Rice Husk Ash on Swelling Characteristics

### 4.4.1 Free swell

The effect of RHA on the free swell of Woreta expansive soil resulted in the laboratory test is shown in Figure 4-6. It can be observed from the figure; the free swell value of untreated soil reduces from 130% to 35% in 20% RHA stabilization due to the reduction of clay content and the pozzolanic reaction of the soil and RHA to form a cementitious material. The detailed result is shown in Appendix 3.

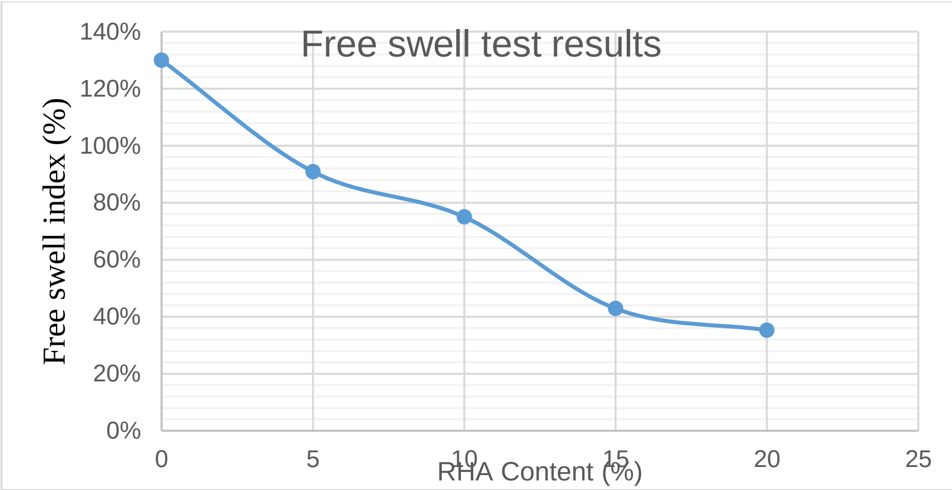



Figure 4-6 Changes in the free swell with varying percentage of rice husk ash

### 4.4.2 Free swell ratio

Figure 4-7 shows the relationships between free swell ratio and rice husk ash content for Woreta expansive soil. It indicates that the higher the rice husk ash content, the lower the free swell ratio which means that the free swell ratio of natural soil (2.3%) decreased to 1.35% for 20% RHA stabilization. As indicated in section 2.7 Sridharan & Prakash (2016) classification of expansive soil based on the free swell ratio, the soil changes from highly expansive to low expansive.

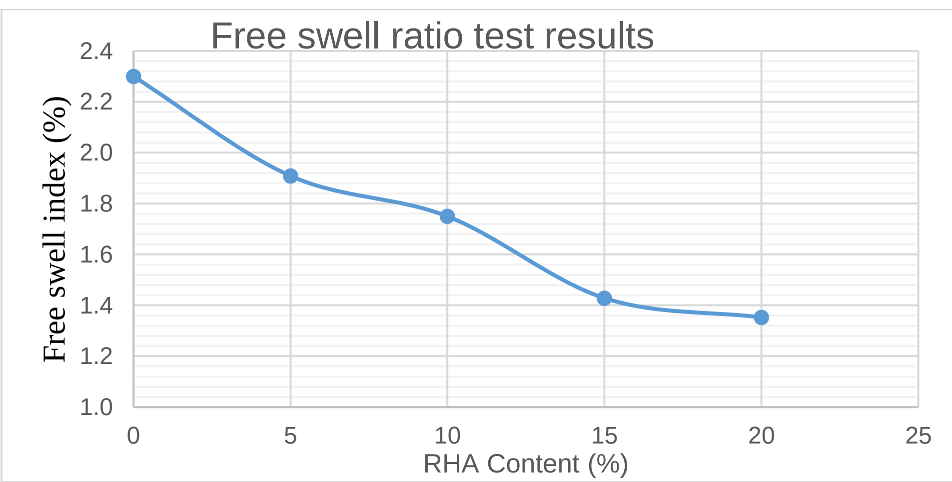
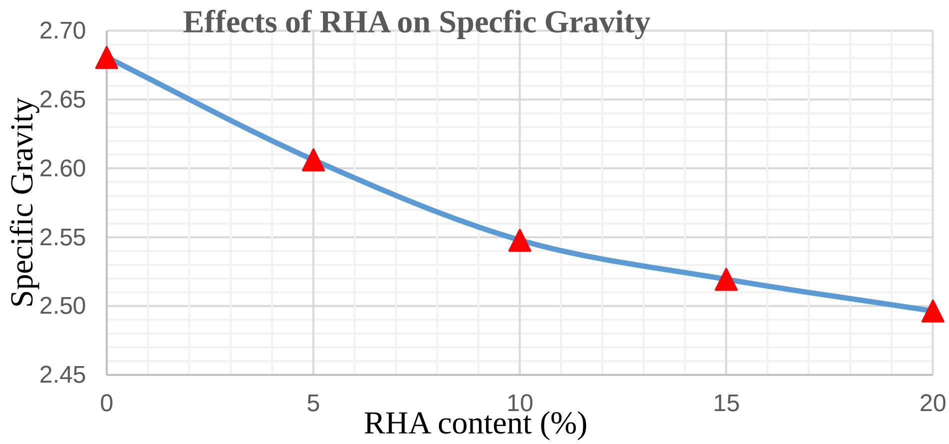



Figure 4-7 Changes in the free swell ratio due to rice husk ash

## 4.5 Effects of Rice Husk Ash on Specific Gravity

This study explains the effect of different RHA percentages on different soil properties from this the variation of specific gravity for the soil-RHA combination at different percentages is shown in Figure 4-8 below. It can be noticed that RHA causes a linearly reduction in the specific gravity of mixture. Due to the lightness (lower specific gravity) of RHA, the specific gravity of the stabilized soil decreased with RHA content increased. At 20% replacement, the specific gravity of the mixture




reduces to 2.50 from 2.68 for untreated soil specific gravity.

Figure 4-8 Effects of rice husk ash addition on the specific gravity of Woreta expansive soil

## 4.6 Effects of Rice Husk Ash on Compaction Characteristics

As mentioned in the previous section, a standard compaction test was performed in order to determine the effect of rice husk ash on optimum water content and maximum dry density of stabilized soils. This section presents the compaction characteristic curves determined for sample soils used in the experimental work and details of the result obtained are attached in Appendix 4. Summary of compaction curves with the application of different RHA contents for uncured and 7 days cured samples are presented in Figure 4-9 bellows.

The addition of rice husk ash affected the compaction parameters of expansive soil. The maximum dry density and optimum moisture content of untreated soil were 1.23g/cm3 and 35% respectively. As the added RHA contents were increased, the value of MDD decreased from 1.23 g/cm3 to 1.114 g/cm3 for uncured and 1.102 g/cm3 for 7 days cured at 20% of RHA content. In contrast, the value of optimum moisture content increased with the increase in the amount of RHA contents and curing time. The trend is in line with Isah (2015 ) Alhassan (2008). These variations of MDD and OMC due to stabilizers contents are depicted in Figure 4-9 and it is clearly illustrated that the compaction curves of RHA treated soils shifted downward to the right side of the plot which means that, the optimum moisture content values increased and the maximum dry density values decreased by increasing RHA content. The decrease in the MDD may be attributed to the replacement of soil by RHA in the mixture which has a relatively lower specific gravity of 2.04 compared to that of the soil which is 2.68.

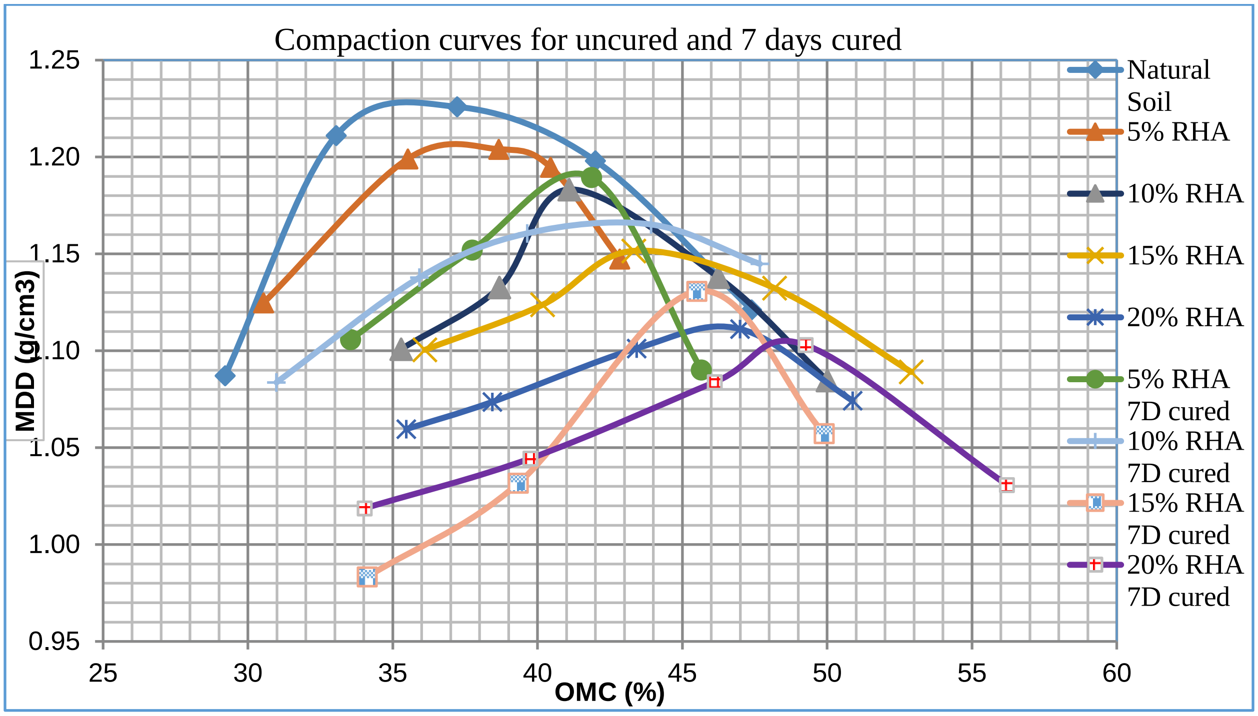



Figure 4-9 Compaction curves for uncured and 7 days cured

The increase in water content is due to the increase in the specific surface area of soil and RHA particle and also the pozzolanic reaction of RHA with soil requires more water for compaction. The summarized results for variation of compaction parameter (maximum dry density and the corresponding moisture content) with a different percent of rice husk ash, are shown in Figure 4-10 below.

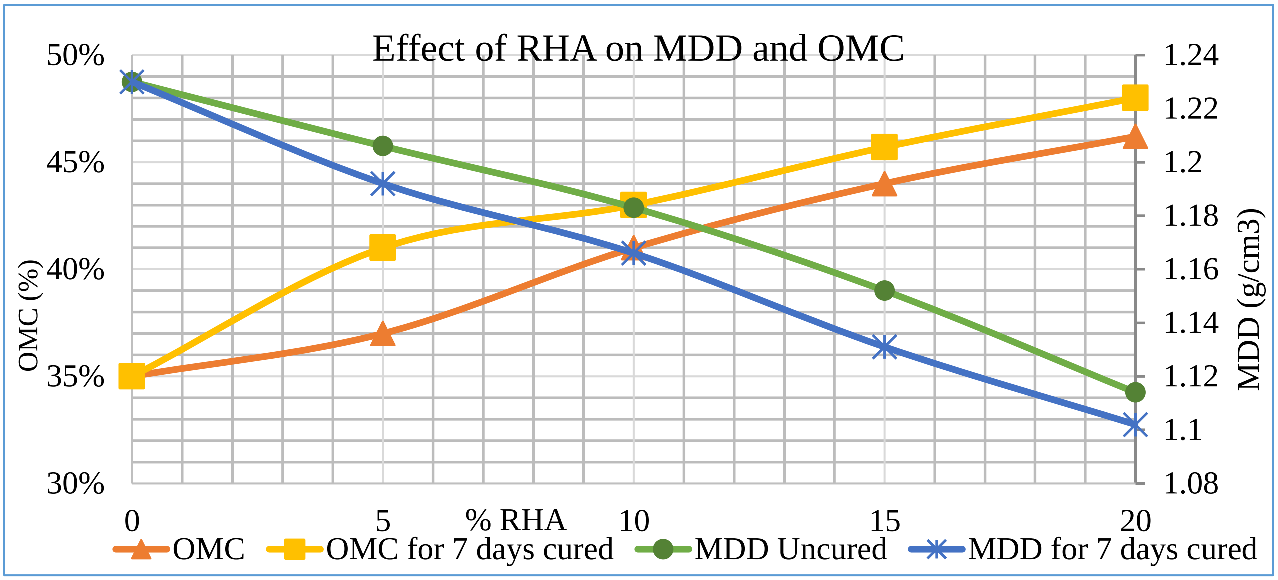



Figure 4-10 Effects of rice husk ash addition on compaction parameters

It can be concluded that more water will be required to compact soil with RHA mixture and the achieved maximum dry density will be lower than that of untreated soil due to the nature of RHA low specific gravity value (Alhassan, 2008; Osula, 1991). As indicated in the result of compact soil with RHA mixture more water is needed (Osinubi, 1999). So rice husk ash effectively dries wet soil and provides an initial rapid strength gain, which is useful during construction in wet and unstable ground conditions. In general, it can be utilized in improving the workability of wet soils.

## 4.7 Effects of Rice Husk Ash on Unconfined Compressive Strength

Variations of stress-strain responses of the expansive soil due to the addition of different percent rice husk ash are presented in Figure 4-11 for both uncured and Figure 4-12 for seven days cured samples. It can be observed that the expansive soil attained a peak stress of 131 kPa. With the addition of 5% and 10% rice husk ash, the compressive strength has increased to 161 kPa and 219 kPa respectively, resulting in a 23% and 67% rise in strength over that of the virgin soil. This is believed to be due to better packing of soil-RHA particles leading to a coherent structure that sustains higher loading. similarly, for seven days of curing UCS of treated soil increases with the percentage of RHA, and its maximum increase is observed at 10 percent addition of RHA which is 119 percent. The reason for the increment in UCS may be due to the gradual formation of cementitious compounds in the soil by the reaction between the RHA and some amounts of CaOH present in the soil (Sharma, 2008). Thus, the material ductility and compressive stress were enhanced due to the addition of RHA.

In general, there was a considerable improvement in its properties of RHA treated expansive soil. Nonetheless, the unconfined compressive stress of treated expansive soil reduced slightly when the RHA content was greater than 10%, which indicates that 10% RHA content could be the optimum RHA content achieving the highest compressive stress. The details of the result obtained from the laboratory test are attached in Appendix 6.

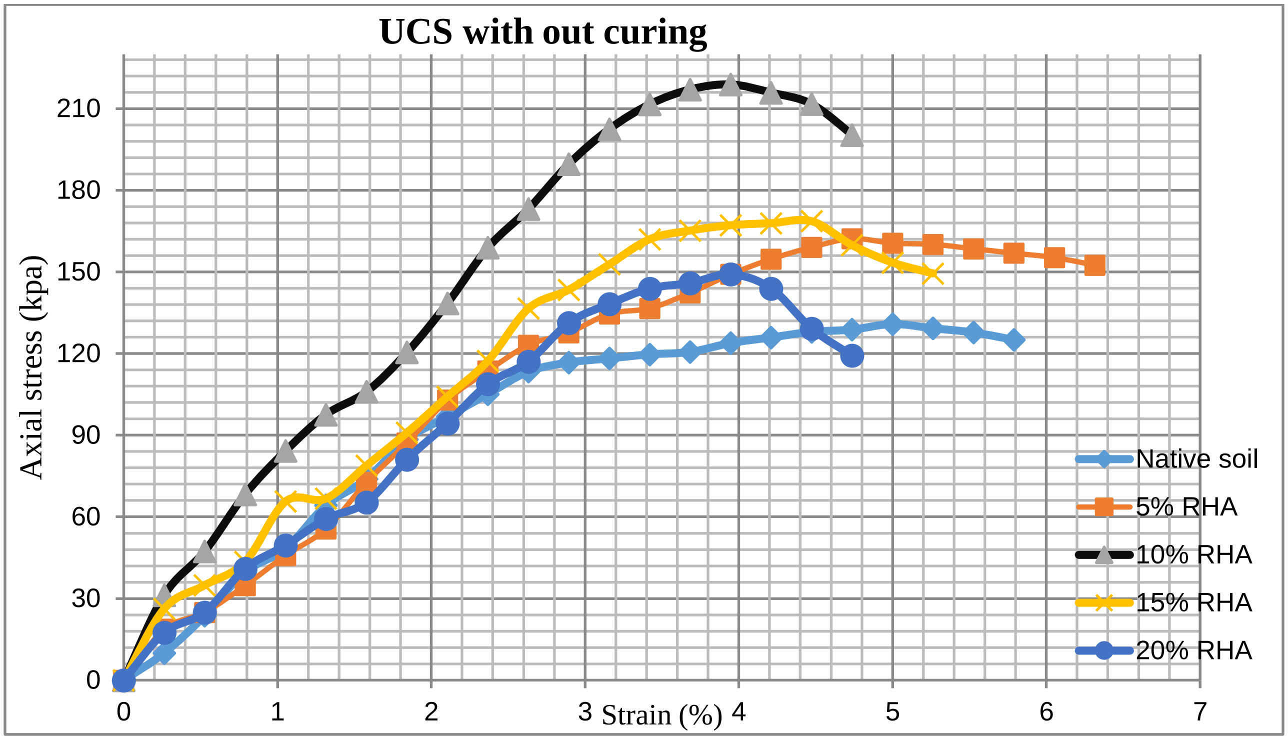



Figure 4-11 UCS curves for un-cured soil samples stabilized by RHA

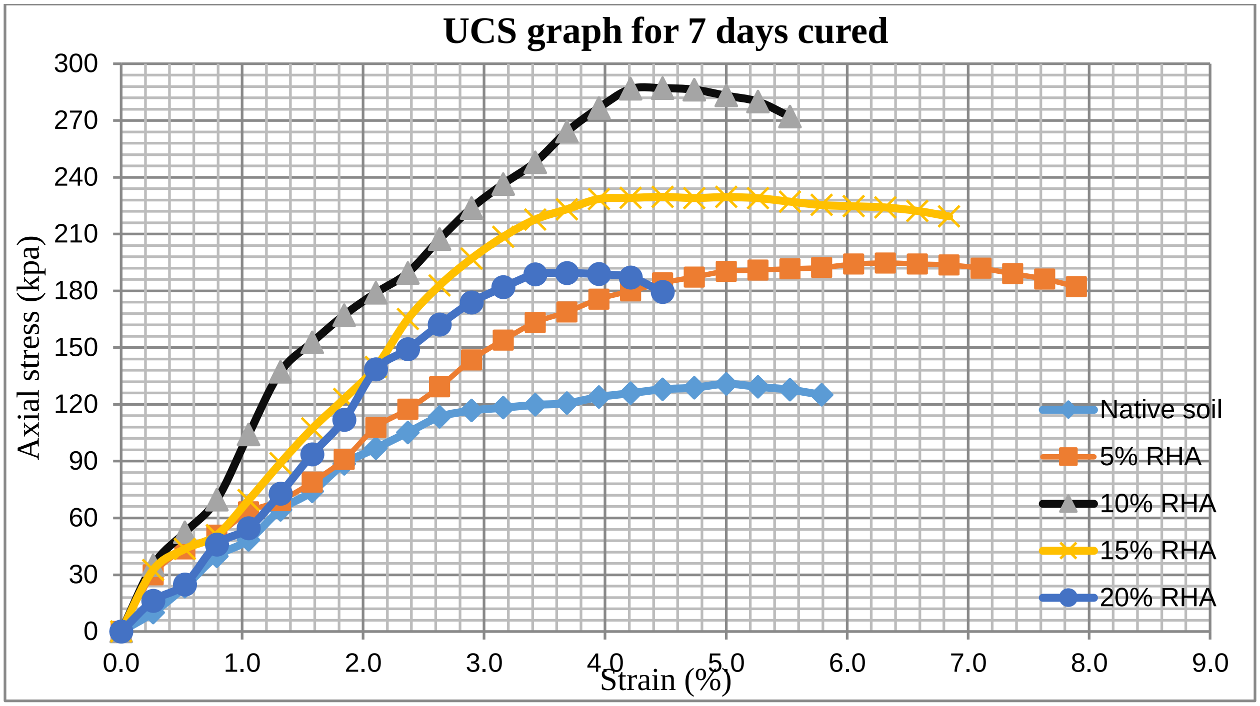



Figure 4-12 UCS curves for 7- days cured soil samples stabilized by RHA

## 4.8 Effects of Rice Husk Ash on California Bearing Ratio

The design and strength assessment of the road subgrade for flexible pavements is commonly in terms of the California Bearing Ratio (CBR) as an indicator of compacted soil strength and bearing capacity and it is also one of the common tests used to evaluate the strength and bearing capacity of stabilized soil. CBR tests were conducted on air-dried and pulverized soil passing no 4 sieve by mixing with rice husk ash at optimum moisture content and compacted in a CBR mold to the maximum dry density after soaking the sample for 96 hrs. In this study, an attempt was made to perform CBR tests on soil stabilized with different proportions of RHA. Figure 4-13 shows the results of these tests carried out on both the virgin and stabilized expansive soil samples for uncured and 7 days cured samples.

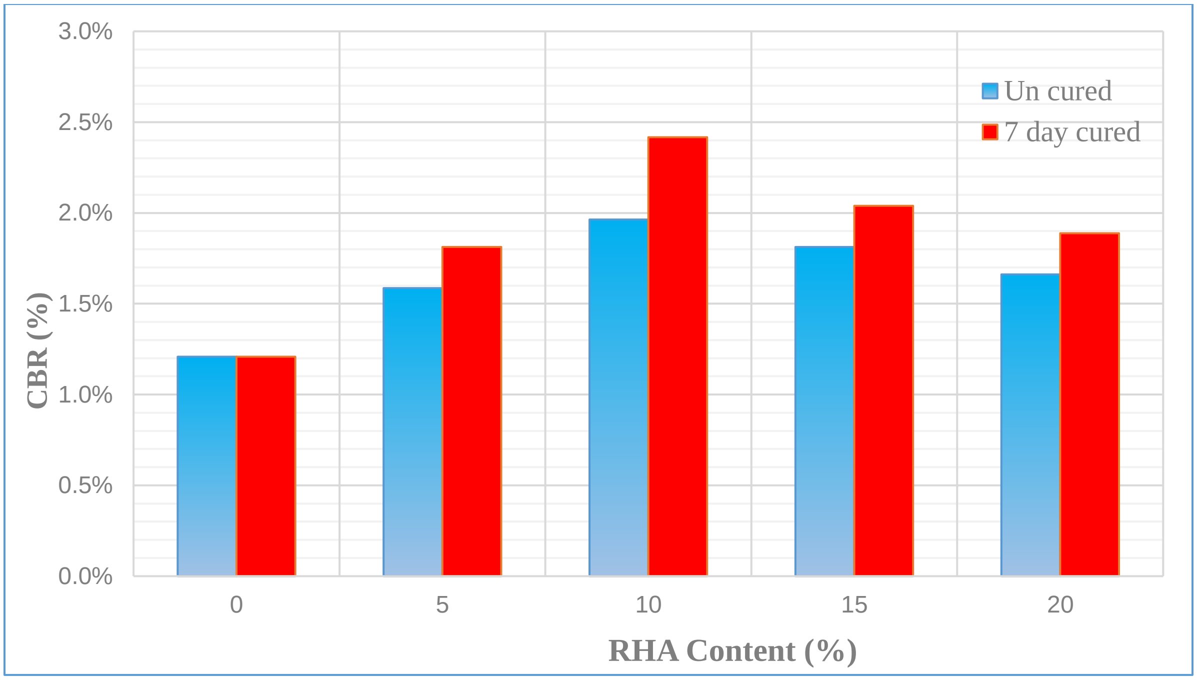



Figure 4-13 Effects of rice husk ash addition on CBR values

As shown in the figure CBR of the soil is generally increased with increasing in RHA content for uncured and 7 days cured soil samples up to 10%, and beyond this, the CBR value decreases. The results show that CBR values increased from 1.2% to 1.6% and 2% with an increase in RHA content from 0% to 5% and 10%, respectively for uncured and also for 7 days cured it increased to 1.8% and 2.4%, respectively. Further, the CBR value is slightly decreased for RHA content of 15% and 20% but it is still greater than the native soil CBR value and its value is 1.8% and 1.7% for uncured and 2% and 1.9% for 7 days cured respectively. The gradual formation of cementitious compounds by the pozzolanic reaction between RHA and expansive soil increases the CBR value (Isah, 2015 ). The decrease in CBR at RHA content of 15 percent and 20 percent may be due to extra RHA that could not be mobilized for the reaction which consequently occupies spaces within the sample. This extra RHA reduced the bond in the mixture. Appendix 8 shows the detailed result obtained.

## 4.9 USE OF RICE HUSK ASH ON LIME TREATED SOIL AS A PARTIAL REPLACEMENT, ANOTHER PERSPECTIVE

### 4.9.1 Introduction

In expansive soil stabilization using pozzolanic materials, the amount of calcium ion in the pozzolanic material and its access to water affect the pozzolanic reaction of stabilized soil due to this the presence of a small amount of calcium ion in the rice husk ash make the soil-RHA mixture, not a successful soil stabilizer. This shows that a certain amount of calcium from others like lime is necessary. Then, first estimates the optimum lime content according to the AASHTO standard using the percentage of soil passing the No. 40 sieve and the plasticity index of the soil as shown in Figure 4-14. Based on this method the optimum lime content to adequately stabilize this soil (PI= 62.4 and the percentage of soil passing the No. 40 sieve is 100%) is 8%. Therefore, in my perspective replacing half of this optimum lime content (4%) by varying the content of RHA.

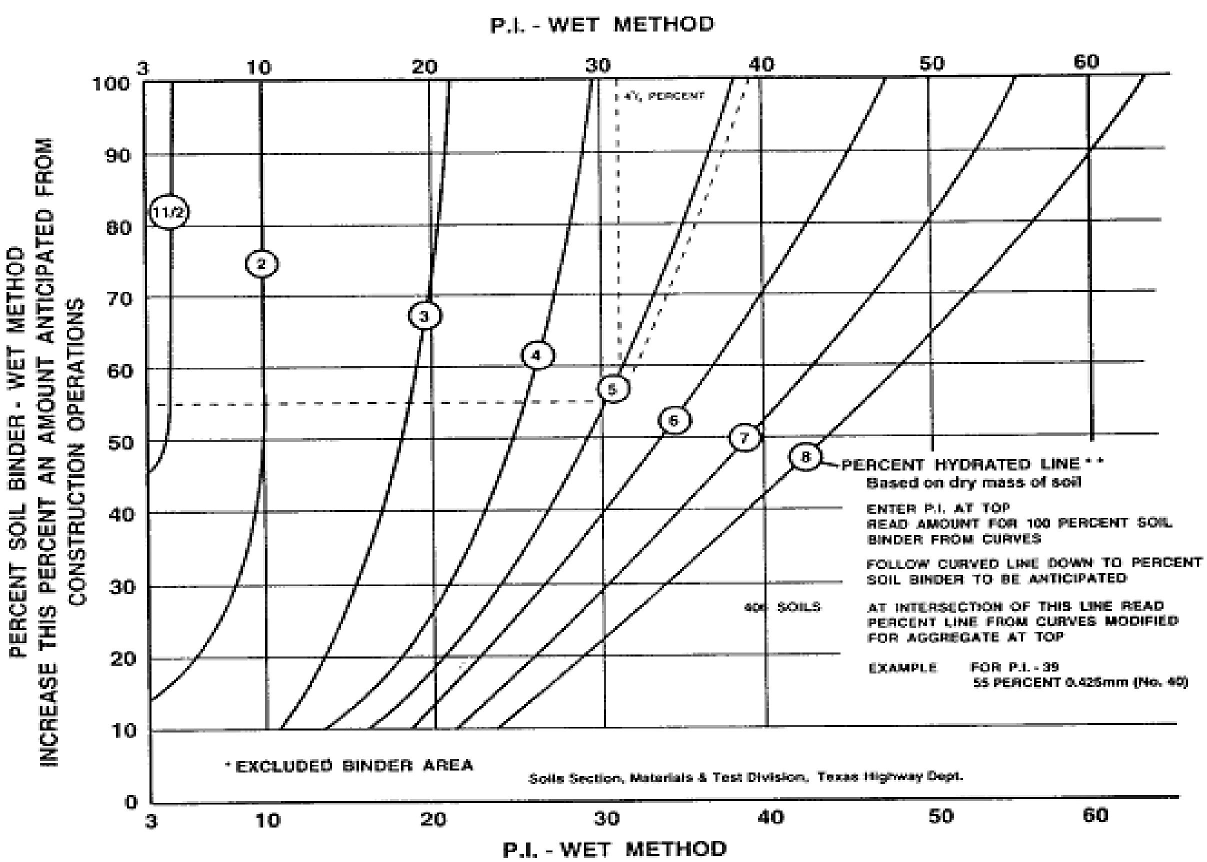



Figure 4-14 Determination of the strength of soil-lime mixtures (AASHTO, 1995)

### 4.9.2 Effects of additive content on Atterberg limits

The effects of rice husk ash on the Atterberg limit of soil stabilized with rice husk ash and rice husk ash amended with lime have been evaluated and presented in Figure 4-3 and Figure 4-15 respectively. The plastic index of black cotton soil treated by RHA and lime is decreased significantly when increasing the quantities of ash added amended by lime but there is no considerable effect due to curing. The addition of 5%, 10%, 15%, and 20% RHA amended with 4% lime diminished the plastic index of untreated soils by 51%, 56%,61%, and 64% respectively.

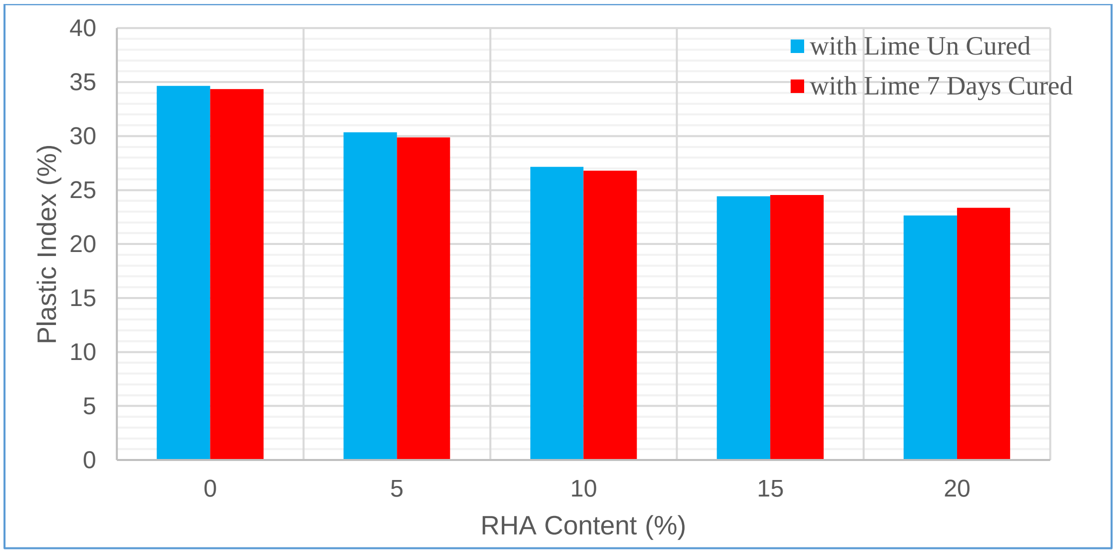
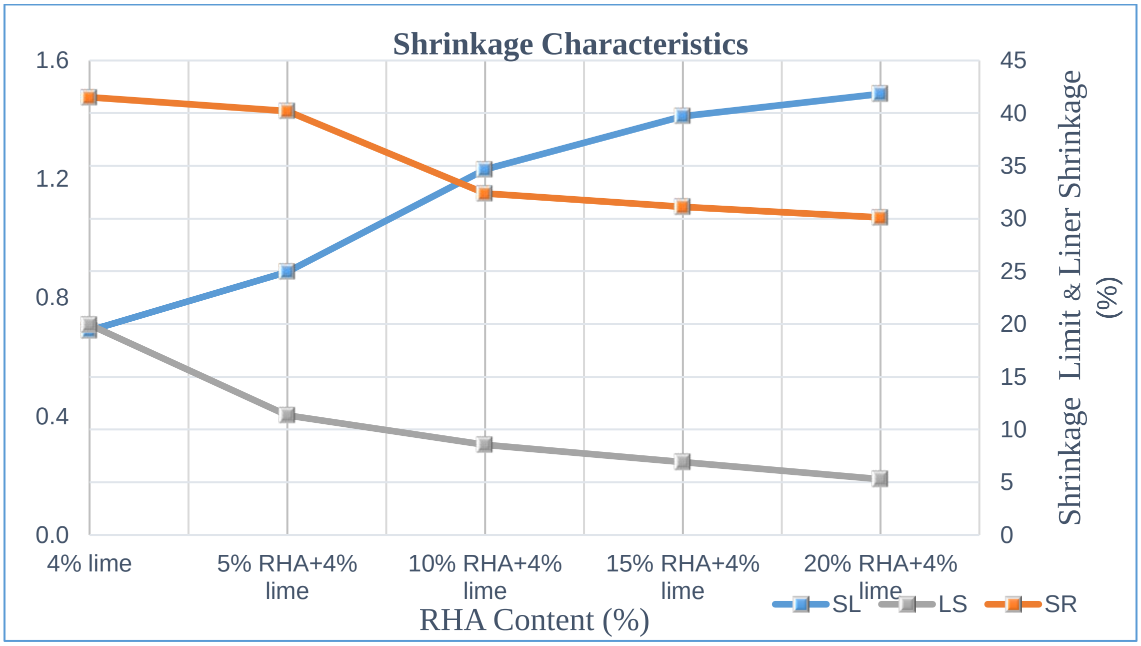



Figure 4-15 Effects of rice husk ash and lime addition on plasticity index

The addition of RHA and lime has a remarkable effect on the plasticity of cohesive soils. The decrease in plasticity indices are probably due to the change of soil texture through flocculation of the clay particles takes place when rice husk ash and lime is mixed with expansive soil. As the concentration of stabilizers is increased, there is a reduction in clay content and a correspondingly increase in the percentage of coarser particles. Details of the Atterberg limit test results are shown in Appendix 2.

### 4.9.3 Effects of rice husk ash on shrinkage characteristic

As can be seen from Figure 4-16, the addition of RHA increases the shrinkage limit and reduces volumetric shrinkage, linear shrinkage, and shrinkage ratio of black cotton soil and it means enhancement of volume stability of the soil. The gradual improvement is observed up to 20% of RHA amended with 4% lime added and is considered on further addition of stabilizer. The observed significant improvement in shrinkage characteristics is attributed to the replacement of the finer clay particles by relatively stronger and coarser particles and make it flocculation and aggregation phenomena.



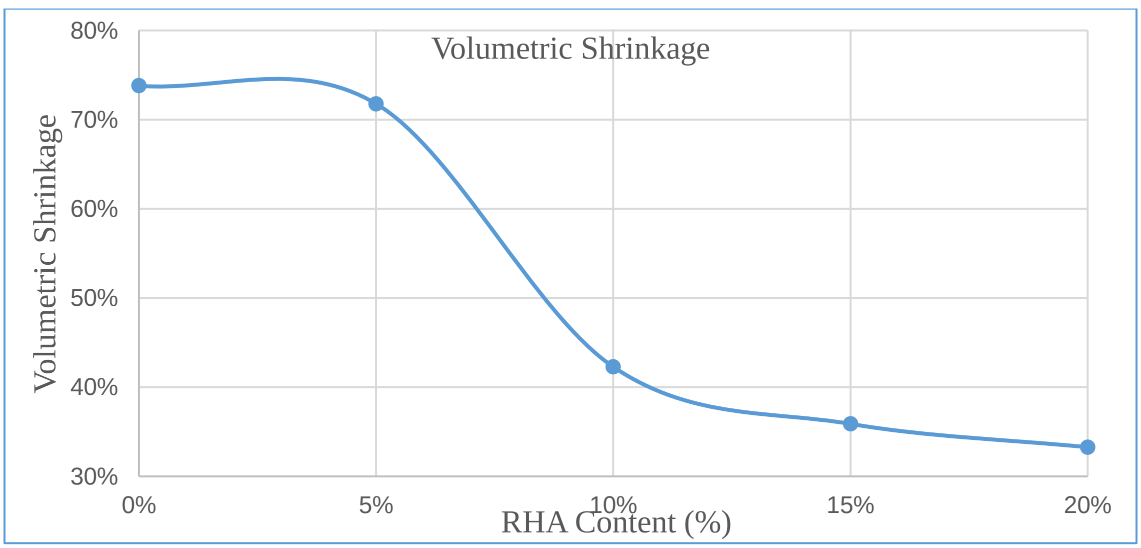




Figure 4-16 Influence of additive on shrinkage characteristics

### 4.9.4 Effects of additive content on swelling characteristics

#### 4.9.4.1 Influence of additive content on free swell

The effect of additive (RHA and lime) on the free swell properties of Woreta expansive soil is tested in the laboratory and its result shown in Figure 4-17 below. Where it is due to the replacement of clay particle by coarser particles (RHA and Lime) free swell value decreased from 130% to 35% with increased additive content from 0% to 20% and its reduction is directly proportional to the additive content as indicated in Figure 4-17.

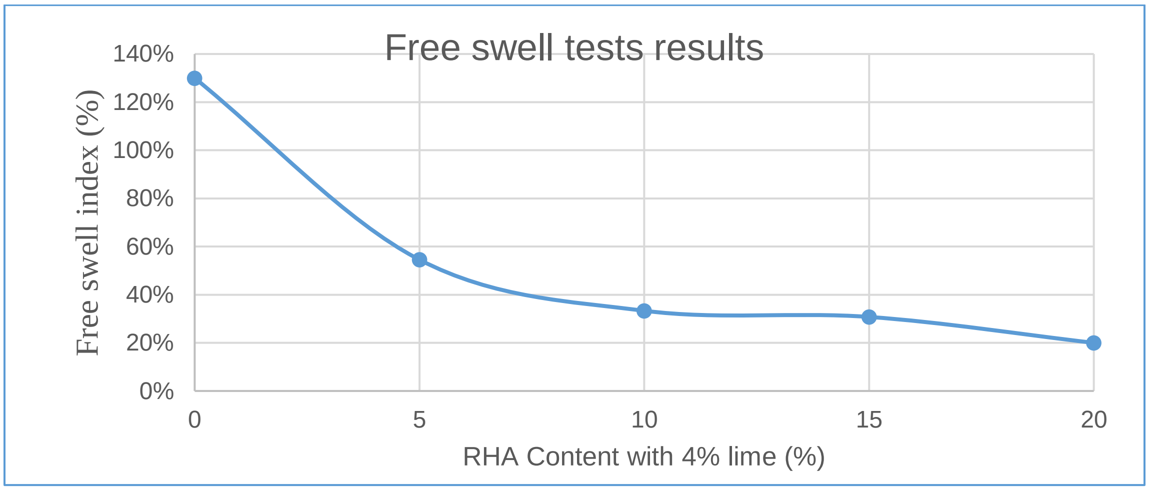



Figure 4-17 Influence of additive on the free swell

#### 4.9.4.2 Influence of additive content on free swell ratio

The free swell ratio tests were conducted on natural soil and treated soil samples and determined as the ratio of the final volume in water to final volume in kerosene, expressed as a percentage. As it is shown in Figure 4-18 when the additive content is increased the free swell ratio decreases.

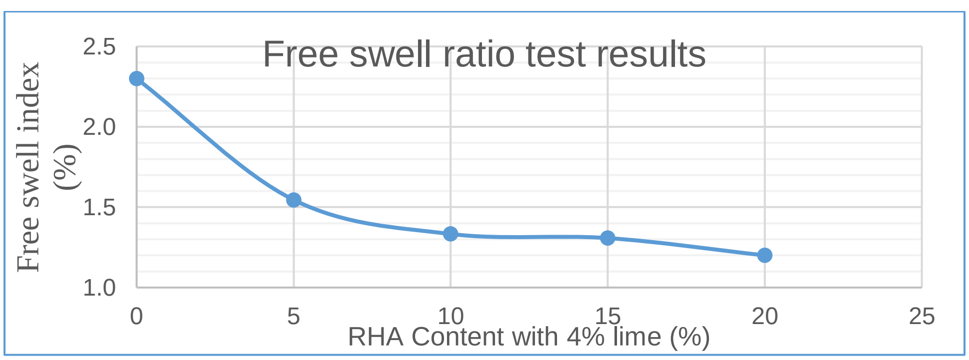



Figure 4-18 Influence of additive on the free swell ratio

According to Sridharan & Prakash (2016) classification of soils based on free swell ratio soil changes from high swelling soil (2.3% FSR) to low (1.2% FSR) when the content of RHA increases to 20% with 4% lime.

### 4.9.5 Influence of additive content on compaction characteristics

The effects of rice husk ash on the MDD and OMC of the soil-lime and soil-lime-RHA mixtures are shown in Figure 4-19 and Figure 4-20 for both 7 days cured and uncured soil samples. From the figure, it is indicated that for uncured soil sample MDD decreases for all mixes from the virgin's soil MDD value of 1.23g/cm$^3$ to 1.213g/cm$^3$, 1.198g/cm$^3$, 1.171g/cm$^3$, 1.146g/cm$^3$, and 1.106g/cm$^3$ with the addition of 0%, 5%, 10%, 15%, and 20% of RHA amended with 4% lime respectively. Similarly, for 7 days cured soil sample it decreases from 1.23g/cm$^3$ to 1.206g/cm$^3$, 1.176g/cm$^3$, 1.162g/cm$^3$, 1.125g/cm$^3$, and 1.067g/cm$^3$ with the addition of 0%, 5%, 10%, 15%, and 20% of RHA with the amended of 4% lime respectively.

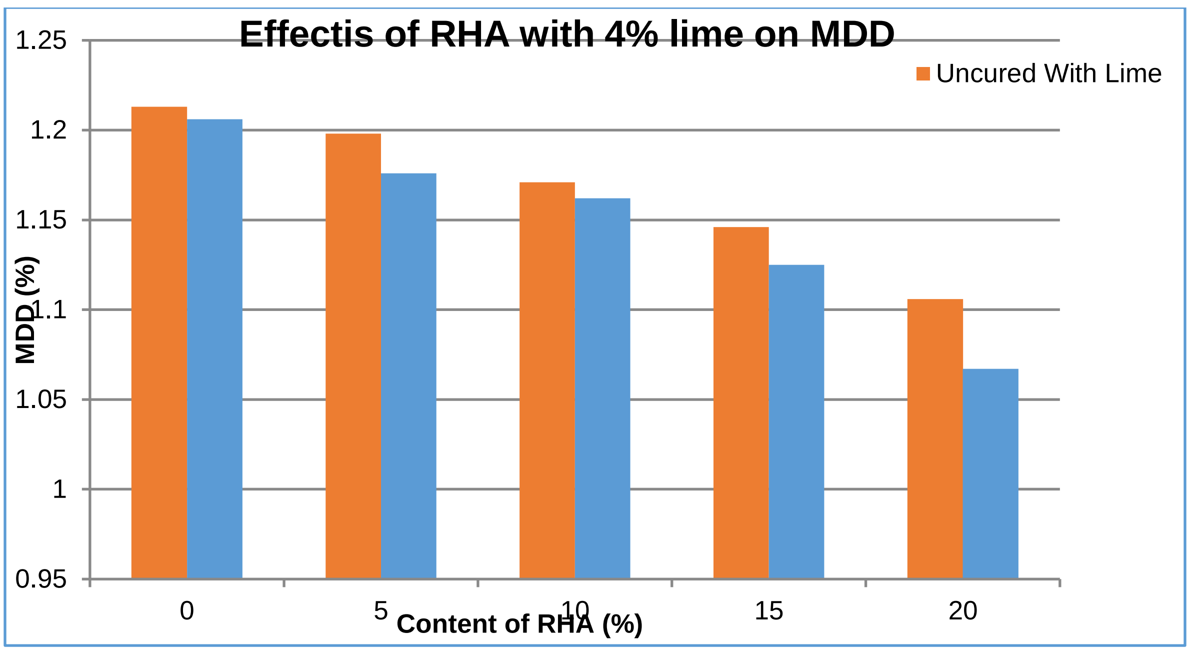



Figure 4-19 Effects of rice husk ash and lime addition on MDD

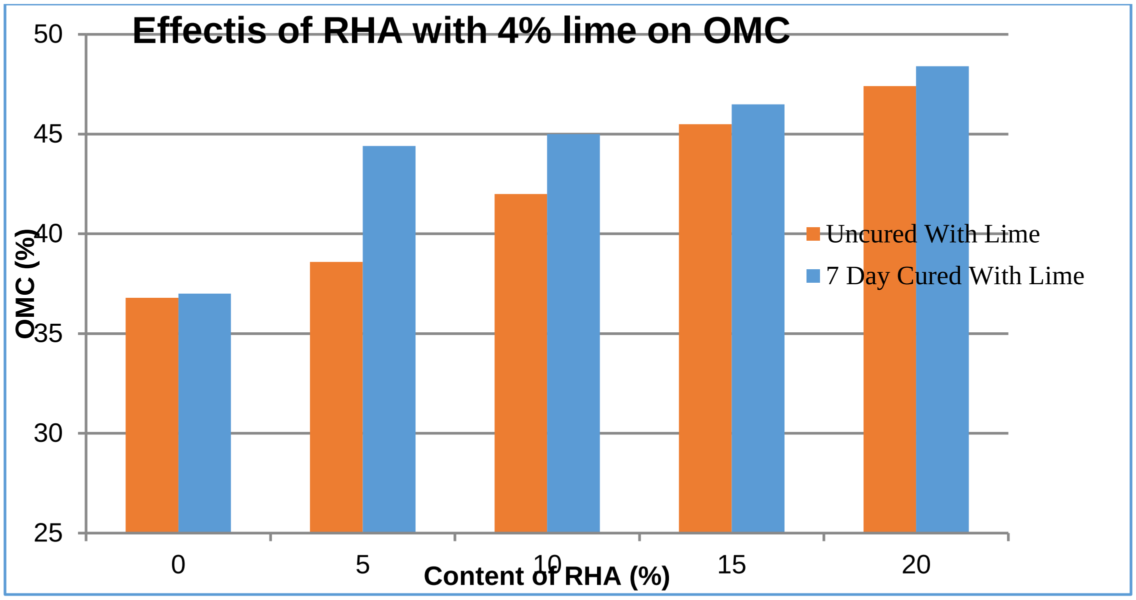



Figure 4-20 Effects of rice husk ash and lime addition on OMC

On the other hand, as indicated in Figure 4-20 the OMC for uncured soil sample increases for all mixes from the untreated soil value of 35% to 36.8%, 38.6%, 42%, 45.5%, and 47.4% with the addition of 0%, 5%, 10%, 15%, and 20% of RHA amended by 4% lime respectively. Similarly, for 7 days cured soil sample it increases from 35% to 37%, 44.4%, 45%, 46.5% and 48.4% with the addition of 0%, 5%, 10%, 15%, and 20% of RHA with the amended of 4% lime respectively. The addition of RHA with the amendment of lime led to a more increase of the OMC and a more decrease of the MDD compared to the addition of rice husk ash and lime individually.

Mainly, an increase in dry density and a decrease in moisture content is an indicator of soil improvement. Unfortunately, both RHA and lime instead reduce the dry density and increase the moisture content. Alhassan (2008) revealed an opinion that the change-down in dry density occurs due to the influence of both the particle size and specific gravity of the soil and stabilizer. Decreasing dry density indicates that it needs low Compaction energy to attain its maximum dry density, as a result, the cost of compaction will be economical (Muntohar & Hantoro, 2000). The details of the result obtained are attached in Appendix 5.

#### 4.9.6 Influence of additive content on unconfined compressive strength

Variation of UCS with an increase in RHA from 0% to 20% amended by 4% lime was investigated and the results for uncured and 7 days cured tests are shown in Figure 4-21.

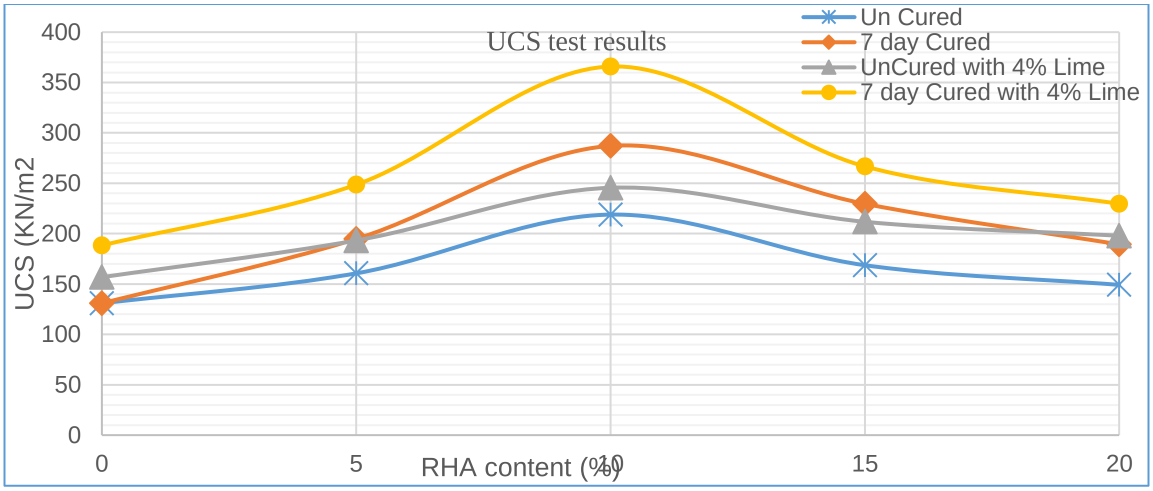



Figure 4-21 Effect of rice husk ash and lime on UCS values

The UCS values increase with the subsequent addition of RHA to its maximum at 10% RHA with 4% lime but further, it slightly decreased. From these plots, it is observed that the maximum failure stress value recorded was 246 and 364 KN/m2 at 10% RHA with 4% lime contents for uncured and after 7 days cured respectively. Appendix 7 shows the details of the results obtained in the laboratory.

### 4.9.7 Effects of additive content on CBR values

Soaked CBR-tests were carried out on uncured and 7 days cured specimens stabilized by lime and RHA compacted to their corresponding MDD and OMC. Its results are presented in Figure 4-22 below.

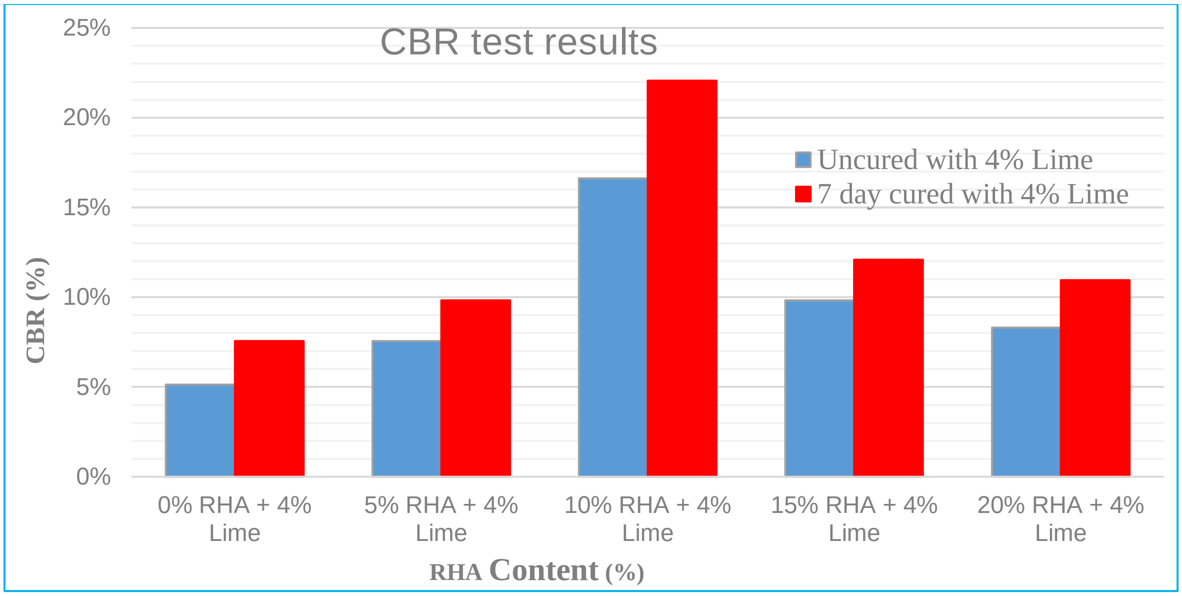



Figure 4-22 Effect of rice husk ash and lime on CBR values

The result shows that the CBR increased from 1.2% to 16.6% and 22.1% with an increase in RHA content from 0% to 10% amended by 4% lime for uncured and seven days cured respectively but reduced with further addition of RHA.

The amendment of RHA with lime for stabilizing expansive soil leads to more increase in the CBR value and also curing has a significant effect on the strength development of expansive soil stabilized by lime and rice husk ash. This shows that the load-bearing capacity of the soil increased considerably with RHA and lime treatment. Therefore, this amendment satisfies the minimum criteria specified by the Ethiopian Road Authority pavement design manual (2002) specification for materials suitable for use as subgrade material of not less than 3% CBR determined at MDD and OMC.

When lime and RHA both are mixed with the virgin soil the strength characteristics have further increased. This increase was due to the formation of various cementing agents by the pozzolanic reaction between the calcium present from lime and the readily available amorphous silica and/or alumina present from both the soil and rice husk ash. This reaction produces stable cementitious compounds calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH). It was also observed that the CBR value increased with curing age for all mixes. This is attributed to the pozzolanic reaction between the lime, soil, and rice husk ash resulting in the formation of more cementitious compounds. They form the matrix that contributes to the strength of stabilized soil layers.

Soil treated by rice husk ash and Lime has comparatively higher CBR value and reaching a maximum value of 22.1% at 10% RHA content amended by 4% lime content by dry weight of the soil when the sample subjected to a curing period of 7 days. This depicts the potential usage of RHA to stabilized Woreta city Expansive soil with the amendment of 4% lime is the optimum amount and it is also improving its engineering properties. The CBR curve details for individual admixture have been presented in Appendix 9.

# Chapter 5 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

The following conclusions are drawn based on the outcome of the investigation:

- ✓ Chemical composition test shows that, the combine percent composition of Silica ($SiO_2$), Alumina ($Al_2O_3$), and Iron Oxide ($Fe_2O_3$) is more than 70%. This shows that, it is a good pozzolana that could help to mobilize the CaOH in the soil for the formation of cementations compounds.
- ✓ Due to the flocculation and replacement of finer soil particles with RHA the liquid limit and plasticity index decreased as the additive content increased this reduction is an indication of a marked improvement in workability.
- ✓ The specific gravity decreased with the addition of RHA from 2.68 to 2.5.
- ✓ The addition of RHA improves the volume stability of the soil.
- ✓ The compaction curves show that, the addition of RHA increases the optimum moisture content and decreases the maximum dry density.
- ✓ The strength characters are analyzed in terms of UCS, and the result reveals that UCS value increases as the proportion of RHA are raised with and without lime. This is because of the disturbance caused to the black cotton soil skeleton by ash. Also, the UCS of the mix increases when curing is allowed, due to the pozzolanic reactions between the soil and stabilizers.
- ✓ The CBR value was improved by the addition of RHA and this improvement is significant when soil is treated with the admixture of RHA and lime. This enhancement has been due to the contribution of the soil-RHA mixture to the frictional resistance, as well as the production of various cementing agents through a pozzolanic reaction. As curing time increases, the CBR of the treated soil increases accordingly. About the sample with 14% RHA-lime content (10%RHA + 4% lime) and the $7^{th}$-day curing period, the maximum strength is about 11 times that of uncured soil.
- ✓ The RHA had very little CaO content as a result; stabilization using RHA alone did not give a significant improvement because of this lime amendment was required.

- ✓ The optimum amount of RHA for the achievement of the peak CBR and UCS values for the soil under analysis was around ten percent RHA. The addition of RHA beyond this amount tends to cause a decrease in the CBR and UCS value.
- ✓ The modified soil with an optimum 10 % RHA amendment with 4% lime meets the ERA (2013) specification requirement for stabilized soil.

## 5.2 Recommendations

Based on the investigated experimental results several recommendations are highlighted below for future investigations: -

- Awareness needs to be raised about construction practices of chemical stabilization in Ethiopia.
- There is not enough investigation done on rice husk ash as a soil stabilizer in Ethiopia so far. So it is recommended that extensive researches on soil samples taken from different places in Ethiopia with different samples of rice husk ash should be done to compare with the results obtained in this investigation. This will enable us to gain a better understanding as well as provide a possible option for utilizing waste by-products for expansive soil stabilization.
- Since rice husk ash is discovered its usefulness all concerned bodies should contribute to collect and store properly.
- The field application of chemical stabilization is not investigating in the study. Therefore; further studies on the field application of chemical stabilization and its suitable technology may be important.
- This study was conducted on a laboratory basis. Therefore; their actual performance in the field shall be studied.
- The use of rice husk ash as stabilizing agents can be economically attractive in regions near to the areas where these waste by-products are obtained. Therefore; bearing in mind its economic and environmental advantage all concerned bodies should be aware of this potential soil stabilizing material and promote its level of quality required, collection, production, and application.
- It is recommended that a Standard for soil stabilization with RHA be developed. The standard should give guidelines on requirements on chemical composition, grinding, optimal blend, particle size distribution, packaging, and storage of RHA
- Utilization of RHA in soil stabilization is highly recommended in addition to engineering application it will reduce environmental pollution and encourage further production of rice within and outside the rice-growing regions of the country and hence boost food security.

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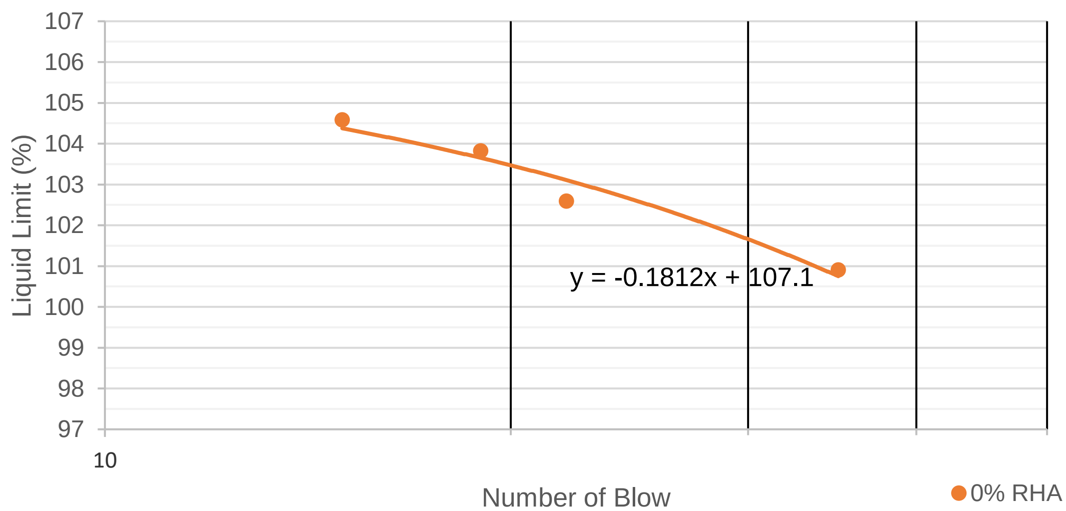
# Appendix

## Appendix 1: Atterberg limit Test Results for a varying percentage of RHA Content

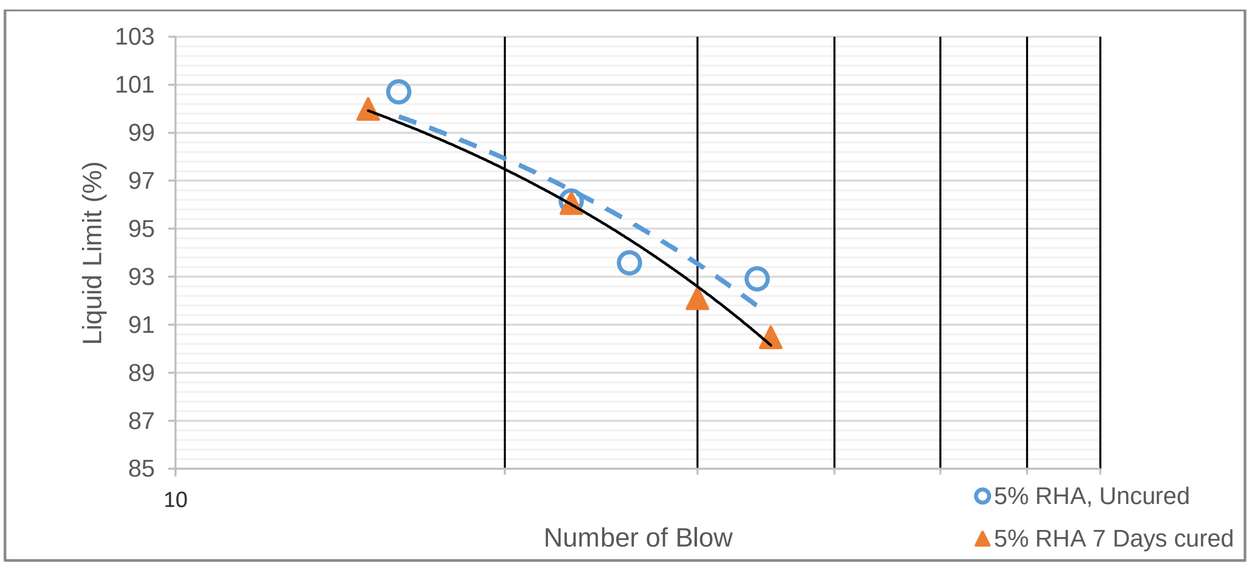
### 1. 0% Rice husk ash

| Native soil | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 35 | 19 | 15 | 22 |
| Container No. | 2 | 4 | 12 | 14 | 15 | 16 | 17 |
| Container + Wet Sample ($w_1$) | 20.8 | 18.9 | 21.5 | 33.6 | 48 | 42.5 | 39.2 |
| Container + Dry Sample ($w_2$) | 19.3 | 18 | 19.8 | 22.4 | 31.7 | 28.8 | 27.3 |
| Container ($w_3$) | 15.7 | 15.6 | 15.7 | 11.3 | 16 | 15.7 | 15.7 |
| Moisture Content $((w_1-w_2)/(w_2-w_3))$ | 41.7 | 37.5 | 41.5 | 100.9 | 103.8 | 104.6 | 102.6 |
| Plastic/ Liquid Limit | **40.2%** | | | **102.6%** | | | |
| Plasticity Index | **62.4%** | | | | | | |



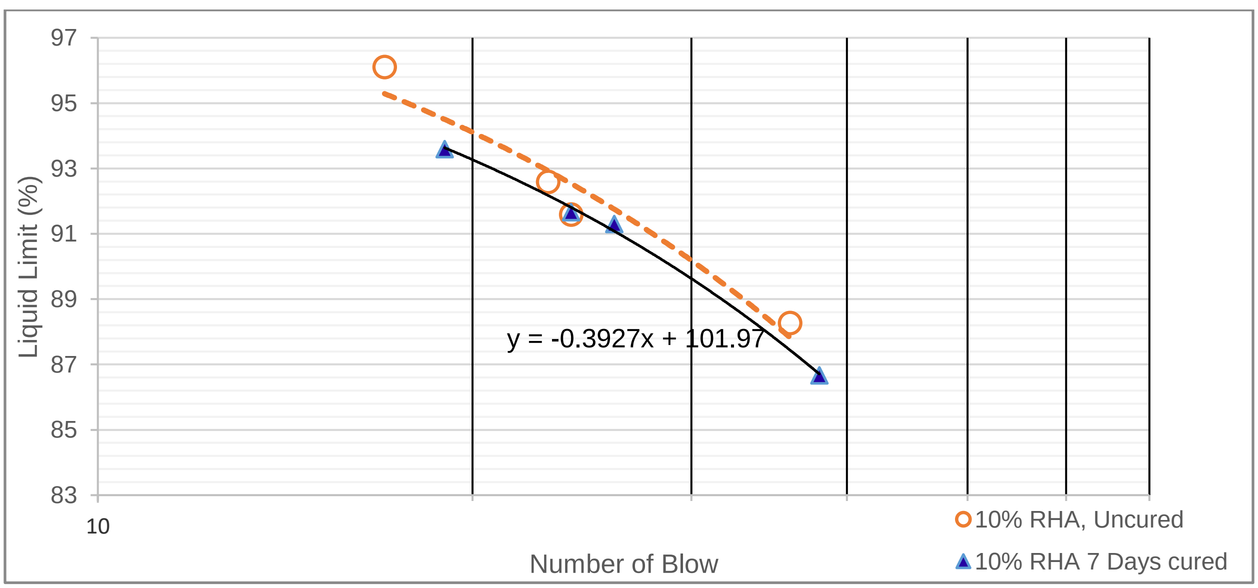
## 2. 5% Rice husk ash

| 5% RHA, Uncured | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 16 | 23 | 34 | 26 |
| Container No. | C3 | 116 | w9 | A2 | C4 | 54 | 116 |
| Container + Wet Sample ($w_1$) | 19.2 | 20.3 | 19 | 43.6 | 35.6 | 40.1 | 36.6 |
| Container + Dry Sample ($w_2$) | 18.1 | 18.8 | 18 | 29.5 | 25.6 | 28.3 | 26.4 |
| Container ($w_3$) | 15.6 | 15.4 | 15.7 | 15.5 | 15.2 | 15.6 | 15.5 |
| Moisture Content $((w_1-w_2)/(w_2-w_3))$ | 44.0 | 44.1 | 43.5 | 100.7 | 96.2 | 92.9 | 93.6 |
| Plastic/ Liquid Limit | **43.9** | | | **95.7** | | | |
| Plasticity Index | **51.9** | | | | | | |
| **5% RHA 7 Days cured** | | | | | | | |
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 35 | 30 | 23 | 15 |
| Container No. | 7 | 8 | C-19 | 3 | 6 | 111 | C7 |
| Container + Wet Sample ($w_1$) | 20.3 | 19.7 | 19.3 | 31.5 | 30.1 | 36 | 36.7 |
| Container + Dry Sample ($w_2$) | 18.8 | 18.4 | 18.2 | 23.9 | 23.1 | 26.2 | 26.1 |
| Container ($w_3$) | 15.5 | 15.5 | 15.6 | 15.5 | 15.5 | 16 | 15.5 |
| Moisture Content $((w_1-w_2)/(w_2-w_3))$ | 45.5 | 44.8 | 42.3 | 90.5 | 92.1 | 96.1 | 100.0 |
| Plastic/ Liquid Limit | **44.2** | | | **95.0** | | | |
| Plasticity Index | **50.8** | | | | | | |



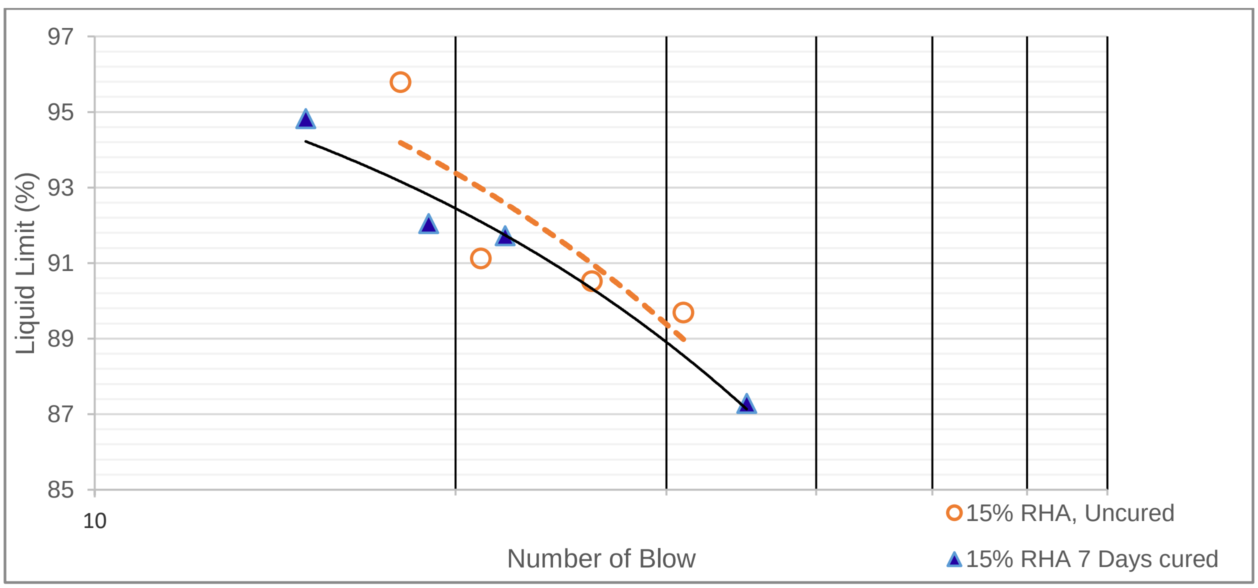
**3. 10% Rice husk ash**

| **10% RHA, Uncured** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 17 | 36 | 23 | 24 |
| Container No. | 60 | 61 | Se | 10 | 7 | 2 | 66 |
| Container + Wet Sample ($w_1$) | 21.4 | 21.6 | 16.1 | 35.7 | 39.5 | 41.7 | 38.1 |
| Container + Dry Sample ($w_2$) | 19.6 | 19.7 | 14.5 | 25.8 | 28.2 | 29.2 | 27.2 |
| Container ($w_3$) | 15.8 | 15.6 | 11 | 15.5 | 15.4 | 15.7 | 15.3 |
| Moisture Content (($w_1$-$w_2$)/($w_2$-$w_3$)) | 47.4 | 46.3 | 45.7 | 96.1 | 88.3 | 92.6 | 91.6 |
| Plastic/ Liquid Limit | **46.5** | | | **92.1** | | | |
| Plasticity Index | **45.7** | | | | | | |
| **10% RHA 7 Days cured** | | | | | | | |
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 38 | 26 | 24 | 19 |
| Container No. | 13 | 3 | 8 | 77 | 5 | 1111 | Co4 |
| Container + Wet Sample ($w_1$) | 19.9 | 20.5 | 20.8 | 38 | 36.9 | 36.5 | 39.8 |
| Container + Dry Sample ($w_2$) | 18.5 | 18.9 | 19.1 | 27.6 | 26.4 | 26.6 | 28.1 |
| Container ($w_3$) | 15.6 | 15.6 | 15.5 | 15.6 | 14.9 | 15.8 | 15.6 |
| Moisture Content (($w_1$-$w_2$)/($w_2$-$w_3$)) | 48.3 | 48.5 | 47.2 | 86.7 | 91.3 | 91.7 | 93.6 |
| Plastic/ Liquid Limit | **48.0** | | | **91.4** | | | |
| Plasticity Index | **43.5** | | | | | | |



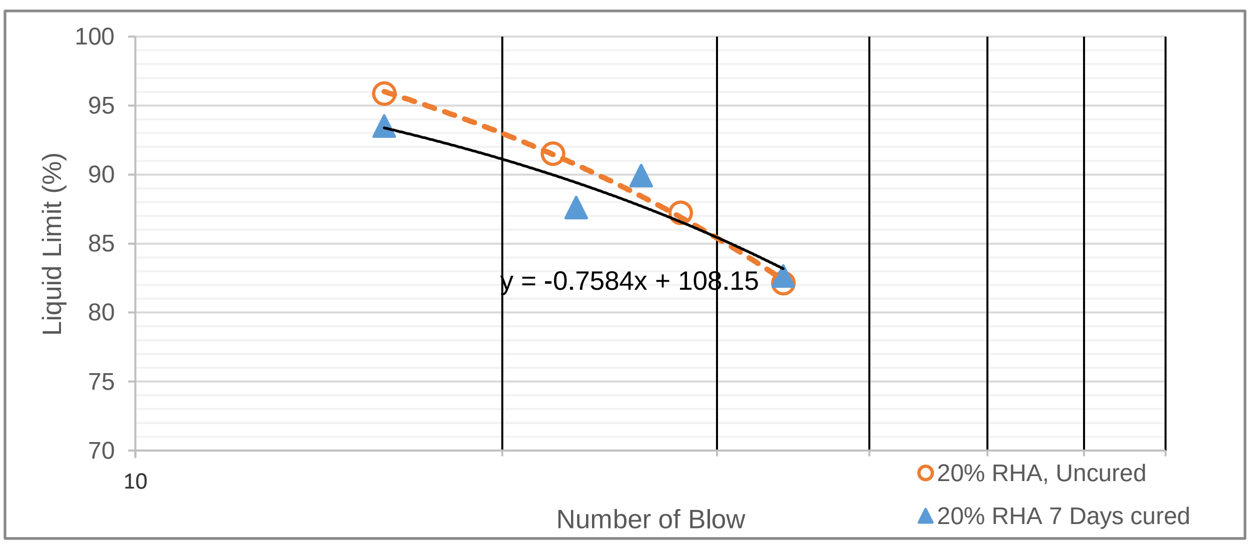
4. **15% Rice husk ash**

| 15% RHA, Uncured | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 31 | 18 | 21 | 26 |
| Container No. | 116 | 52 | 2 | 8 | 21 | 22 | 61 |
| Container + Wet Sample ($w_1$) | 20.1 | 20.34 | 20.6 | 33.9 | 34.5 | 38.6 | 32.7 |
| Container + Dry Sample ($w_2$) | 18.65 | 18.87 | 19 | 25.2 | 25.4 | 27.3 | 24.1 |
| Container ($w_3$) | 15.62 | 15.75 | 15.7 | 15.5 | 15.9 | 14.9 | 14.6 |
| Moisture Content (($w_1$-$w_2$)/($w_2$-$w_3$)) | 47.9 | 47.1 | 48.5 | 89.7 | 95.8 | 91.1 | 90.5 |
| Plastic/ Liquid Limit | **47.8** | | | **91.4** | | | |
| Plasticity Index | **43.6** | | | | | | |
| **15% RHA 7 Days cured** | | | | | | | |
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 35 | 19 | 22 | 15 |
| Container No. | 3 | 4 | 6 | 14 | 15 | 16 | 17 |
| Container + Wet Sample ($w_1$) | 20.6 | 21 | 20.7 | 33.4 | 45 | 41.2 | 38.3 |
| Container + Dry Sample ($w_2$) | 18.9 | 19.2 | 19 | 23.1 | 31.1 | 29 | 27.3 |
| Container ($w_3$) | 15.5 | 15.6 | 15.5 | 11.3 | 16 | 15.7 | 15.7 |
| Moisture Content (($w_1$-$w_2$)/($w_2$-$w_3$)) | 50.0 | 50.0 | 48.6 | 87.3 | 92.1 | 91.7 | 94.8 |
| Plastic/ Liquid Limit | **49.5** | | | **90.7** | | | |
| Plasticity Index | **41.2** | | | | | | |



## 5. 20% Rice husk ash

| 20% RHA, Uncured | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 34 | 28 | 22 | 16 |
| Container No. | 55 | 15 | 61 | 14 | 15 | 18 | 12 |
| Container + Wet Sample ($w_1$) | 19.81 | 22.3 | 20.3 | 32 | 43.41 | 38.81 | 38.74 |
| Container + Dry Sample ($w_2$) | 18.46 | 20.08 | 18.7 | 22.53 | 30.5 | 27.9 | 27.6 |
| Container ($w_3$) | 15.72 | 15.6 | 15.5 | 11 | 15.7 | 15.98 | 15.98 |
| Moisture Content $((w_1-w_2)/(w_2-w_3))$ | 49.3 | 49.6 | 50.0 | 82.1 | 87.2 | 91.5 | 95.9 |
| Plastic/ Liquid Limit | 49.6 | | | 89.2 | | | |
| Plasticity Index | 39.6 | | | | | | |
| 20% RHA 7 Days cured | | | | | | | |
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 16 | 34 | 23 | 26 |
| Container No. | 111 | 12 | 13 | A2 | C4 | 54 | 116 |
| Container + Wet Sample ($w_1$) | 21.9 | 21.4 | 21.3 | 30.5 | 33.1 | 36.8 | 40 |
| Container + Dry Sample ($w_2$) | 19.9 | 19.5 | 19.4 | 23.3 | 25 | 26.9 | 28.4 |
| Container ($w_3$) | 16 | 15.7 | 15.8 | 15.6 | 15.2 | 15.6 | 15.5 |
| Moisture Content $((w_1-w_2)/(w_2-w_3))$ | 51.3 | 50.0 | 52.8 | 93.5 | 82.7 | 87.6 | 89.9 |
| Plastic/ Liquid Limit | 51.4 | | | 88.3 | | | |
| Plasticity Index | 36.9 | | | | | | |

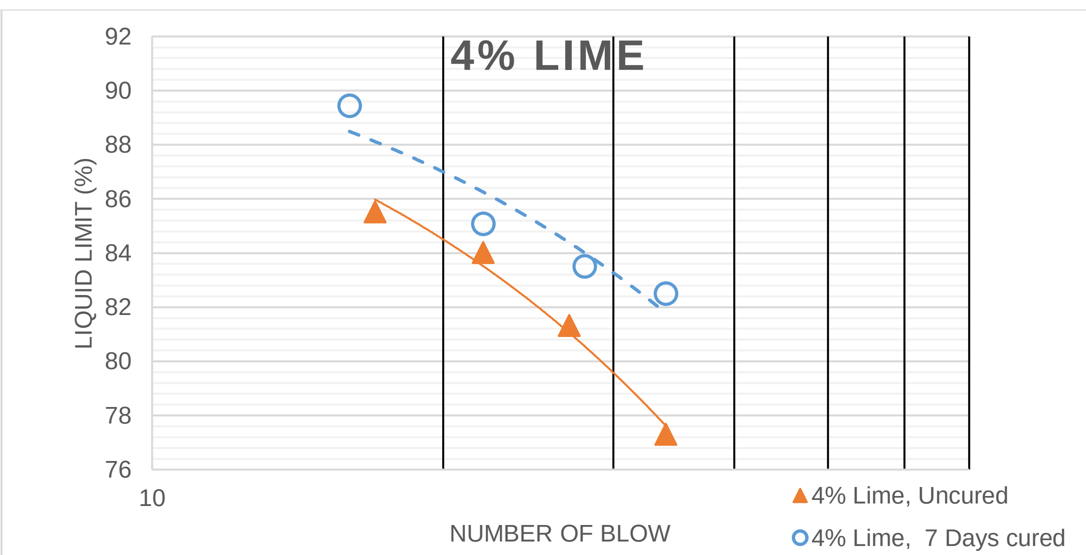


**Appendix 2: Atterberg limit Test Results for a varying percentage of RHA Content with 4% Lime**

**1. 0% Rice husk ash with 4% Lime**

| **4% Lime, Uncured** | | | | | | |
|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | Liquid Limit | | | |
| No. Of Blows | | | 17 | 22 | 28 | 34 |
| Container No. | W3 | C0-16 | W29 | Co-9 | W34 | Co-4 |
| Container + Wet Sample ($w_1$) | 19.211 | 15.57 | 41.103 | 47.285 | 40.715 | 45.177 |
| Container + Dry Sample ($w_2$) | 17.743 | 13.922 | 29.161 | 32.947 | 29.214 | 31.799 |
| Container ($w_3$) | 14.761 | 10.59 | 15.197 | 15.881 | 15.442 | 15.585 |
| Moisture Content $((w_1-w_2)/(w_2-w_3))$ | 49.2 | 49.5 | 85.5 | 84.0 | 83.5 | 82.5 |
| Plastic/ Liquid Limit (%) | **49.3** | | **84.0** | | | |
| Plasticity Index (%) | **34.7** | | | | | |

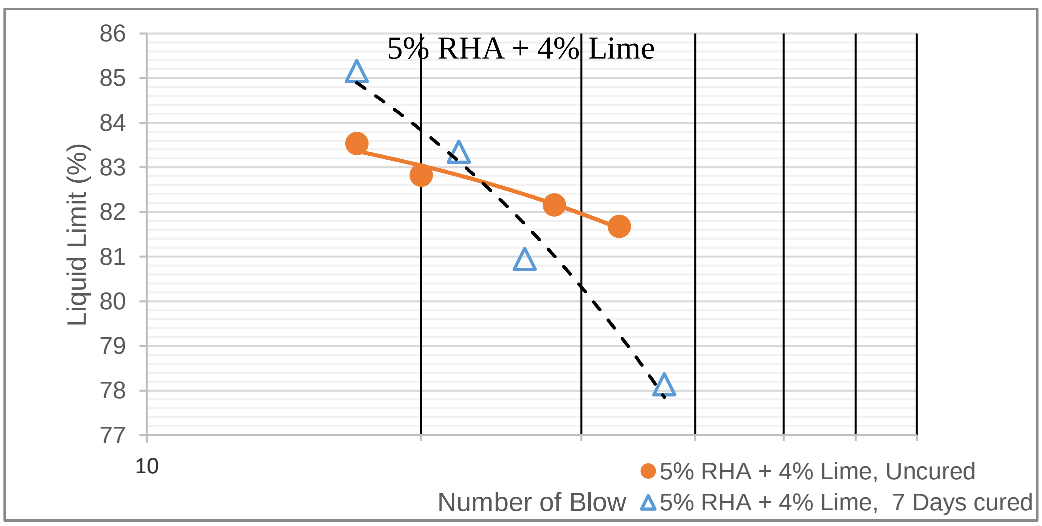
| 4% Lime, 7 Days cured | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 16 | 22 | 27 | 34 |
| Container No. | W36 | W33 | W28 | W44 | W43 | W42 | W41 |
| Container + Wet Sample ($w_1$) | 20.72 | 19.76 | 20.28 | 33.2 | 37.2 | 32.12 | 35.21 |
| Container + Dry Sample ($w_2$) | 19.08 | 18.38 | 18.81 | 24.7 | 27.4 | 24.64 | 26.81 |
| Container ($w_3$) | 15.72 | 15.58 | 15.74 | 15.20 | 15.88 | 15.44 | 15.59 |
| Moisture Content $((w_1-w_2)/(w_2-w_3))$ | 48.8 | 49.3 | 47.9 | 89.4 | 85.1 | 81.3 | 74.8 |
| Plastic/ Liquid Limit | 48.7 | | | 83.0 | | | |
| Plasticity Index | 34.3 | | | | | | |



## 2. 5% Rice husk ash with 4% Lime

| 5% RHA + 4% Lime, Uncured | | | | | | |
|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | Liquid Limit | | | |
| No. Of Blows | | | 17 | 20 | 28 | 33 |
| Container No. | 13 | W0 | Y3 | C2 | S10 | 7511 |
| Container + Wet Sample ($w_1$) | 19.04 | 19.34 | 41.72 | 36.56 | 40.08 | 40.82 |
| Container + Dry Sample ($w_2$) | 17.87 | 18.02 | 29.60 | 27.06 | 29.22 | 29.51 |
| Container ($w_3$) | 15.57 | 15.56 | 15.10 | 15.59 | 15.99 | 15.66 |
| Moisture Content $((w_1-w_2)/(w_2-w_3))$ | 51.24 | 53.26 | 83.54 | 82.83 | 82.16 | 81.68 |
| Plastic/ Liquid Limit (%) | **52.3** | | **82.6** | | | |
| Plasticity Index (%) | **30.3** | | | | | |

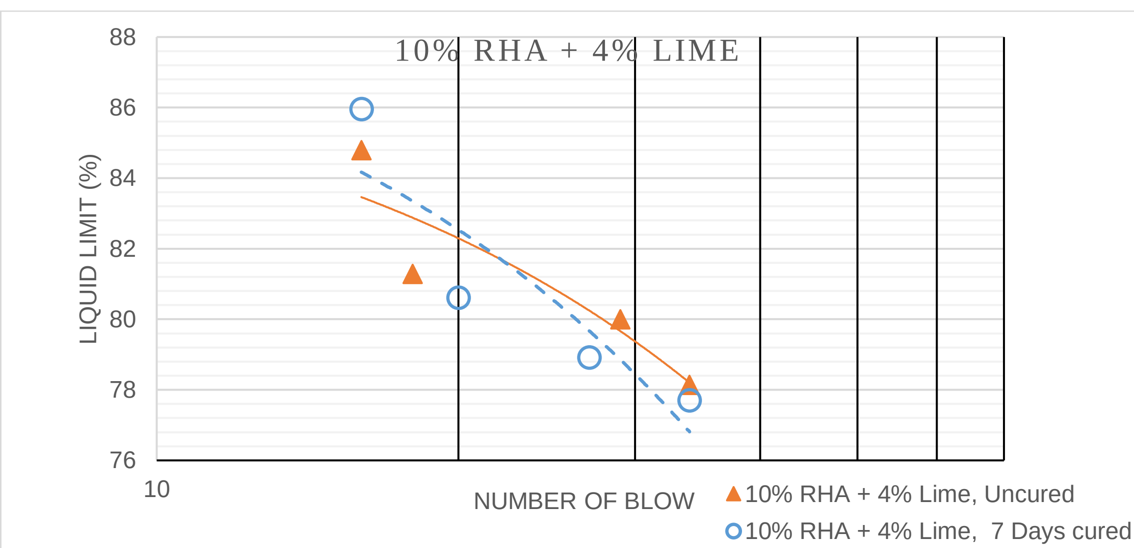
| 5% RHA + 4% Lime, 7 Days cured | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 37 | 26 | 22 | 17 |
| Container No. | W36 | W32 | W38 | W36 | W33 | W35 | W32 |
| Container + Wet Sample ($w_1$) | 20.51 | 21.08 | 19.85 | 37.4 | 38 | 34.1 | 31.8 |
| Container + Dry Sample ($w_2$) | 18.89 | 19.2 | 18.41 | 27.89 | 27.97 | 25.69 | 24.34 |
| Container ($w_3$) | 15.72 | 15.58 | 15.6 | 15.72 | 15.58 | 15.6 | 15.58 |
| Moisture Content $((w_1-w_2)/(w_2-w_3))$ | 51.1 | 51.9 | 51.2 | 78.1 | 81.0 | 83.3 | 85.2 |
| Plastic/ Liquid Limit | **51.4** | | | **81.3** | | | |
| Plasticity Index | **29.9** | | | | | | |



### 3. 10% Rice husk ash with 4% Lime

| 10% RHA + 4% Lime, Uncured | | | | | | |
|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | Liquid Limit | | | |
| No. Of Blows | | | 16 | 18 | 29 | 34 |
| Container No. | T-1 | W6 | W0 | 75 | 12 | W6 |
| Container + Wet Sample ($w_1$) | 20.01 | 18.15 | 55.21 | 53.11 | 41.00 | 38.53 |
| Container + Dry Sample ($w_2$) | 18.50 | 16.86 | 37.01 | 36.38 | 29.89 | 27.97 |
| Container ($w_3$) | 15.72 | 14.45 | 15.56 | 15.81 | 16.00 | 14.45 |
| Moisture Content (($w_1$-$w_2$)/($w_2$-$w_3$)) | 54.51 | 53.23 | 84.79 | 81.28 | 80.00 | 78.14 |
| Plastic/ Liquid Limit (%) | **53.9** | | **81.0** | | | |
| Plasticity Index (%) | **27.1** | | | | | |

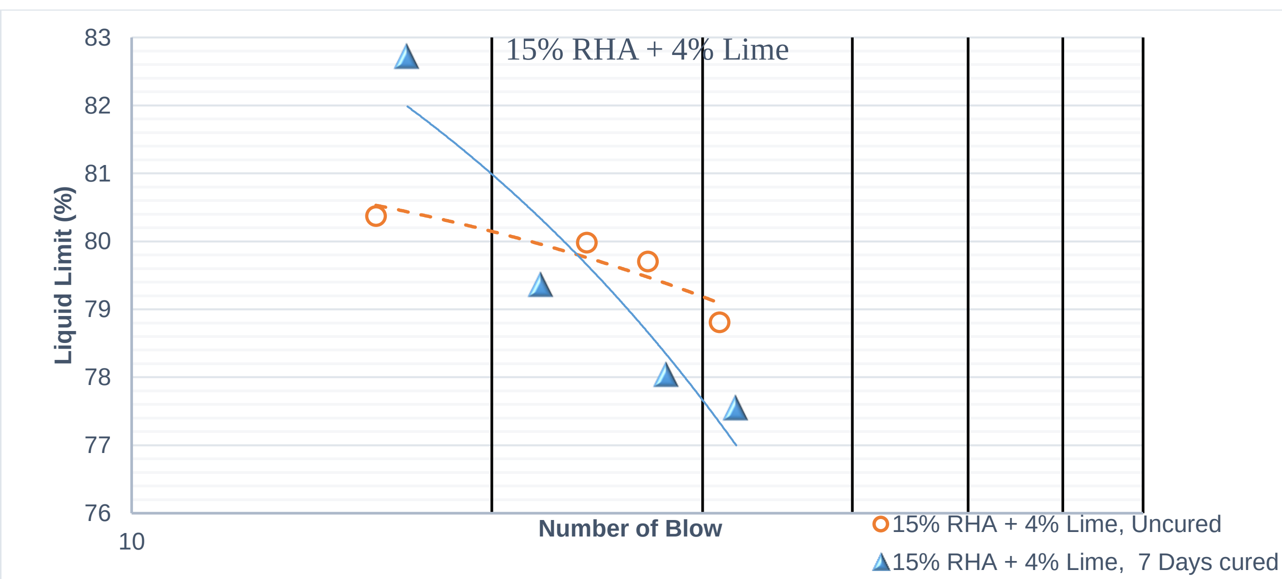
| 10% RHA + 4% Lime, 7 Days cured | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 34 | 27 | 20 | 16 |
| Container No. | W37 | W33 | W35 | W37 | co9 | W11 | W7 |
| Container + Wet Sample ($w_1$) | 20.2 | 20.44 | 19.67 | 38.03 | 35.39 | 41.37 | 38.9 |
| Container + Dry Sample ($w_2$) | 18.59 | 18.78 | 18.26 | 28.24 | 26.78 | 29.85 | 28.13 |
| Container ($w_3$) | 15.64 | 15.68 | 15.6 | 15.64 | 15.87 | 15.56 | 15.6 |
| Moisture Content (($w_1$-$w_2$)/($w_2$-$w_3$)) | 54.6 | 53.5 | 53.0 | 77.7 | 78.9 | 80.6 | 86.0 |
| Plastic/ Liquid Limit | **53.7** | | | **80.5** | | | |
| Plasticity Index | **26.8** | | | | | | |



**4. 15% Rice husk ash with 4% Lime**

| 15% RHA + 4% Lime, Uncured | | | | | | |
|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | Liquid Limit | | | |
| No. Of Blows | | | 16 | 24 | 27 | 31 |
| Container No. | 756 | W5 | W25 | 754 | W21 | 75 |
| Container + Wet Sample ($w_1$) | 20.60 | 19.83 | 41.65 | 42.39 | 43.19 | 43.39 |
| Container + Dry Sample ($w_2$) | 18.94 | 18.30 | 30.05 | 30.48 | 31.09 | 31.23 |
| Container ($w_3$) | 15.96 | 15.53 | 15.63 | 15.59 | 15.91 | 15.80 |
| Moisture Content (($w_1$-$w_2$)/($w_2$-$w_3$)) | 55.57 | 55.20 | 80.37 | 79.98 | 79.70 | 78.81 |
| Plastic/ Liquid Limit (%) | **55.4** | | **79.8** | | | |
| Plasticity Index (%) | **24.4** | | | | | |

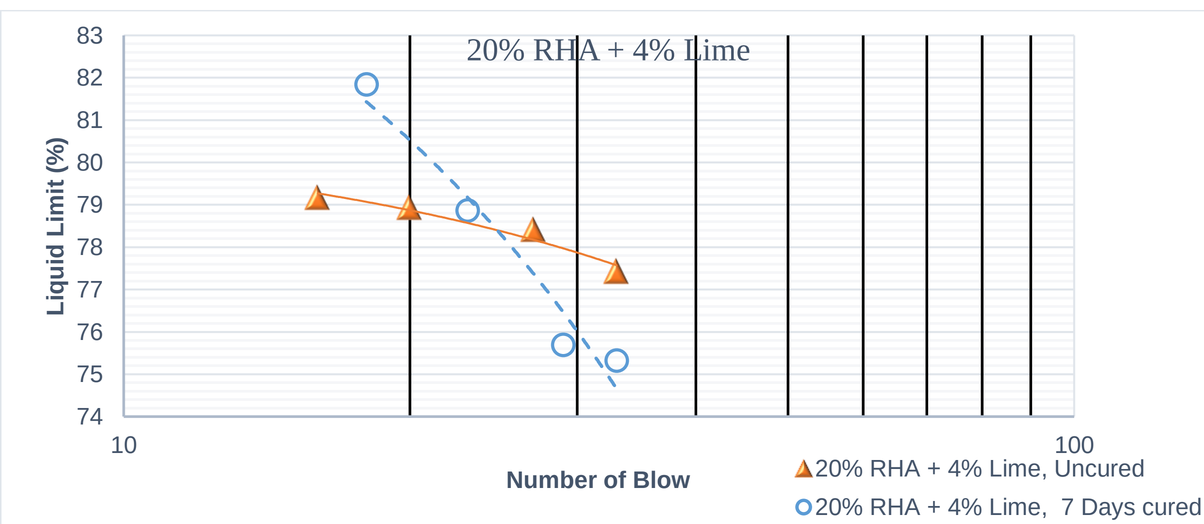
| 15% RHA + 4% Lime, 7 Days cured | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 17 | 32 | 28 | 22 |
| Container No. | Co9 | W21 | W12 | W28 | W12 | W21 | W29 |
| Container + Wet Sample ($w_1$) | 20.78 | 20.83 | 19.9 | 35.82 | 34.92 | 33.83 | 36.3 |
| Container + Dry Sample ($w_2$) | 19.03 | 19.11 | 18.46 | 26.73 | 26.6 | 25.98 | 27 |
| Container ($w_3$) | 15.87 | 15.92 | 15.87 | 15.74 | 15.87 | 15.92 | 15.28 |
| Moisture Content (($w_1$-$w_2$)/($w_2$-$w_3$)) | 55.4 | 53.9 | 55.6 | 82.7 | 77.5 | 78.0 | 79.4 |
| Plastic/ Liquid Limit | **55.0** | | | **79.5** | | | |
| Plasticity Index | **24.5** | | | | | | |



**5. 20% Rice husk ash with 4% Lime**

| **20% RHA + 4% Lime, Uncured** | | | | | | |
|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | Liquid Limit | | | |
| No. Of Blows | | | 16 | 20 | 27 | 33 |
| Container No. | S10 | 12 | 50 | 65 | 66 | K3 |
| Container + Wet Sample ($w_1$) | 31.75 | 43.83 | 36.39 | 34.4 | 38.29 | 37.63 |
| Container + Dry Sample ($w_2$) | 26.09 | 33.88 | 27.2 | 26.09 | 28.42 | 28.1 |
| Container ($w_3$) | 15.99 | 16 | 15.59 | 15.56 | 15.83 | 15.79 |
| Moisture Content $((w_1-w_2)/(w_2-w_3))$ | 56.0 | 55.6 | 79.2 | 78.9 | 78.4 | 77.4 |
| Plastic/ Liquid Limit (%) | **55.8** | | **78.5** | | | |
| Plasticity Index (%) | **22.7** | | | | | |

| **20% RHA + 4% Lime, 7 Days cured** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Test Type | Plastic Limit | | | Liquid Limit | | | |
| No. Of Blows | | | | 18 | 23 | 29 | 33 |
| Container No. | W5 | W0 | W29 | K3 | S10 | W5 | W0 |
| Container + Wet Sample ($w_1$) | 20.43 | 21.32 | 23.13 | 38.43 | 38.9 | 34.31 | 33.64 |
| Container + Dry Sample ($w_2$) | 18.71 | 19.29 | 20.3 | 28.24 | 28.8 | 26.22 | 25.87 |
| Container ($w_3$) | 15.53 | 15.56 | 15.28 | 15.79 | 15.99 | 15.53 | 15.56 |
| Moisture Content $((w_1-w_2)/(w_2-w_3))$ | 54.1 | 54.4 | 56.4 | 81.8 | 78.9 | 75.7 | 75.3 |
| Plastic/ Liquid Limit | **54.9** | | | **78.3** | | | |
| Plasticity Index | **23.4** | | | | | | |

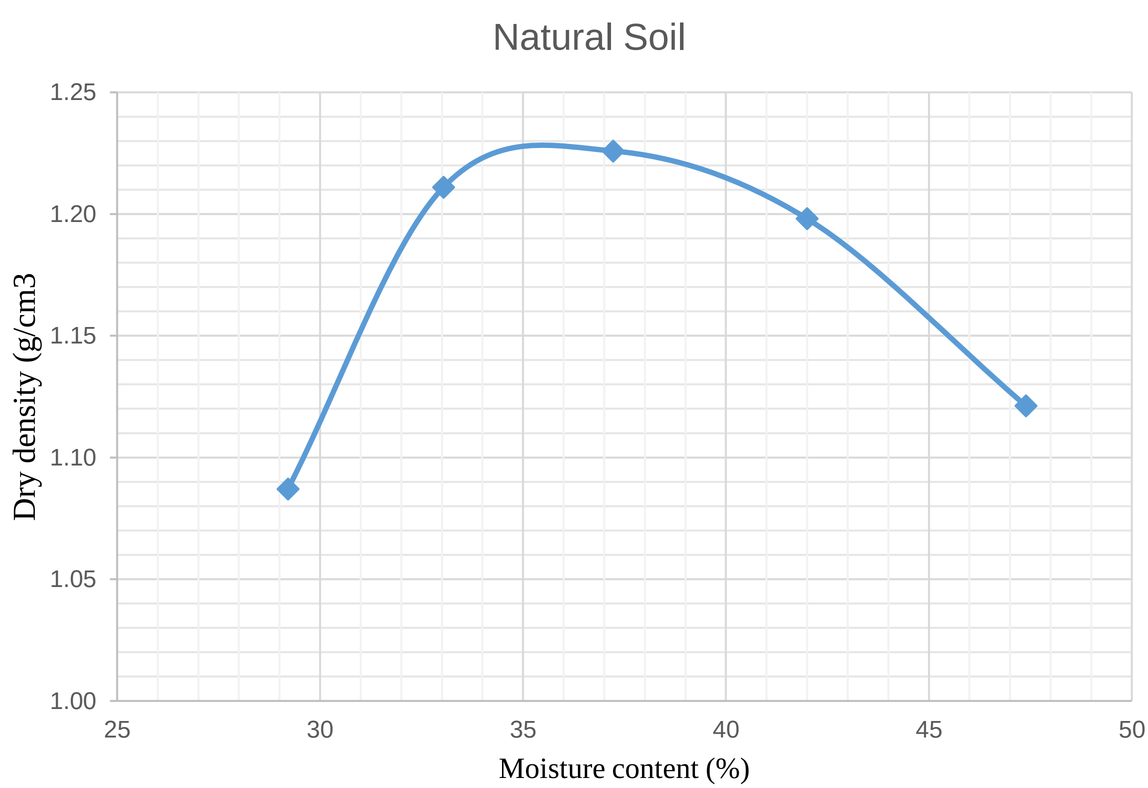


**Appendix 3: Free Swell test result for the varying percentage of Rice husk ash with and without lime**

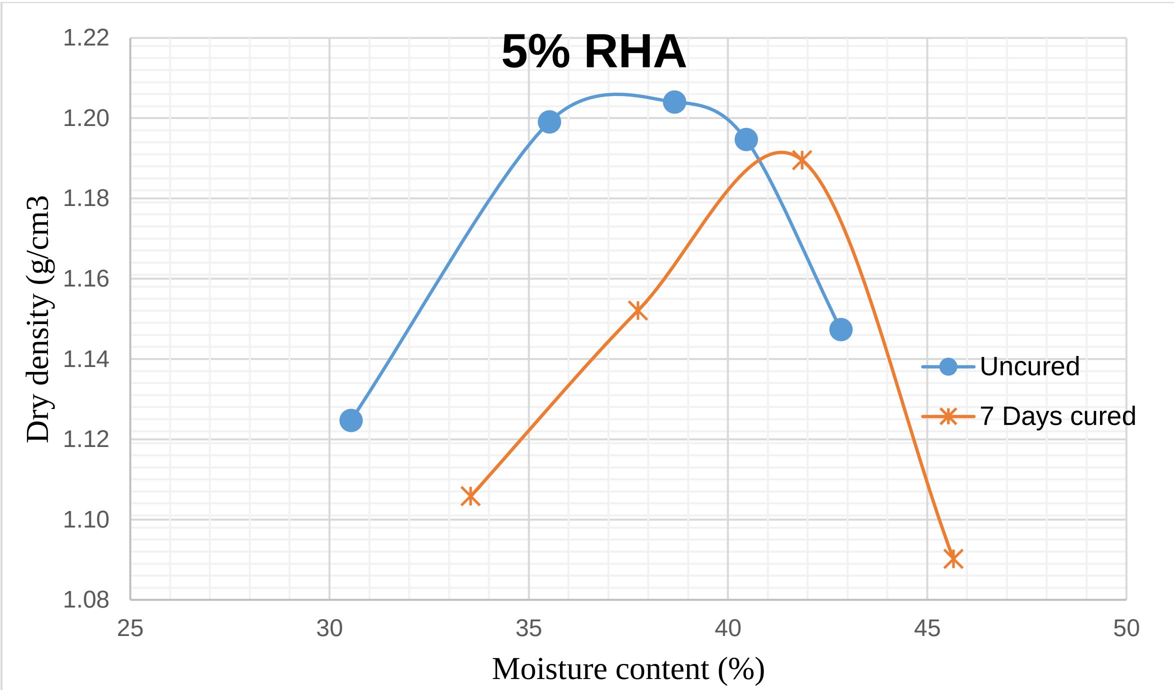
| Rice Husk Ash only | | | | | | |
|---|---|---|---|---|---|---|
| % RHA | 0 | 5 | 10 | 15 | 20 | 100 |
| Volume in kerosene | 10 | 11 | 12 | 14 | 17 | 29 |
| Volume in Water | 23 | 21 | 21 | 20 | 23 | 30 |
| free swell | 130% | 91% | 75% | 43% | 35% | 3% |
| free swell ratio | 2.30 | 1.91 | 1.75 | 1.43 | 1.35 | 1.03 |
| Rice Husk Ash with 4% Lime | | | | | | |
| % RHA + 4% lime | 0 | 5 | 10 | 15 | 20 | 4 |
| Volume in kerosene | 10 | 11 | 12 | 13 | 15 | 10 |
| Volume in Water | 23 | 17 | 16 | 17 | 18 | 16 |
| free swell | 130% | 55% | 33% | 31% | 20% | 60% |
| free swell ratio | 2.30 | 1.55 | 1.33 | 1.31 | 1.20 | 1.60 |

**Appendix 4: Compaction curves Test Results for a varying percentage of RHA Content**

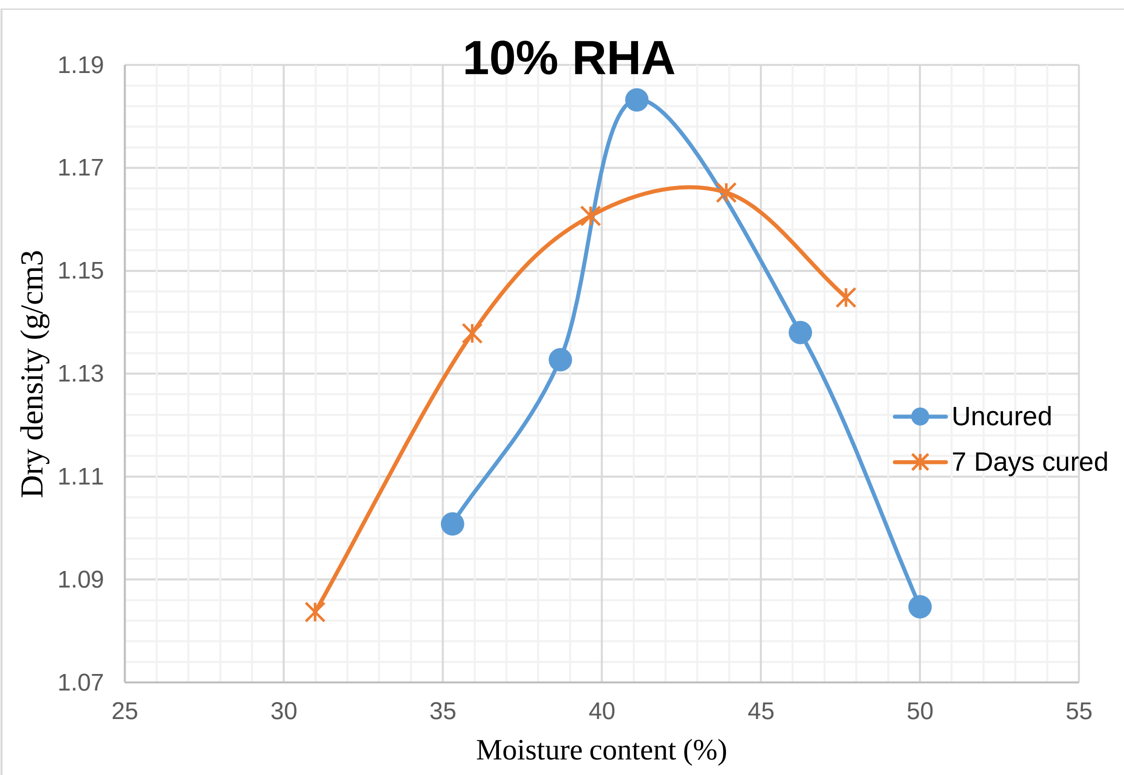
1. **0% Rice husk ash**



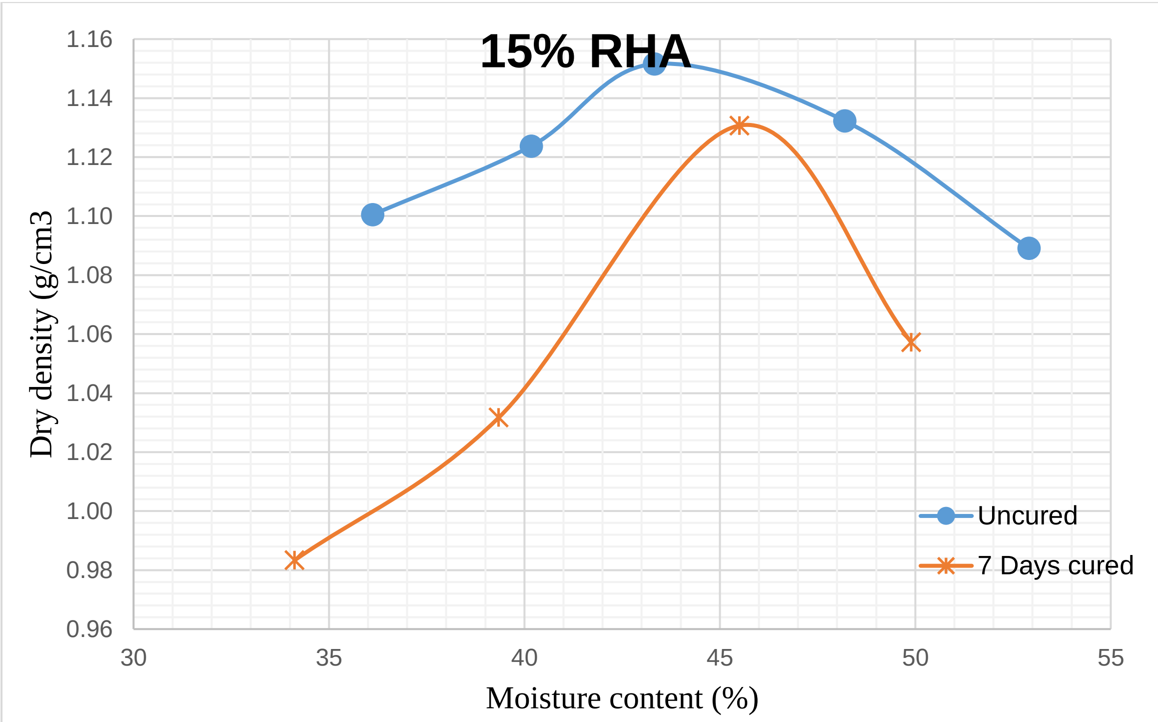
2. **5% Rice husk ash**



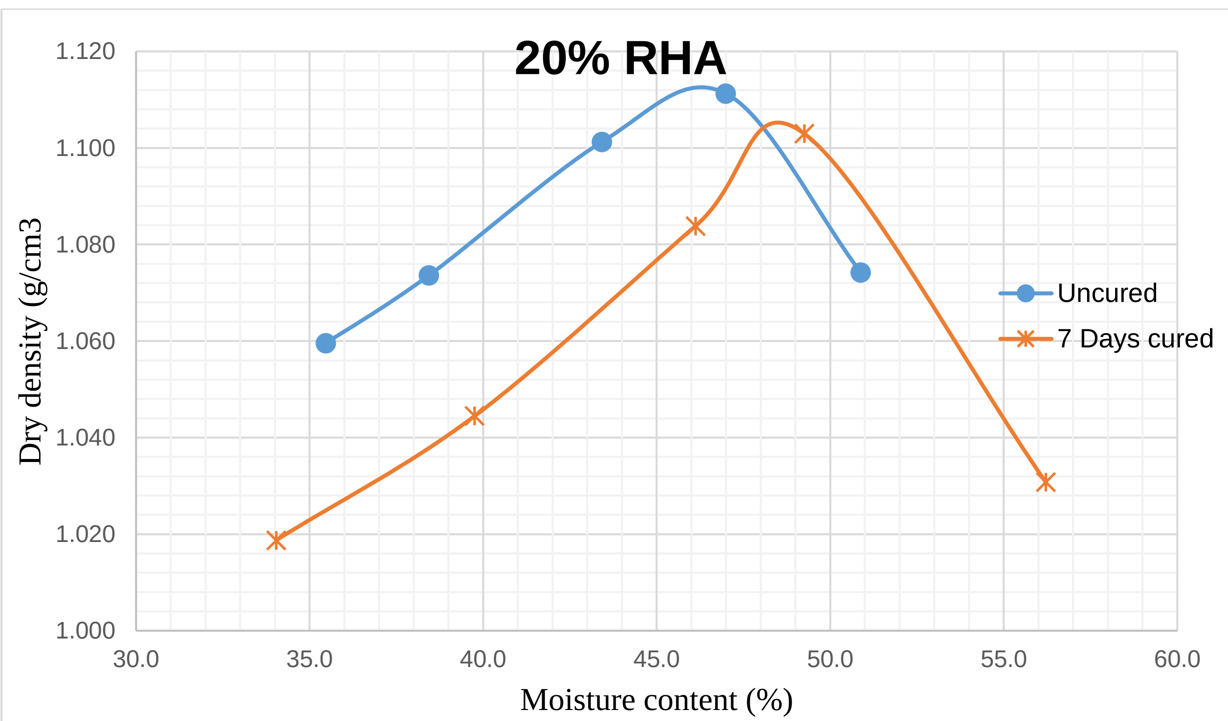

3. **10% Rice husk ash**



4. **15% Rice husk ash**

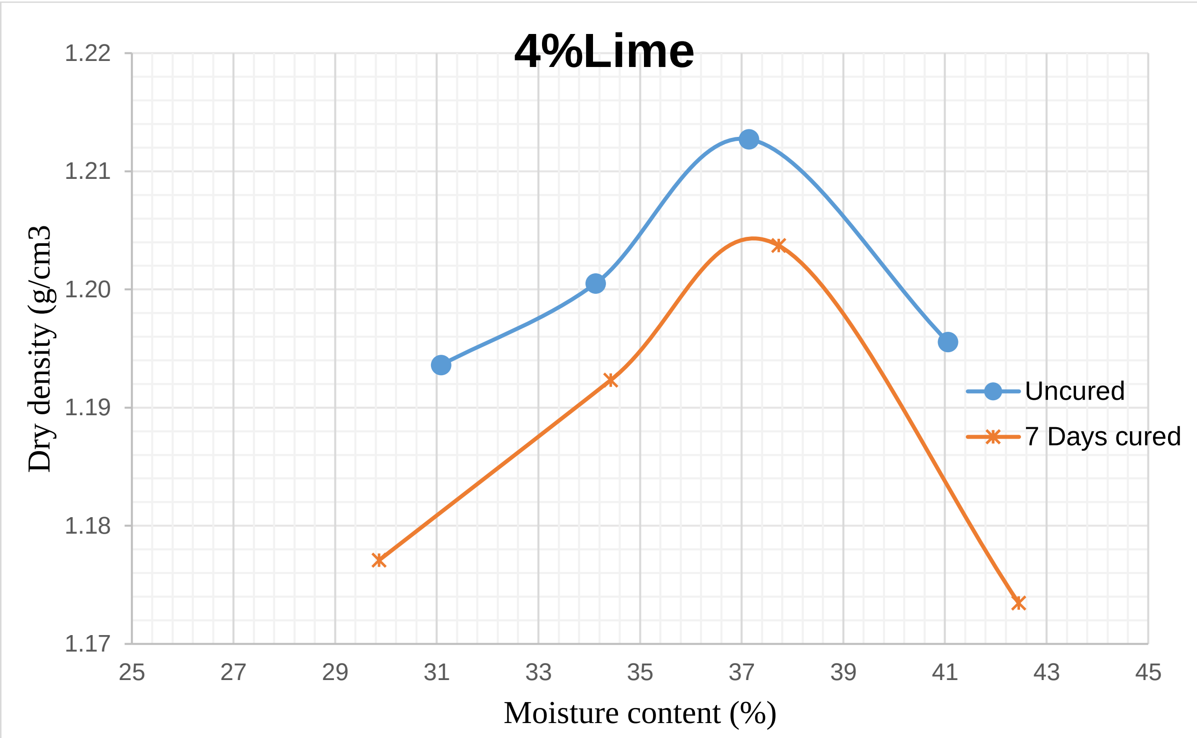



5. **20% Rice husk ash**

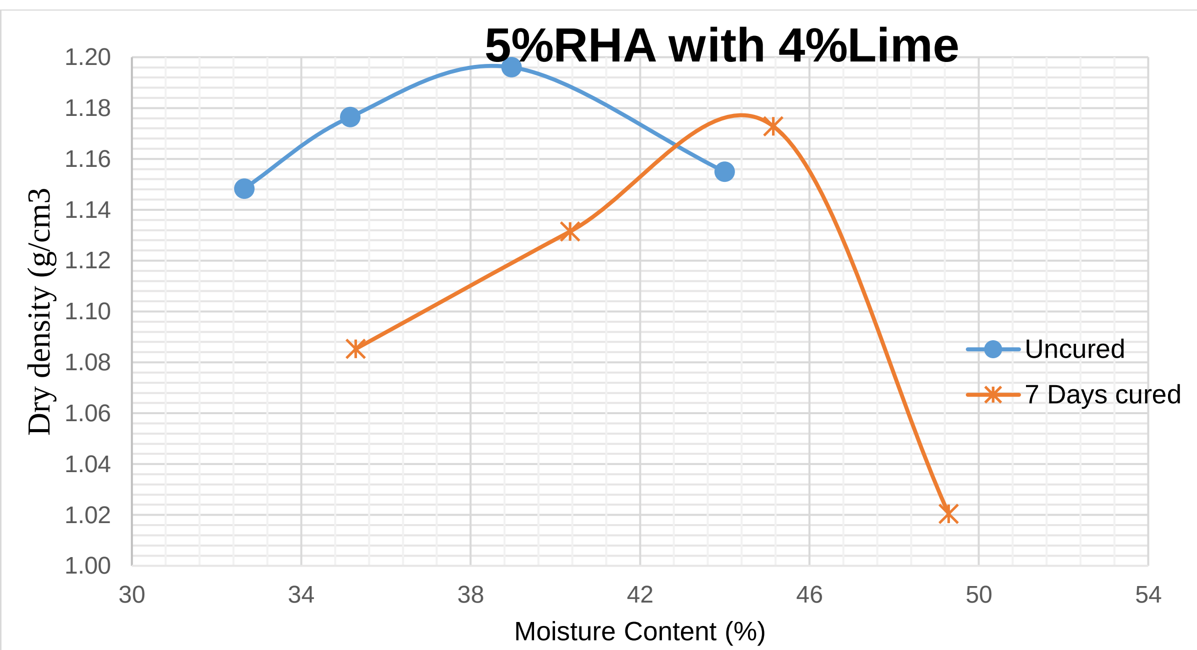


**Appendix 5: Compaction curves test results for the varying percentage of RHA Content with 4% lime**

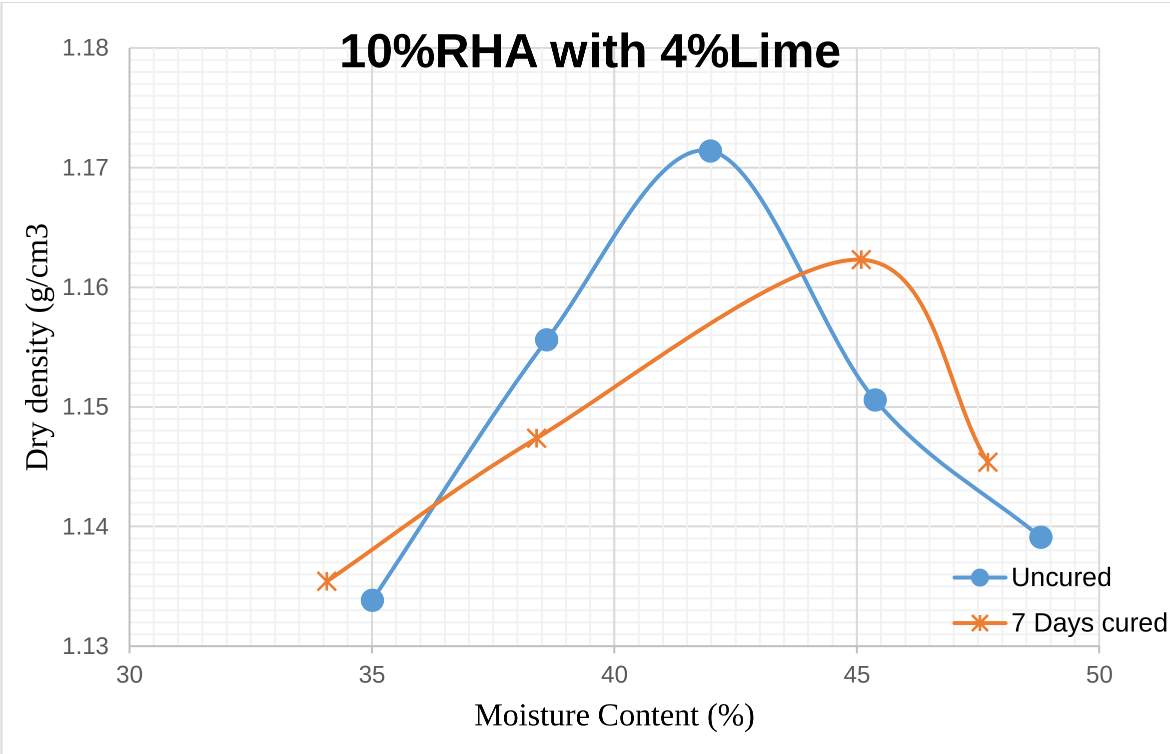
1. **0% Rice husk ash with 4% Lime**



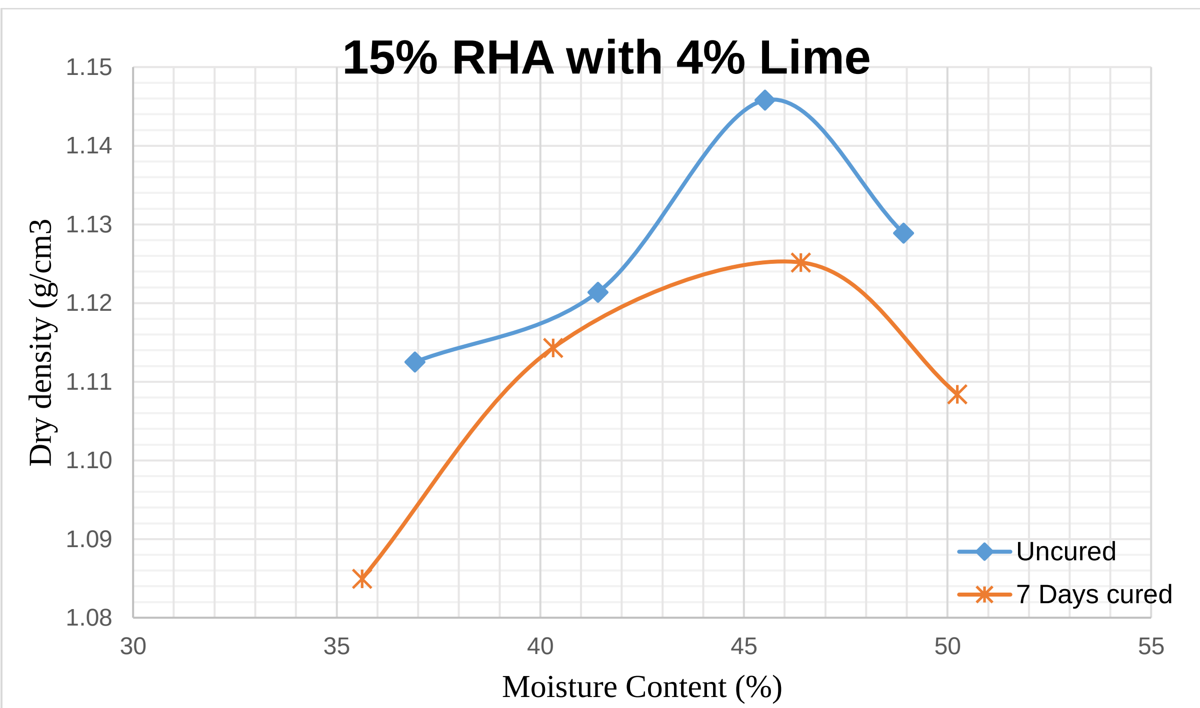

2. **5% Rice husk ash with 4% Lime**



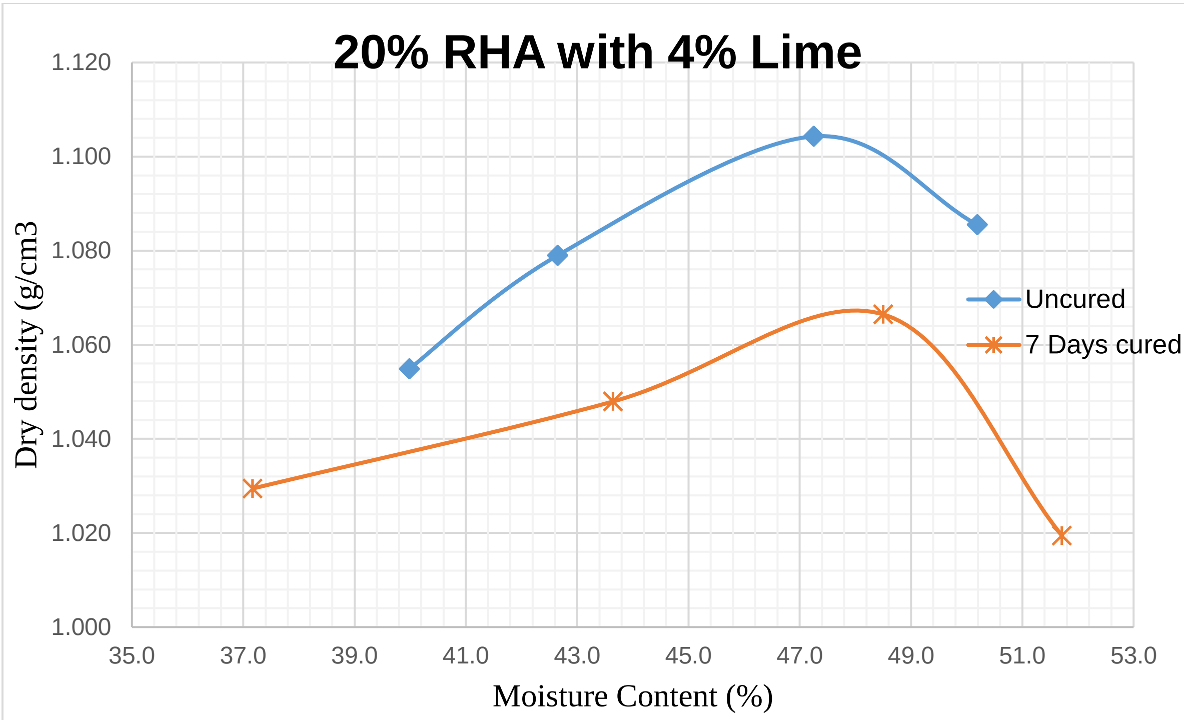
**3. 10% Rice husk ash with 4% Lime**




**4. 15% Rice husk ash with 4% Lime**

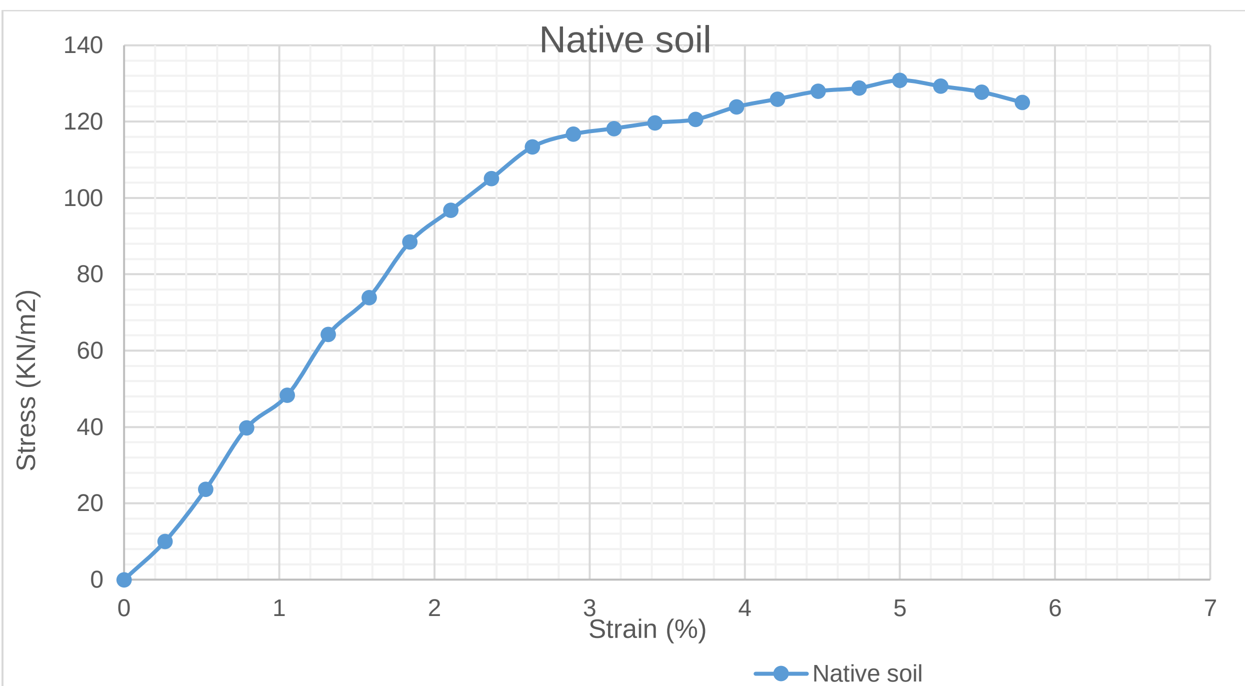


5. **20% Rice husk ash with 4% Lime**

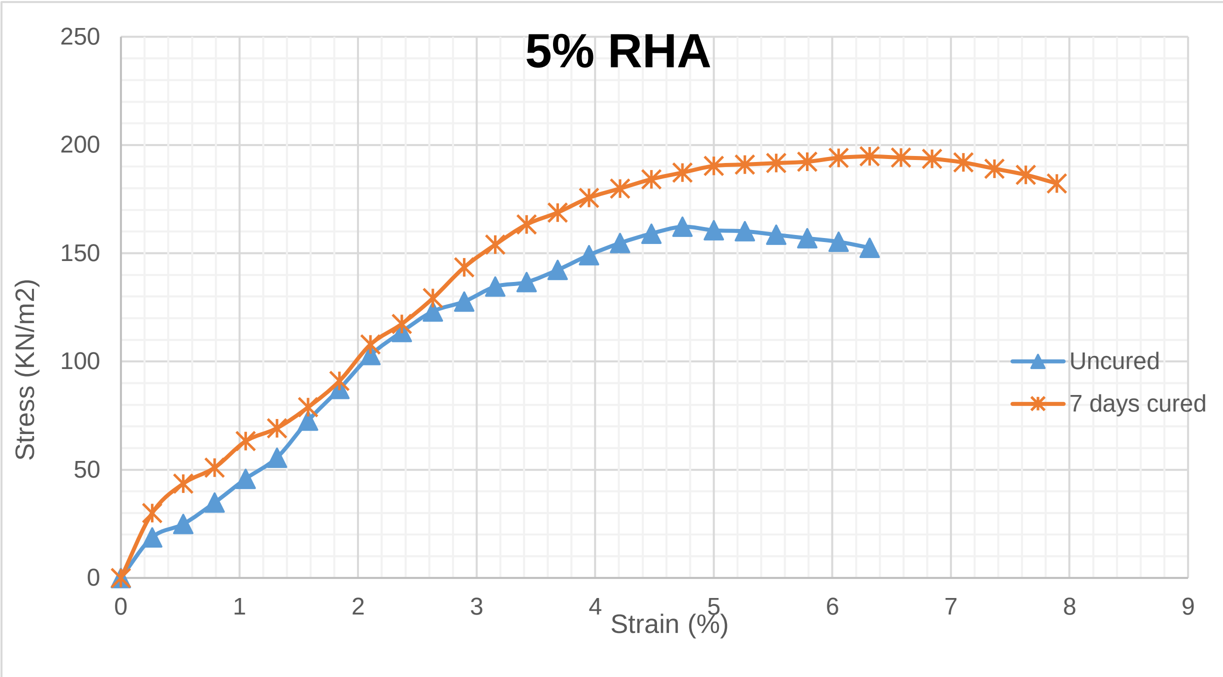



**Appendix 6: UCS curves for a varying percentage of RHA Content**

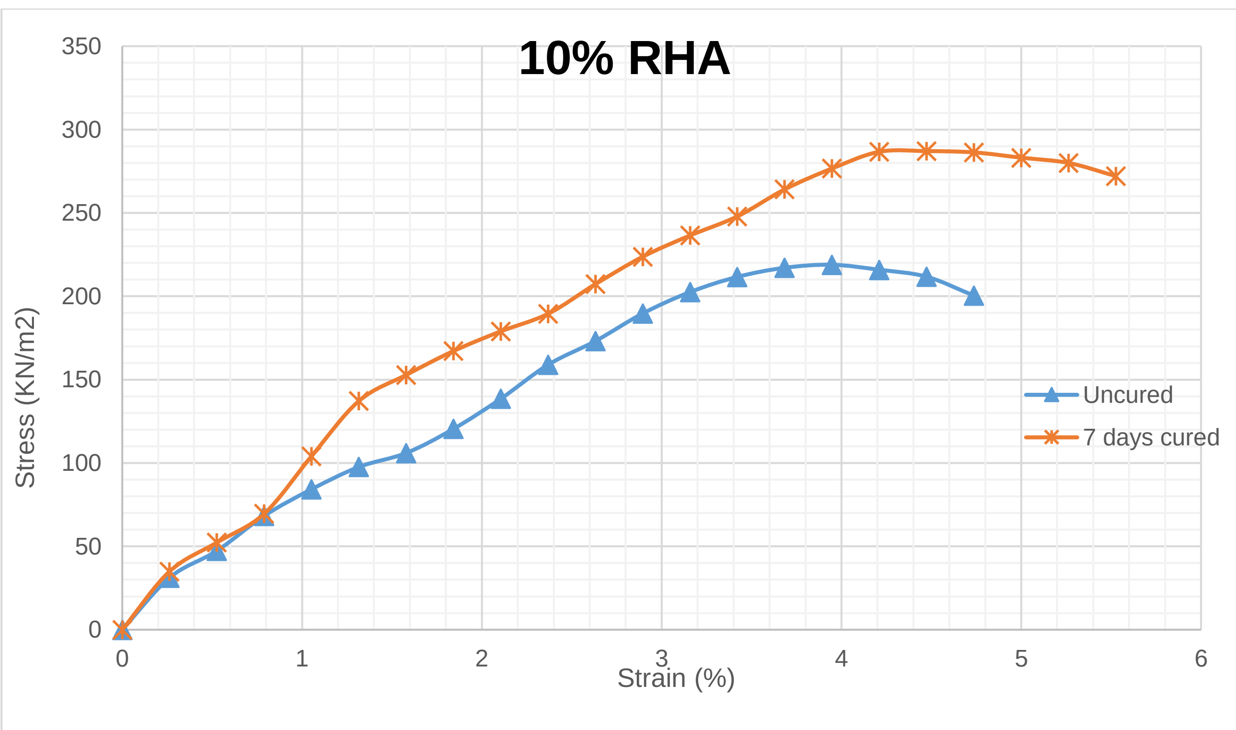
1. **0% Rice husk ash**



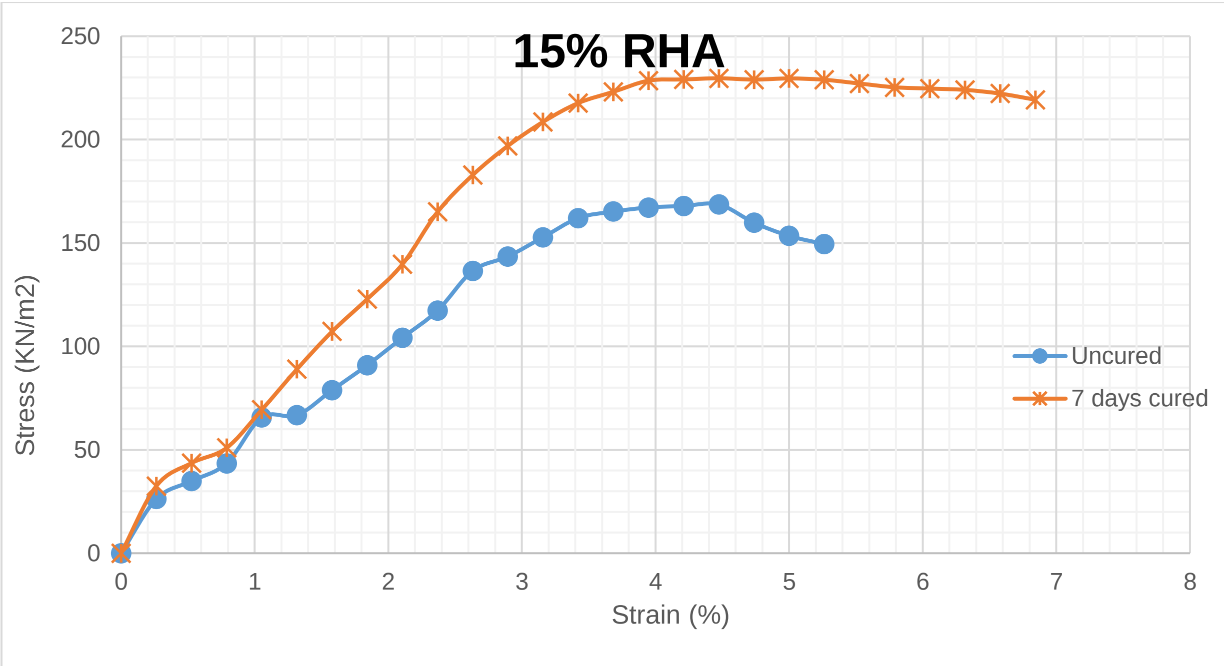
2. **0% Rice husk ash**



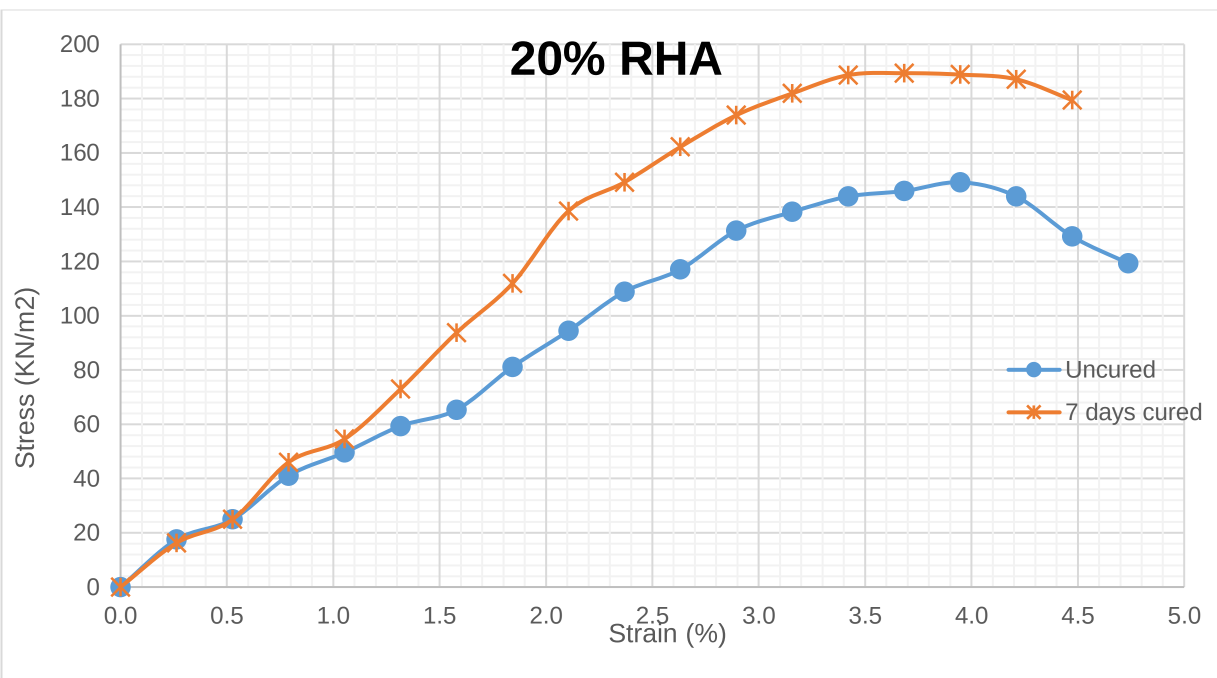

3. **10% Rice husk ash**



4. **15% Rice husk ash**

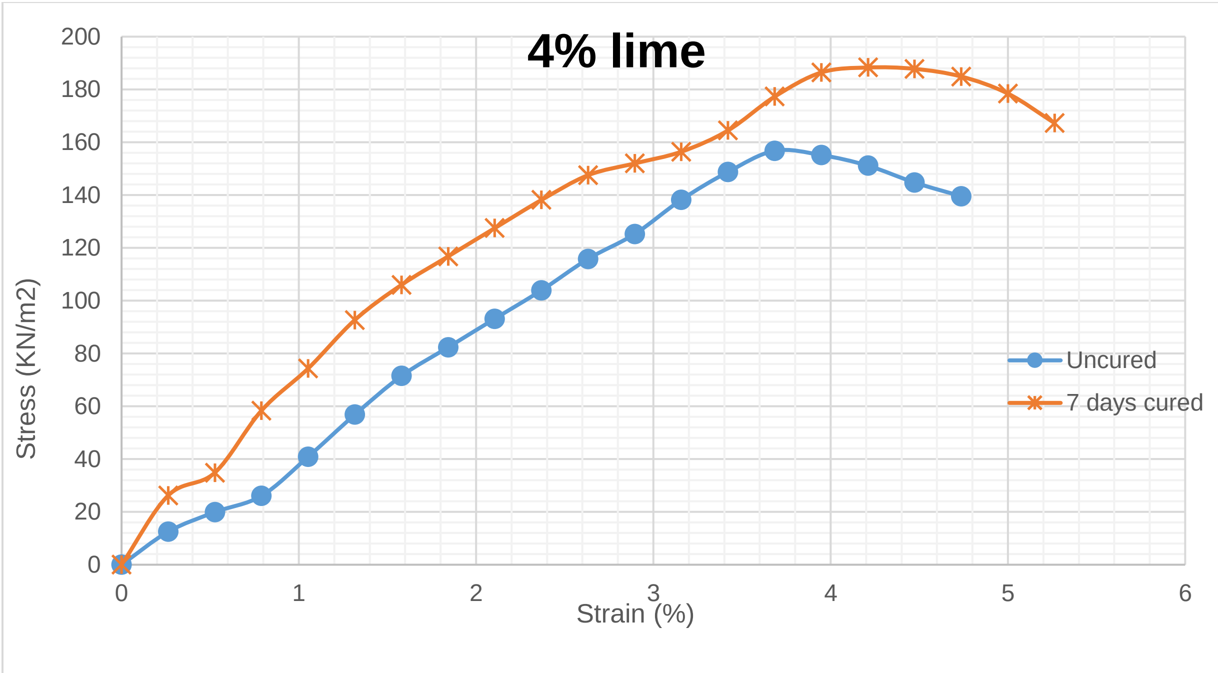



5. **20% Rice husk ash**

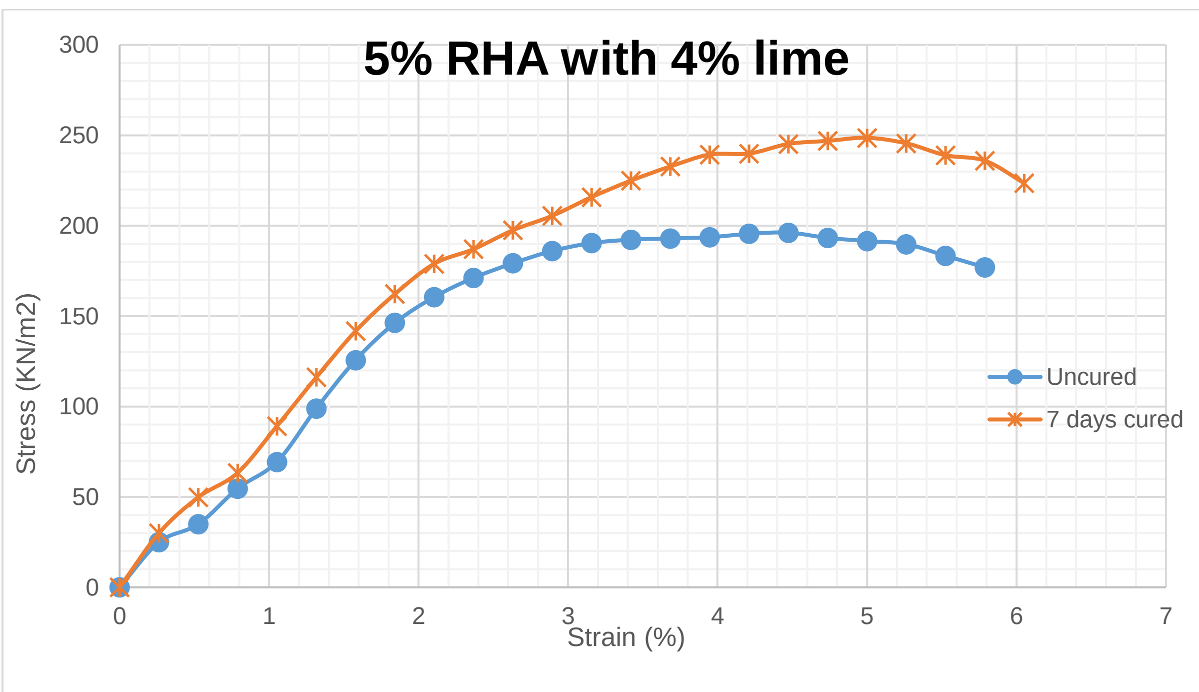


## Appendix 7: UCS curves for a varying percentage of RHA content with 4% lime

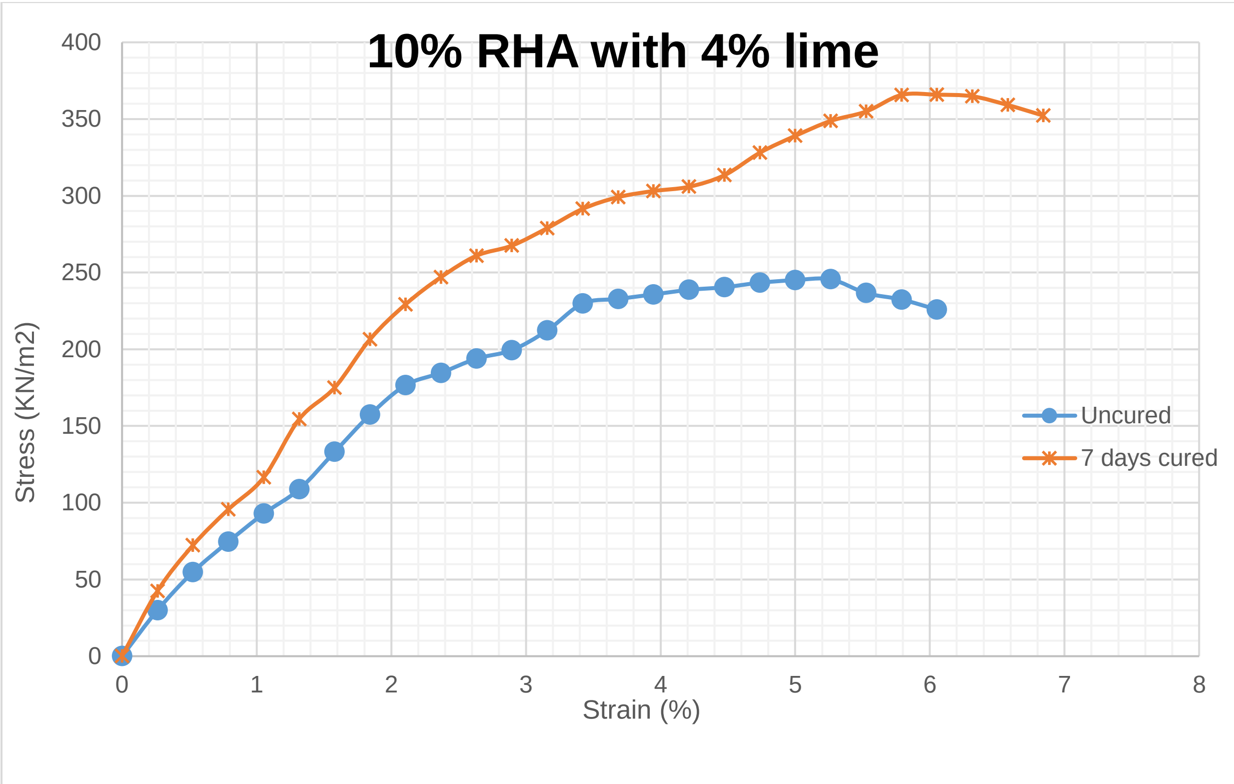
### 1. 0% Rice husk ash with 4% Lime



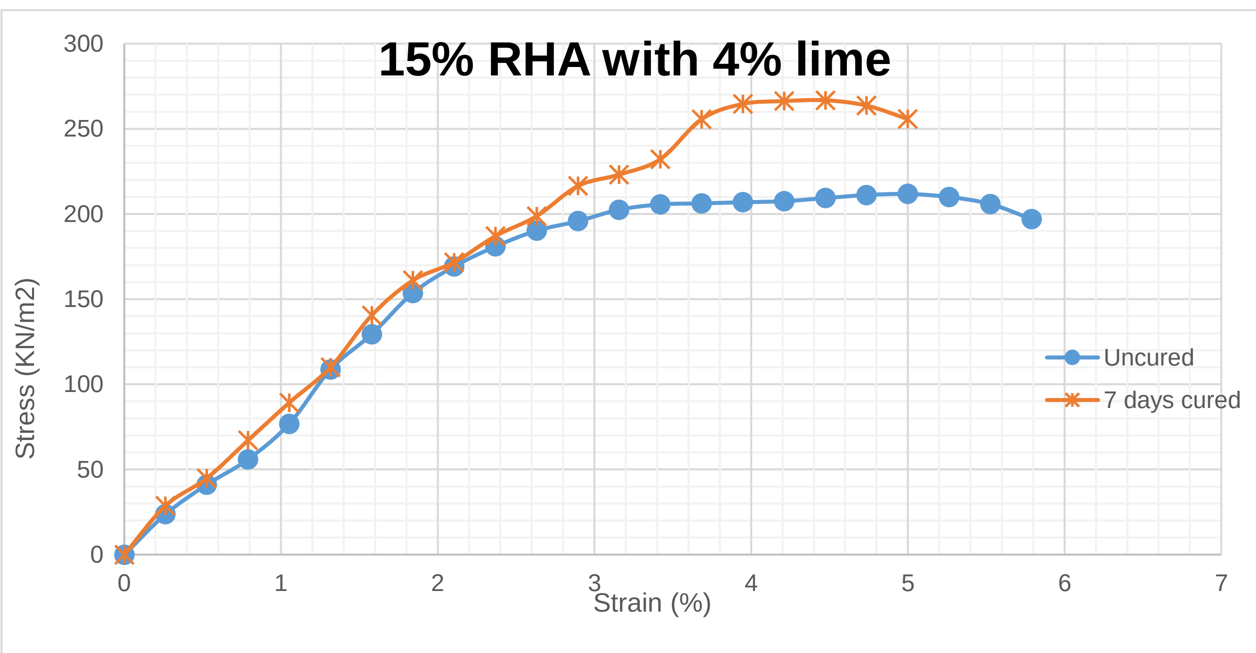

### 2. 5% Rice husk ash with 4% Lime



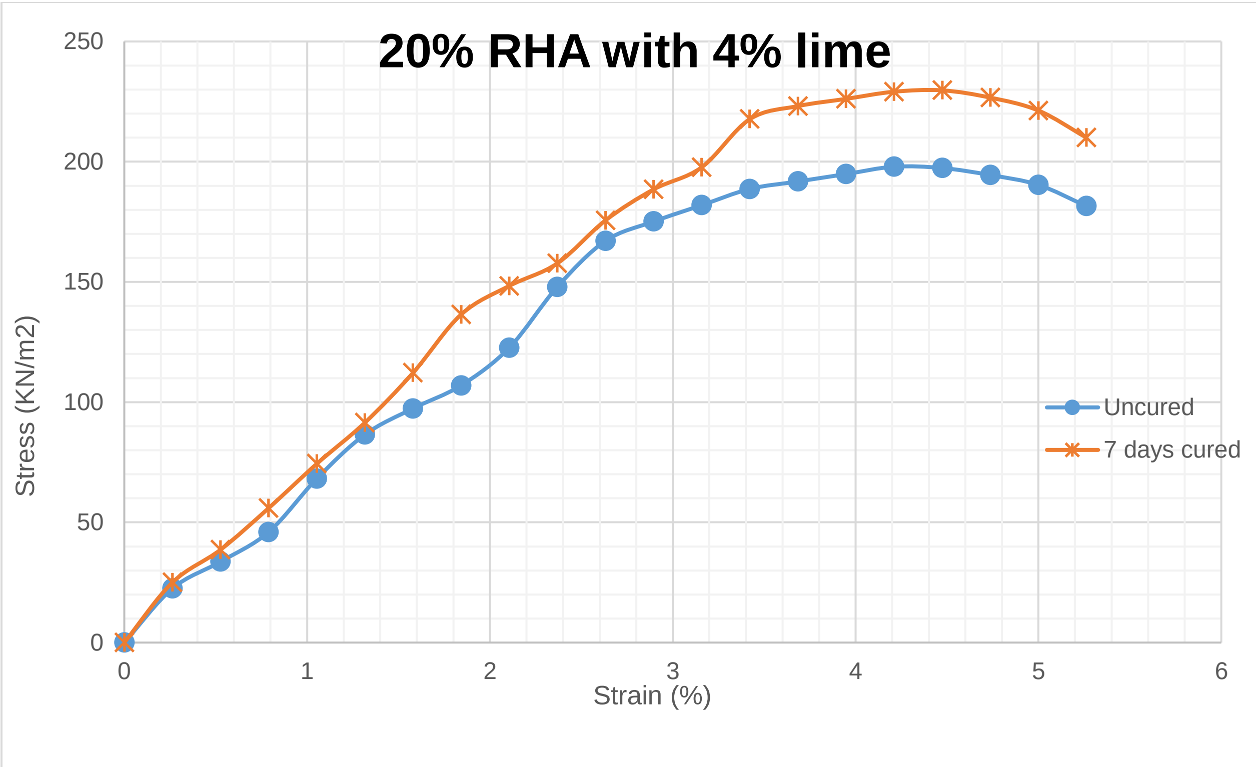
3. **10% Rice husk ash with 4% Lime**




4. **15% Rice husk ash with 4% Lime**

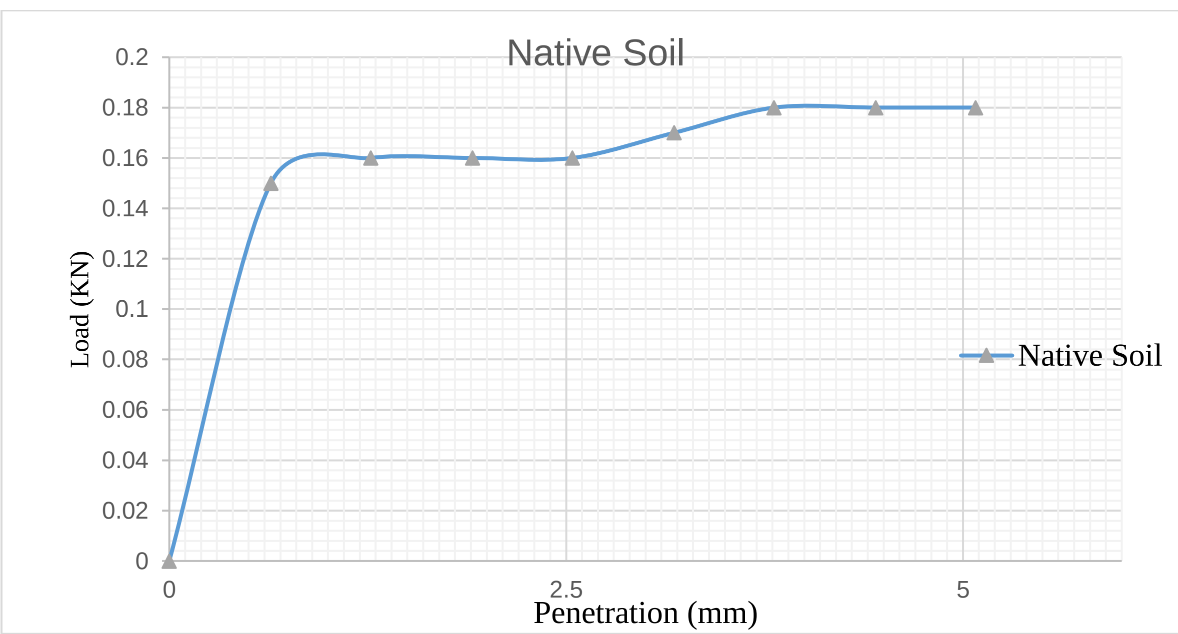


5. **20% Rice husk ash with 4% Lime**

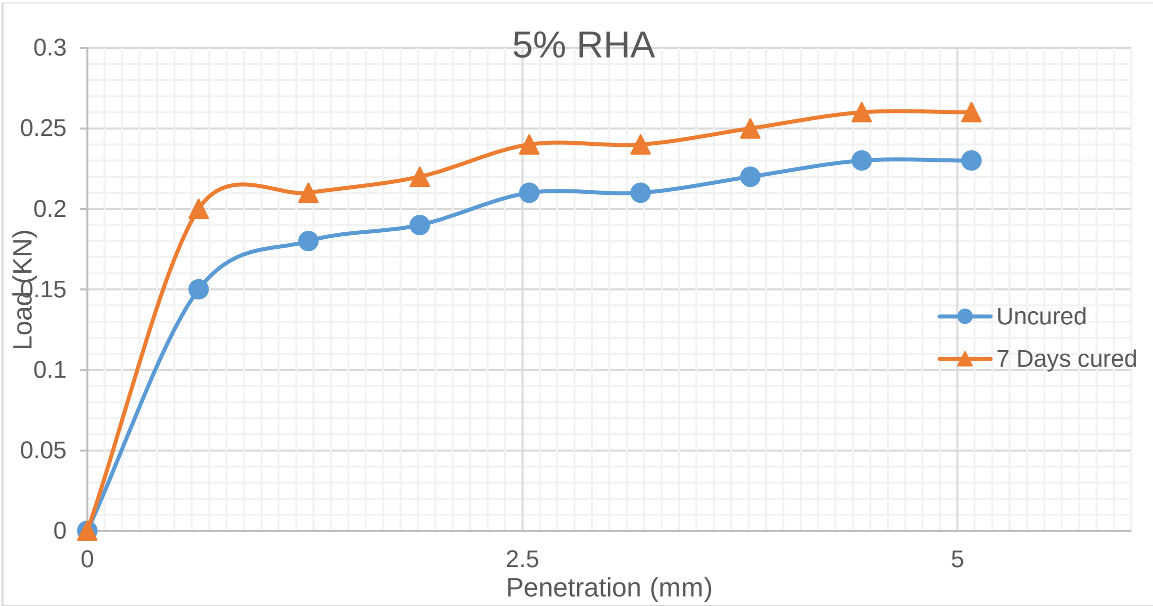



**Appendix 8: CBR curves for the varying percentage of RHA content**

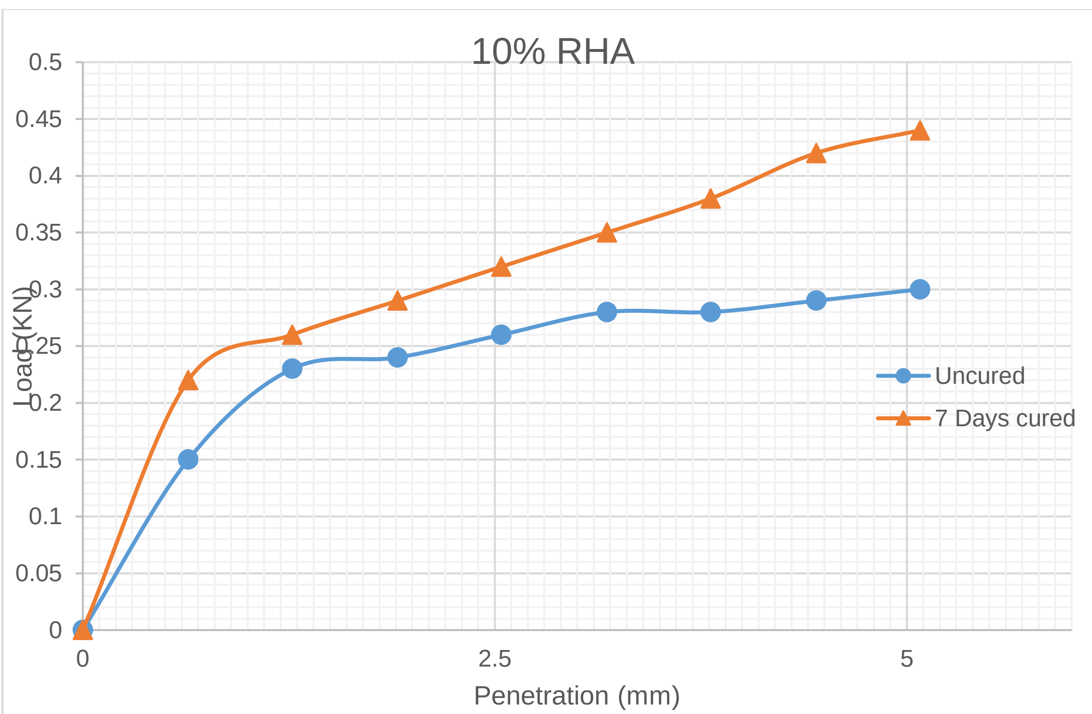
1. **0% Rice husk ash**



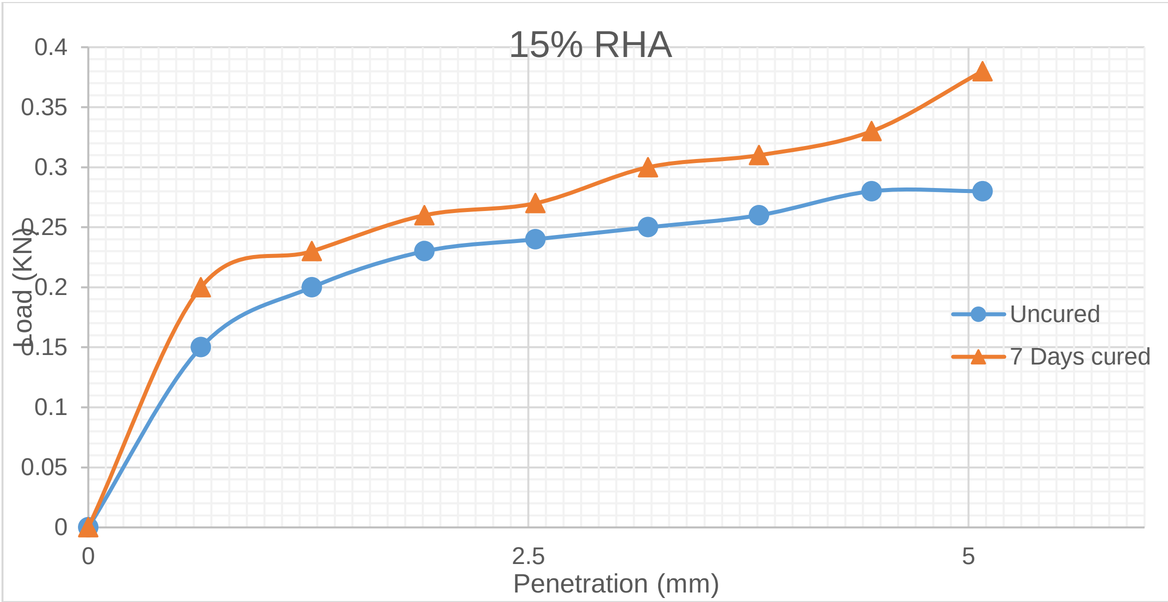

2. **5% Rice husk ash**



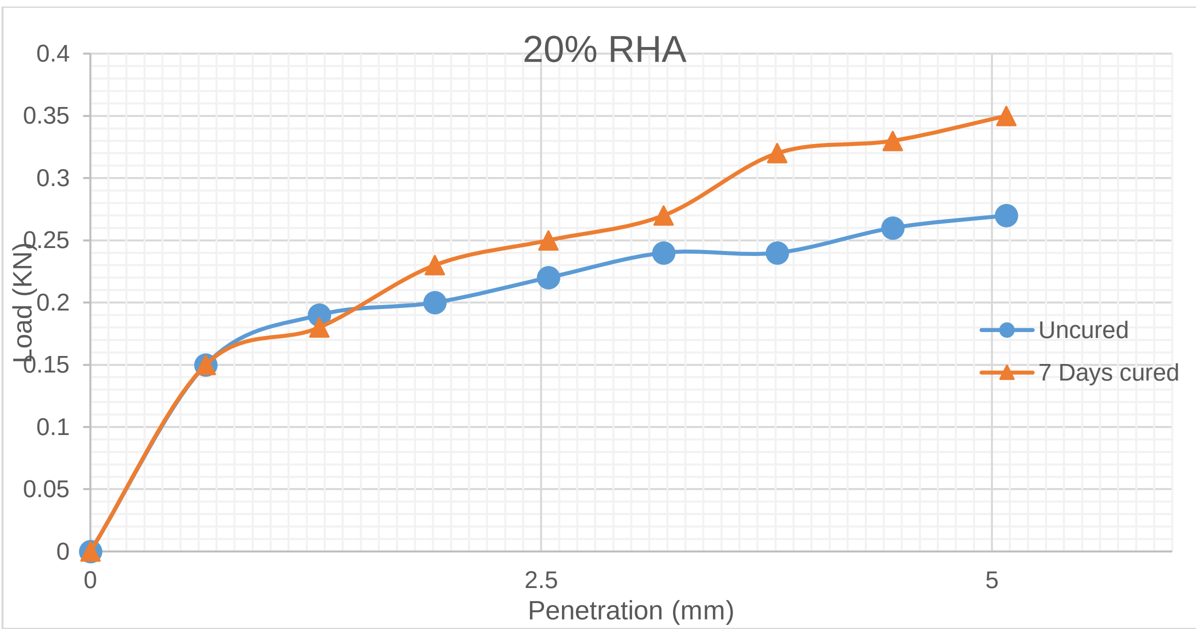

**3. 10% Rice husk ash**



4. **15% Rice husk ash**

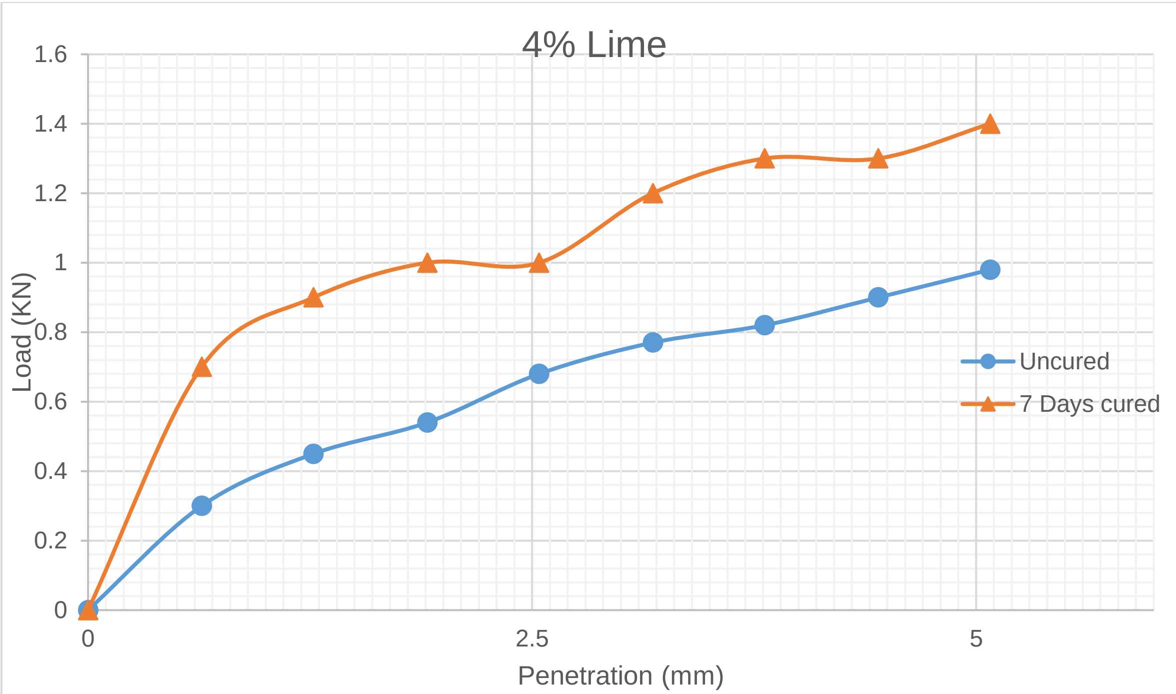



5. **20% Rice husk ash**

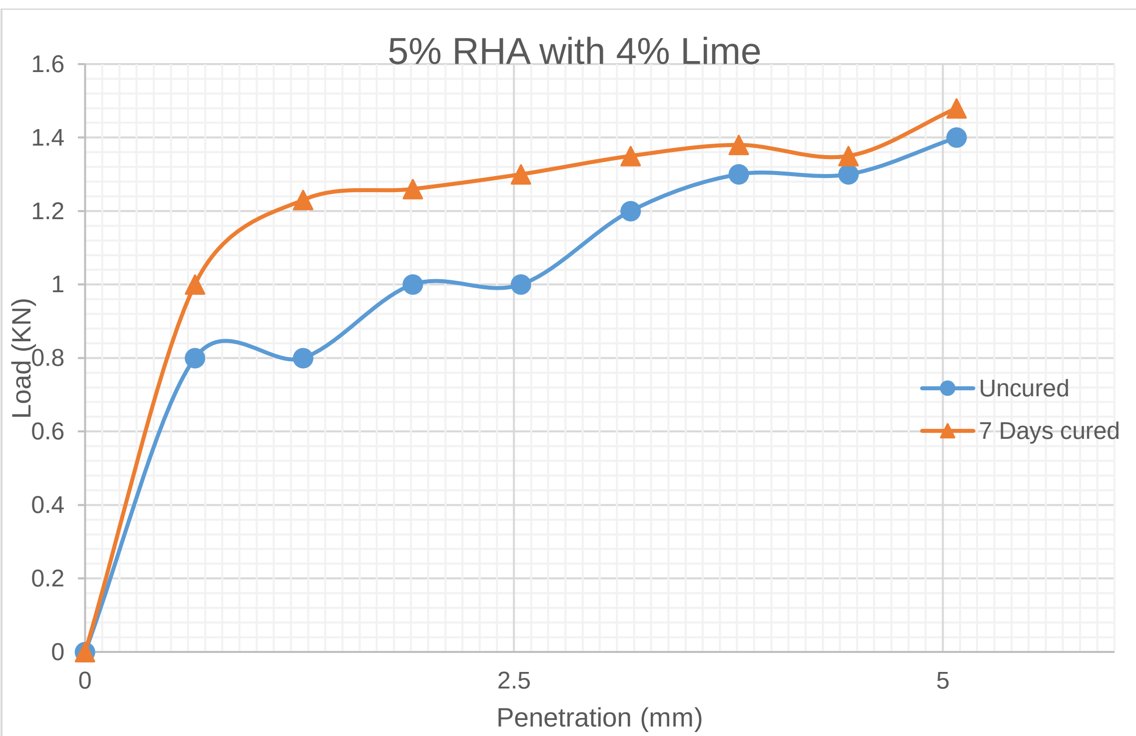


**Appendix 9: CBR curves for a varying percentage of RHA content with 4% lime**

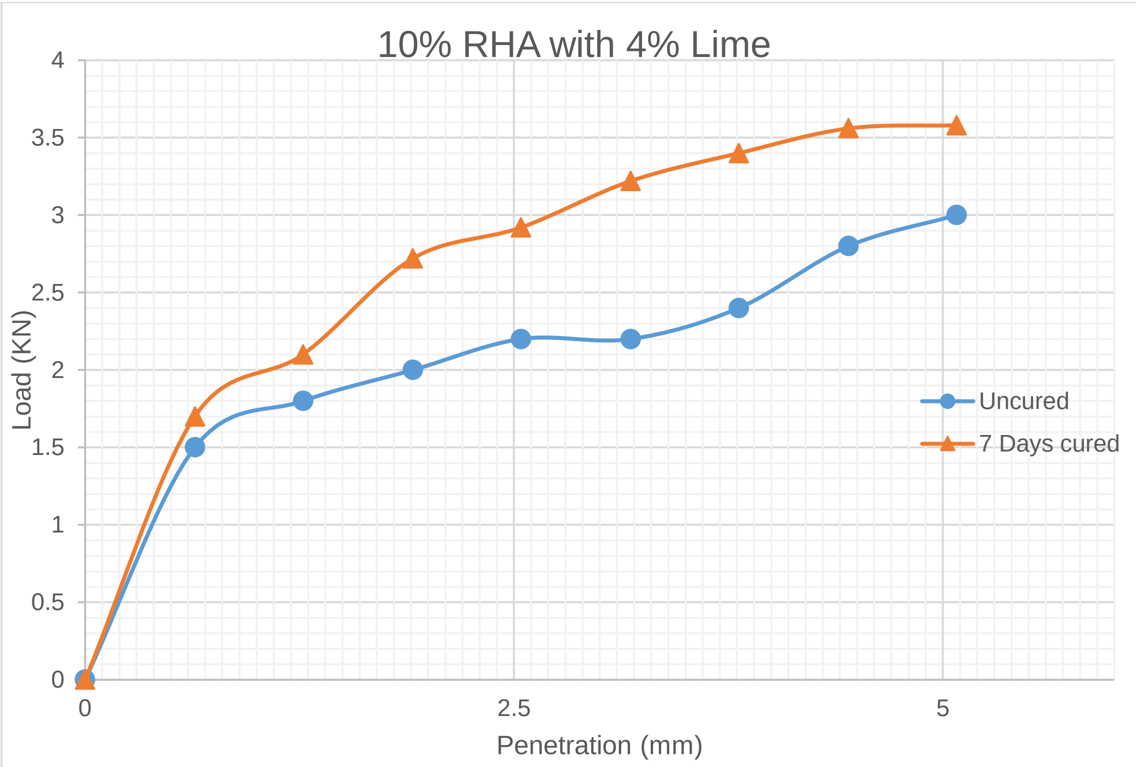
1. **0% Rice husk ash with 4% Lime**



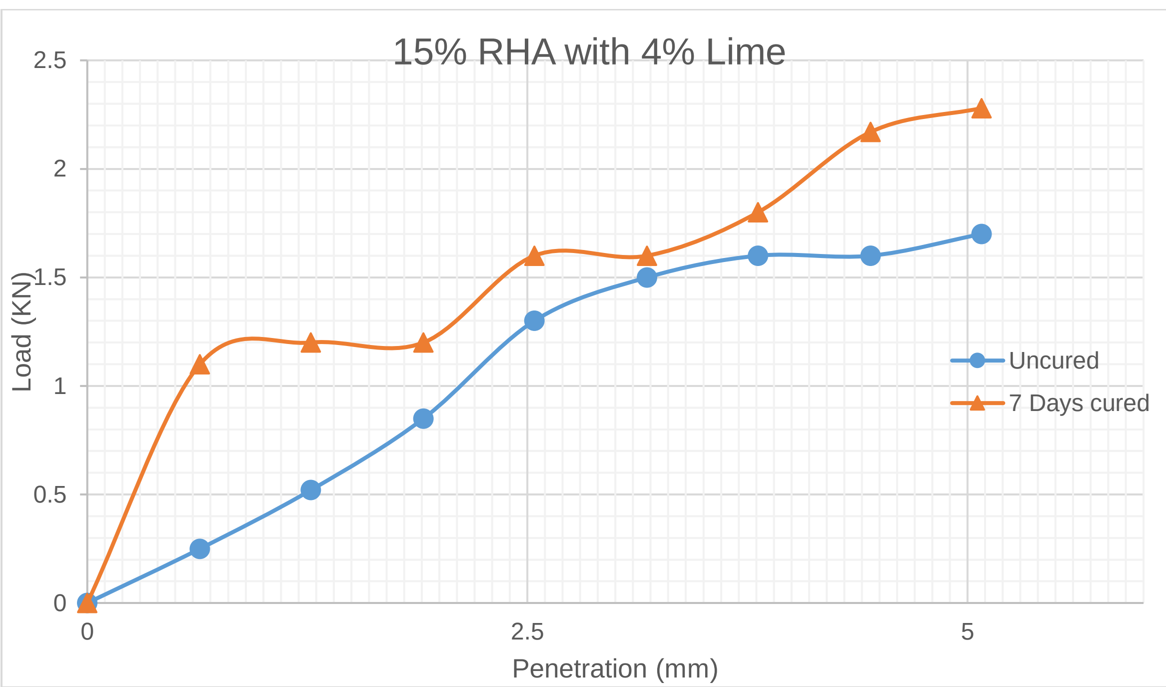

2. **5% Rice husk ash with 4% Lime**



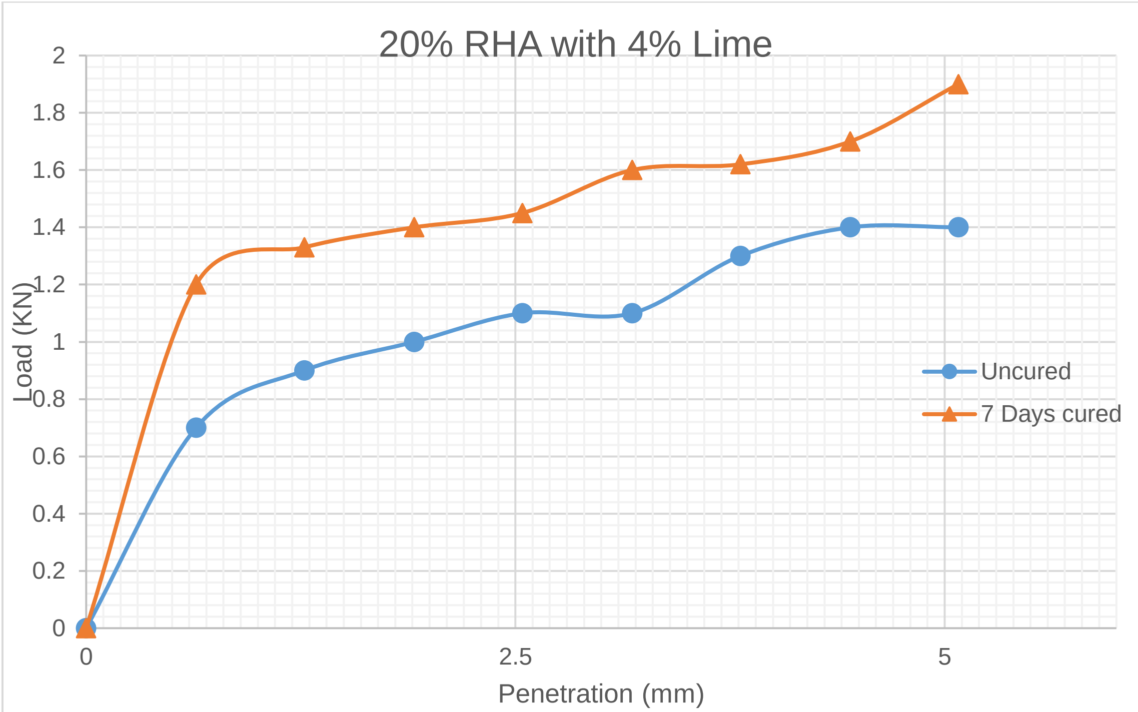
3. **10% Rice husk ash with 4% Lime**




4. **15% Rice husk ash with 4% Lime**



**5. 20% Rice husk ash with 4% Lime**



| | | | |
|---|---|---|---|
| | **GEOLOGICAL SURVEY OF ETHIOPIA** | **Doc.Number: GLD/F5.10.2** | **Version No: 1** |
| | **GEOCHEMICAL LABORATORY DIRECTORATE** | | Page 1 of 1 |
| Document Title: | **Complete Silicate Analysis Report** | **Effective date:** | **May, 2017** |

Issue Date: -05/10/2020

Customer Name: - Chalachew Adams

Request No:- GLD/RQ/138/20

Report No:- GLD/RN/633/20

Sample type:- RHA

Sample Preparation: - 200 Mesh

Date Submitted: - 26/08/2020

Number of Sample:- One(1)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

| Collector's code | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | MnO | $P_2O_5$ | $TiO_2$ | $H_2O$ | LOI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rice Hush Ash | 75.50 | 3.50 | 0.88 | 2.20 | 0.60 | <0.01 | 1.48 | 0.12 | 1.12 | 0.02 | 4.62 | 10.71 |

**Note:** - This result represent only for the sample submitted to the laboratory.

| Analysts | Checked By | Approved By | Quality Control |
|---|---|---|---|
| Lidet Endeshaw | Yohannes Getachew | Gosa Haile | Negash Worku |
| Tizita Zemene | | | |
| Kindie Kassahun | | | |
| Elsa Fisseha | | | |