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STABILIZATION OF SOIL BLOCK MASONRY WITH PUMICE

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LIST OF ABBREVIATIONS

AASHTO	American Association of Highway and Transportation Officials
ASTM	American Society for Testing and Materials
IS	Indian standard
LL	Liquid Limit
PL	Plastic Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plastic Index
PL	Plastic Limit
UCS	Unconfined compressive strength
8P	8% pumicite
10P	10% pumicite
12P	12% pumicite
10P3S	10% pumicite and 3% straw fiber
10P6S	10% pumicite and 6% straw fiber
10P9S	10% pumicite and 9% straw fiber
E3S	Earth and 3% straw fiber
E6S	Earth and 6% straw fiber
E9S	Earth and 9% straw fiber
E	Only earth
TWA	Total Water Absorption

ABSTRACT

The old traditional earth block methods of construction are currently reconsidered as a very environmentally friendly alternative to modern buildings due to the advantages they provide, such as the complete recycling of materials, low energy consumption during the manufacturing process and service life, as well as the comfort and health aspects of people living in them. Soil is widely used in the traditional construction of mud houses called "Chika bet''. Soil as a building material is available in most areas of the country.

The weak sides of earth block masonry such as low bearing capacity and low resistance to moisture have been overcome by stabilizing it with pumicite/volcanic ash. The compressive strength of the mud blocks increased by the pumicite.

This thesis studies the effect of the proportion between the soil and the stabilizers (such as pumicite and straw fiber) on stabilized earth blocks strength. It also compares mechanical properties (compressive strength and absorption) of stabilized earth blocks which are prepared using only local soils (which is taken from Adama, Boku area) and with the addition of stabilizers (pumicite and straw fiber).

This research provides detailed technical information on suitable soil types for stabilized earth house construction, stabilizers and production of stabilized earth blocks. Related literatures review show that soil types, proportions between soil and amount of stabilizer and compaction pressure applied to the moist soil mix affects the quality of the stabilized earth block. In this study pumicite/volcanic ash is used as a stabilizing agent. It is highly porous volcanic rock and highly deposited in Bulbula, Ziway area. Soil from Adama was the target for testing and investigation.Laboratory tests were conducted on Boku area soil and provided detailed information on the soil grading and other engineering properties of the natural soil. The result was compared with standard values to verify suitability of the soil for soil stabilized earth block production. It is possible to determine the suitability of other area soils by applying the same technique.

Using soil from Boku area of Adama and stabilizers (pumicite and straw fiber), ten different types of samples were prepared. Tests were conducted on these samples in order to evaluate their performance such as compressive strength and total water absorption capacity on which the durability of the blocks depends.

The effect of the pumicite and the straw fiber content in stabilized mixture was evaluated and comparisons were made for all block samples.

The investigation has revealed that, out of all block samples, blocks which are produced from 10% pumicite (10P), 10% pumicite with 3% straw fiber (10P3S), 10% pumicite with 6% straw fiber (10P6S) and 10% pumicite with 9% straw fiber (10P9S) have total water absorption values that fulfills the recommended value.

This research could help in providing possible solution for adequate shelter problem in Adama and in Ethiopia in general and to overcome some defects of mud blocks.

CHAPTER ONE

1 INTRODUCTION

1.1 Background

In Ethiopia, adequate shelter is a main problem in most part of the country. According to the Ethiopian Urban Sector Study, Ethiopian urban population is currently estimated to be 11 Million; 80% of these live in substandard housing units and environmentally unfit living conditions in slum neighborhoods [1]. Entirely, these houses are made from mud or earth by traditional techniques.

Mud walls have been used for the buildings since ancient times. In developing countries like Ethiopia, earth construction is economically the most efficient means for house construction with the least demand of resources. But, traditional earth construction techniques such as Wattle and Daub ("Chika bet'') and Cob suffer from erosion by rain and shrinkage cracks.

Using mud for wall construction has distinct advantages. Mud is readily available locally, low cost, recyclable and environment friendly and it provides better thermal comfort than other materials. Major drawbacks of mud walls are short life time, low compressive strength, ease of attack by environmental hazard, loss of strength on saturation and erosion due to rain impact. These drawbacks can be minimized by making blocks using soil that is stabilized, as this adds strength and durability to the raw material. Stabilization gives better wet and dry compressive strength, better cohesion between particles by reducing porosity which reduces changes in volume due to moisture fluctuations, and improved resistance to rain erosion. Optimum methods depend greatly on the type of soil, and a careful study of the local soil is necessary to suggest an effective method of stabilization. Stabilized mud blocks are produced via soil stabilization processes.

Stabilized mud blocks (SMBs) are manufactured by compacting a wetted mixture of soil, sand, and stabilizer in a machine into a high-density block. Such blocks are used for masonry construction in Adama and many other cities of the country

In this chapter, attempts have been made to outline the motivation and objectives for the research work, and explain the need of the research.

The limitations and delimitations and the methods to achieve the research objectives are also presented. The final section of the chapter outlines the structure of the thesis and informs the reader certain conventions used throughout the thesis.

1.2 Statement of the problem

The traditional building techniques which are practiced in most part of Ethiopia for mud house construction have serious defects. The main defects or problems are: walls can easily be eroded by rain and suffer from extended shrinkage cracks, the construction consumes natural resource such as woods. Especially, this is common in forestry areas. However, this accelerates deforestation.

Deforestation is a major issue in Ethiopia, since it is one of the main causes of widespread land degradation. Tree cutting or deforestation is a common event which has been taking place for centuries. In present day Ethiopia, however, forests are being destroyed at a large rate. The primary causes of forest destruction are increasing of the demand for construction material, agricultural expansion, fuel wood and charcoal.

Reducing and monitoring deforestation is a vital issue at this time. One of the reliable methods for monitoring deforestation is replacing wooden mud houses by only mud blocks, which would help to restore the ecological balance and to build a house with good quality and low cost.

1.3 Objectives of the thesis

General Objectives

The main objective of the thesis is to find out the possibility of mud block stabilized with pumice and water proofed by used vehicle oil which has required strength for load bearing walls while satisfying less weight and low cost together with simple manufacturing process by varying the mixing proportions of mud, straw fiber and pumice with water in order to reduce construction costs especially for low income housing as well as adopting easy and effective solutions for their repair and maintenance and to improve local production techniques and quality of output.

Specific Objectives

The specific objectives of the thesis includes

- To investigate local soils to identify their suitability in stabilized mud block production.
- To study experimentally the effect of altering important variables such as pumice and straw fibre on the properties and performance of stabilized mud blocks.
- To determine the percentage of stabilizer.
- To determine the shear strength parameters of the soil.
- To meet the economic requirements of the local situation by reducing dependence on outside sources and ensuring low cost alternatives.
- Develop the manufacturing procedure of mud block masonry with pumice, achieving good physical and mechanical qualities, with lowest possible cost.
- To minimize the environmental degradation by using renewable or recycle materials in building construction such as stabilized soil blocks.

1.4 Scope of the thesis

The research will cover only the technical and economic analysis of pumice stabilized soil block. It focuses on the soil from Adama Boku area. The research is delimited to the general study in Adama Boku area soil. Relevant data are acquired for pumice from the two manufactures, and index properties of the raw materials and compressive strength tests are conducted at Addis Ababa University, Civil Engineering Department Geotechnical and Construction Materials laboratory.

During the investigation, the research is limited to get soil sample from a single site, because of time and budget constraints. Therefore this research investigation is relied on the soil from Boku area of Adama.

1.5 Methodology

The information regarding stabilized mud block masonry, benefits, and limitations, will be collected through a literature survey on the topic of mud block masonry. This information includes the work of others and different stabilization methods but it is to be used only to set the stage for my thesis work. A thorough understanding of mud block masonry and what will be its economical benefits in the construction industry should be identified and addressed.

Both primary data (collected personally) from the source itself (such as experiments, observations, and photograph records) and secondary data from different research work are collected and used for the analysis.

The analysis of the collected data is both qualitative and quantitative. In general the following methodology is developed to achieve the objective of the research.

Literature review: provide detail information on different types of mud house construction techniques and materials which are required for suitable mud house construction. It also includes identifying materials which are necessary for this work.

Laboratory testing and analyzing results:

- ✓ Preparation of soil samples and stabilizers(pumice and straw fibre)
- ✓ Carry out different laboratory tests on the samples.
- ✓ Preparation of stabilized earth block samples from soil and stabilizer (pumice and straw fibre) with their different volume ratio.
- ✓ Carry out tests on these different types of stabilized earth block samples.
- ✓ Make analysis on their results using standards.
- ✓ Comparison of the soil block results with hollow concrete blocks.

The independent and dependent variables will be established. Within the set of dependent variables, consideration will be given to the physical and mechanical properties. As for the independent variable, the type of soil and compaction pressure will be proposed.

1.6 Structure of the thesis

This thesis is divided in to 6 chapters and each chapter contains a number of sections and further subsections, and the organization of the chapters is presented as follows.

Chapter 1 provides an introduction to the whole thesis. It discusses the background to the research and summarizes the general and specific objectives of the research, and lists the methodologies that have been used for the research. It ends by providing guidelines on the organization and structure of the thesis as a whole including the ordering of chapters, references and appendices.

Chapter 2 provides introduction on house construction and mud house construction in past time and at present time. It also explains about traditional mud house construction in Ethiopia and the environmental impact of the traditional mud house construction and presents the categories of stabilized earth block types

Chapter 3 provides conceptual review on stabilization techniques and previous studies on stabilized mud block masonries.

Chapter 4 The properties of materials, mix proportions and describes experimental set up and tests Procedure for grain size analysis, Atterberg limit, compaction , unconfined compressive strength test, total water absorption and compressive strength tests

Chapter 5 presents the experimental results of tests on soil sample which is taken from Boku area which includes grain size analysis result, Attrerberg limit, specific gravity, compaction and unconfined compressive strength test results and pumice stabilized compressed soil blocks and analysis which include: compressive strength, total water absorption values for each stabilized earth block sample.

Chapter 6 is the final chapter of the thesis, integrating and summarizing the main conclusions and recommendations. At the end of the thesis, references and appendixes are presented.

CHAPTER TWO

REVIEW ON MUD HOUSE CONSTRUCTION

2.1 Introduction

The choice of building materials is one of the important criteria, which determines the strength, quality, and economy of any construction. Originally, stone, sand, earth, grass, logs, skin, etc were used as construction or building materials in their crude form. As technique advanced, the crude as well as the partly refined materials was replaced by others, especially made for different purposes. The history of development of house facilities reveals that man has been modeling his environment throughout the ages for more comfortable living [2].

Provision of housing for developing countries is one of the most important basic needs of low-income groups. It is a very difficult requirement to meet, since land and construction costs are mostly beyond the means of both the rural and urban poor. In order to address this issue various governments have undertaken housing schemes that aim to facilitate some form of housing ownership by low-income groups. These ideas include self-help housing schemes that provide housing subsidies, provision of credit, and/or low interest rates etc [3].

Due to limited means within developing countries, it is necessary to seek ways to reduce construction costs, especially for low-income housing, as well as adopting easy and effective solutions for their repair and maintenance. Such objectives can be achieved partially through the production and use of cheap yet durable locally available building materials [3].

Currently, there are extremely wide variety of alternative construction materials and techniques which are used around the world. Soil is one of the natural building materials, which is absolutely different from wood, rock, and cement or metal. Mud can be formed for our shelters and it can be reformed or recycling ease back to nature, to be simple soil on earth. Moreover, mud can match with all environments and good for being a passive air-conditioning system. Reusability of mud creates tremendous reduction in environmental impact, energy use and capital expenditure.

Mud house from earth or soil is one of the most widely used traditional building materials throughout the world. Currently, one-third of world population stills live in mud house. It can be found mostly in hot-dry and arid area such as some parts of India, Nepal, China, African continent and even in the West Side of North and South American continent [1].

In Ethiopia there are various traditional construction materials which have proved to be suitable for a wide range of buildings and which have a great potential for increased use in the future. One such material is the compressed stabilized earth block, an improved form of one of the oldest materials used in building construction (Adobe).

Soil is one of the primary materials used for construction of traditional low-cost dwellings and is well suited to local weather conditions and occupancy patterns. Different soil construction methods are used in the majority of urban and rural areas of Ethiopia

Buildings are constructed entirely, or partially of soil, depending on location, climate, available skills, cost, building use and local tradition. Traditional earth construction techniques such as wattle and daub, cob and adobe need continuous maintenance in order to keep them in good condition. Research works to increase the durability of earth as a construction material is very important.

Unfortunately the quality of compressed stabilized earth blocks in some construction schemes is far from adequate and often materials are wasted in the production process. To extend the use of compressed stabilized earth building blocks to all types of housing e.g. low-cost housing in rural and urban areas and middle income housing in urban areas, production techniques need to be further improved so as to achieve better quality and reduce production costs [4]

In order to do this the following points need to be considered carefully

a) Proportions between soil and stabilizer need to be optimized, taking into consideration the specific characteristics of the soil,
b) Compaction pressure applied to the moist soil mix needs to be sufficient so as to produce blocks that are dense and strong with regular surfaces and edges.
c) Block surfaces need to be smooth so that they have the potential to be used without an additional surface coating or render.

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2.2 Mud house construction in history

Earth has been used in the construction of ancient houses for thousand years together with others natural materials such as wood and stone. The constructional technologies (techniques) used for the earth houses construction vary with the geographical zone and with the historical period. The technology called ‘‘torchis’’ is based on the use of branches of shrub to build the frame of the habitation and the mud is used to fill the cavity between the branches [13].

In another technology, called ‘‘pisè’’, the earth wall is made by compacting the earth (mud) into wood formworks. A typical technology, called ‘‘amaltoni’’, is used in the past century in the rural areas of the Marche region (Italy) and it is characterized by the use of cylindrical elements of earth blocks. The constructive system called ‘‘adobe’’ is based on the use of mud bricks to make earth buildings and it has been utilized in the Mediterranean area since the ancient era [24]. The origins of the compressed earth block technique can be traced back thousands of years to the molded sun-dried earth brick, better known by the name of "adobe". This sun-dried earth brick marks historical stages in the evolution of the human race.

Fig.2.1.Ancient mud house in morocco

2.3 Mud house construction at present

Currently, around 30% of the world's populations live in earth-made construction. Approximately 50% of the population in developing countries, including the majority of the rural population and at least 20% of the urban and suburban population, live in earthen houses [15]. Generally low-income urban and rural populations mainly use this type of house. The use of adobe is very common in some of the world's most hazard regions, such as Latin America, Africa, the Indian subcontinent and other parts of Asia, the Middle East, and southern Europe. The recent progression towards the compressed earth block is a logical extension of the benefits of the industrial revolution which brought the significant development of the fired brick. The need to improve the quality of materials and the durability of buildings is linked to better productivity. In most part of the tropics, traditional mud housing is found in rural areas. This traditionally housing is designed by the owner in his spare time together with the assistance of relations, friends and neighbors using local materials. In addition, traditional house reflects cultural heritage of the dwellers.

2.4 Traditional mud house construction in Ethiopia

In Ethiopia, based on climatic conditions and altitude, traditional house construction in Ethiopia are divided into houses of Low Lands-"Kolla" (<1400m); houses of Highlands- "Woina Dega"(1400-2700m) and houses of Highlands "Dega" (2700 above sea level) [1].

In Ethiopia, soil is used extensively in the traditional mud house construction ("Chika bet") in the "Kolla", "Woina Dega" and "Dega" area, especially in the central, northeast, northwest and in the southern eastern rift valley area of the country. "Chika" is a mixture of Clay, fine and short straw of the Ethiopian common cereal, ''Teff '' (Eragroetis Abyssinica) and water [1]. The mixture, after it has thoroughly been mixed by treading with the human feet, is either immediately used, or is left to ferment for some time before it is used as a filling material of the opening between wood poles and finally as plaster. Unfortunately, the traditional building techniques adopted for mud walls in Ethiopia have serious defects as shown in figure. The mud walls suffer from extended shrinkage cracks, which weaken the walls. Mud walls can easily be eroded by rain. Sometimes, the mud walls have been covered with protective coating consisting of animal dung. This was intended to serve as a wearing surface. The protective surface needed continued maintenance and sometimes renewal almost every year.

These entire drawbacks lead most of the people to the misconception that buildings with soil are of inferior quality and should be avoided [1].There is a big gap between the income of the majority of the population and the cost of the buildings.

Fig.2.2. Traditional mud house building in Ethiopia

Additionally, the traditional building method requires a lot of woods for the construction of walls. Especially, this is common in forestry areas. However, this accelerates deforestation (fig.2.3). Deforestation is a major issue in Ethiopia, since it is one of the main causes of widespread land degradation. Tree cutting or deforestation is a common event which has been taking place for centuries.

A long time back in history, some parts of Northern Ethiopia, which are today suffering from conditions caused by land degradation, were covered with forests. In present day Ethiopia, however, forests are being destroyed at a shocking rate and the area covered by forests at present is only 2.4 % compared to the estimated 40 % initial coverage [9].

The primary causes of forest destruction are increasing of the demand for construction material, agricultural expansion, fuel wood and charcoal.

Fig.2.3. Deforestation in Ethiopia

Reducing and monitoring deforestation is a vital issue at this time. There are different methods which are appropriate and reliable for monitoring deforestation. One of these methods is minimizing consumption of materials that have direct contact with forests. This includes materials which are used in building construction. In order to tackle the problem, a concept of low-cost building construction, based on mud as the main building material, was developed.

So, one of this thesis aims is to replacing wooden mud houses by only mud blocks, which would help to restore the ecological balance and to build a house with good quality and with fair price.

The concept of reducing the cost and the environmental effect of construction material has been performed by using locally available building materials such as soil, stones, straw and water.

Stabilized earth block technology is not commonly practices in Ethiopia. So, this opens ways for small-scale entrepreneurs since it does not require high investments and skills. This paper minimizes directly or indirectly the country house problems with economical and environmentally friendship ways by introducing technology. This work can also used for developing countries or for low-income groups.

2.5 Main techniques using earth as a building material

For 10,000 Years, earth has been used as a building material. Today, one third of the world population is living in earth buildings [1]. Some of techniques used earth as a building material includes;

Adobe: Adobe is one of the oldest building materials used by human kind, with the oldest identified adobes produced around 9000BC at Dja'De El Mughara in Syria. These blocks are similar to compressed earth blocks (CEB) and sometimes tagged as the precursor of CEBs. Adobe blocks are usually made of a compacted mixture of clay and straw, however they are less uniform in size and shape than CEB's. Adobe blocks are the simplest and easiest form of earth building.

Adobe blocks can also be made by mixing soil with straw fiber and water and letting them dry in the sun. They are traditionally either hand-shaped or shaped in parallel piped wooden molds.

Soils which are suitable for adobe production should have clay between 15 and 30% [12]. Adobe buildings have thick walls and have good thermal mass. Thermal mass is the ability of a material to absorb heat. On the other hand, Thermal inertia is the rate at which heat moves through the material. Materials with high thermal mass also exhibit slow rates of thermal inertia

In general, adobe brick is a sun-dried brick .it can be a mixture of soil, water and local fiber materials or straw fibers. [8]

Figure.2.4. handmade adobe, india[18]

Rammed earth: The earth is massively dumped into formworks, compacted by means of a rammer, layer by layer, and formwork [10]. The soil is compressed between parallel wooden plates that are later removed and extended further to work on another section of the wall. The availability of useful soil and appropriate local climatic conditions are the factors for rammed earth construction. It is similar to adobe and cob. The soil for this technique is mostly a composition of clay and sand. Rammed-earth walls are simple to construct, non-combustible, thermally massive, strong, and durable However, they are susceptible to water damage if they are inadequately protected or maintained.

Figure.2.5.manual rammed earth technique, india[18]

Molded Earth; Direct shaping makes use of plastic earth and does not require a mold or formwork. The earth, often improved by the addition of straw or other fibers is shaped in to a wall using the same technique as that used for pottery, without tools. This ancient technique is still widely used. The quality of the soil its preparation and the water consistency are known only to the builders, and are highly variable. This technique requires that builders have the proper knowledge regarding soil quality in order to control shrinkage as the walls dry, and is indeed an art form [3, 18]

Straw clay: The earth is spread out in water until a homogenous thick liquid state is attained. This muddy liquid is mixed with straw in order to form a film on every wisp. The building material obtained conserves its straw like aspect. It is put in to place by means of a formwork in order to erect a monolithic wall, which necessitates a primary support structure [11].

In this technique, mud has been plastered or coated over straw-bundle wall. This construction method is commonly used in natural building or "green" construction projects. Straw bale houses have enormously good insulation values, and they can be built with relative ease and speed. They may be load- bearing, but more often they incorporate a post-and-beam frame. [8]

Fig.2.7.compacted, casted Mud block plastering over Straw-bundle [4]

Wattle and Daub: Clayey material, mixed with straw or other fibers, is layered on top of wattles that fill in a timber structure Wattle and daub is the term for the panels of woven wood and mud used to fill between the timbers. Brick noggin might also have been used to fill in between the timbers (the openings in a wooden frame). The construction for wattle and daub starts with a lattice-work of light branches or timber. An earth (mud) mix is then daubed or cover onto the lattice-work, forced into the gaps, and finished to give a serviceable surface. The earth is generally not load-bearing; the load bearing is the timber.

Fig.2.8. mud covering on bamboo wattle wall in India

Since in this technique timber is the main basic material for the construction, this construction technique accelerates deforestation. So, this technique is not suitable since it has environmental impact on our globe [8].

Cob(Stacked earth): The earth, often improved by the addition of straw or other fibers, is shaped in to big balls, which are piled on top of one another and lightly packed, by hand or foot, In order to erect shaped monolithic walls. In order cases, the cob is incorporated into a timber framework or structure [2].

Cob is similar to adobe; however, cob has higher percentage of straw and has no production of uniform blocks. One advantage over adobe is the ability to better incorporate curves and allowing more sculptural forms (i.e. artworks created by shaping or combining the material). The addition of more straw makes the building a bit more insulated than adobe, however not sufficiently to make it comfortable in extreme climates. [8]

Fig.2.9. Cob and cob house in India

Compressed Earth: The earth is compressed, in block form, in a mould in the past; the earth was compressed in the mould by means of a small pestle, or by tamping a very heavy lid forcefully on the mould. [1].

In view of the history of earth construction, the compressed block technique is a new technique. It has been developed in the fifties in the frame of a research program concerning rural housing in Columbia. It is an improvement of the adobe technique. Instead of being molded by hand in a wooden frame, the blocks are formed by compressing earth, slightly moistened, in a steel press. Compared to the hand-molded block, the compressed earth Block is very regular in size and shape, and much denser as shown in the Figure below. It has better resistance to compressive stresses and to water.

Fig.2.10.Typical compressed earth block [1]

It is also the most popular material amongst Europe’s bio-ecological constructors on account of its physical attributes and ability to regulate moisture and temperature. This in turn allows for heating/energy reductions of up to 30 % and in some cases even up to 80% [1, 17]. The technology behind the production of compressed earth blocks is based on a mechanical process. This ensures a high quality product regular in dimension and of durability consistent with high quality traditional brick building. Earth, as opposed to pure clay, is the raw material used in the production of earth blocks.

Earth blocks are blocks of compressed soil that are aesthetically pleasing as well as cost and energy efficient, fire and pest resistant, virtually soundproof, durable and structurally sound. They provide complete architectural freedom and are made from non-toxic readily available natural raw material dirt [17].

Among the techniques, Wattle and Daub technique is well known in our country, Ethiopia. In Ethiopia, this technique has been practiced for long time in the traditional construction way of mud house construction called “Chika bet’’. However, mud walls that are constructed using this traditional building technique have many defects. The main defects are:

- ✓ Walls suffer from extended shrinkage cracks
- ✓ Requires a regular repair.
- ✓ Can easily be eroded by rain
- ✓ accelerate deforestation

Due to these all drawbacks, this technique is not suitable for adequate mud house construction. However, Adobe and Compressed Earth construction techniques have many advantages over this and other techniques. Some of their common advantages are;

- ✓ Reduction of deforestation
- ✓ Non-toxic: materials are completely natural and not harmful for our environment
- ✓ Fire resistant: earthen walls do not burn
- ✓ Insect resistant: the walls are solid and very dense, discouraging insects.
- ✓ Has good compressive strength mild-stone
- ✓ Can be used as load bearing structure

This paper works to solve the problems of traditional mud house construction technique in Adama by taking adobe and compressed earth blocks construction techniques as reference (focus on the integration of both techniques).

CHAPTER THREE

REVIEW ON SOIL STABILIZATION

3.1 Introduction

Stabilization of soil is the process of modifying the soil properties in relation to its strength, texture, voids and water resisting properties, so as to obtain permanent properties compatible with a particular application stabilizing soil leads to irreversible change in the physical properties of soil depending on the quality of building design, materials employed, economic aspects of the project or on issues of durability. The use and adoption of the right stabilization method can improve the compressive strength of soil by as much as 400% to 500% with other supplementary characteristics such as increased cohesion, reduced permeability, improved water repellent, increased durability and minimal shrinkage and expansion of soil during dry and wet conditions [Adam and Agip 2001].

Soil stabilization is the alteration of one or more soil properties, by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties. The process may include blending of soils to achieve a desired gradation or mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil (Guyer, J. P., 2011; US Army, 1994).

3.2 Types of Stabilization

There are several methods of soil stabilization widely used to improve construction quality. Some of the major stabilization techniques are described below.

3.2.1 Mechanical stabilization

Mechanical stabilization involves tamping or compacting the soil by using a heavy weight to bring about a reduction in the air void volume, thus leading to an increase in the density of the soil. The main effects of compaction on the soil are to increase its strength and reduce its permeability. The degree of compaction possible, however, is affected greatly by the type of soil used, the moisture content during compaction and the compression effort applied. Best results can be obtained by mixing the correct proportions of sand and clay in a soil. [3] More recent developments for roads and embankment construction have led to compacting soil with vibrating rollers and tampers. Tampers and block-making presses are also used for single storey constructions.

The major drawback of mechanically compressed stabilized earth blocks is their lack of durability especially in places of moderate to high rainfall. Manual stabilization or compaction methods vary from foot treading to hand tamping equipment, with compacting pressures varying between 0.05 to about 4MPa. Mechanical equipment may achieve compacting pressures of several thousand MPa [3].

Within the civil engineering industry there are several methods of compaction that are used in ground stabilization that use methods of static, vibration and dynamic blows to compact soil. Block compaction uses similar methods and similar technology only on a smaller scale and typically compaction takes place in a confined space rather than in unconfined open areas [1]. Block compaction has predominantly used vibration or slow steady squeezing (quasi-static) compaction to achieve the desired levels of soil consolidation. Until very recently the dynamic element used in block manufacture has been limited to the compression piston coming into contact with the surface of the soil at some speed followed by static pressure being applied to the material

3.2.2 Chemical Stabilization

Chemical stabilizations are used to stabilize soils when mechanical methods of stabilization are inadequate and replacing an undesirable soil is not possible or is too costly. Chemical stabilization includes cement, lime, fly ash and bituminous material stabilization

3.2.2.1 Lime stabilization

Lime is one of the oldest and still popular additives used to improve fine-grained soils. Lime, either alone or in combination with other materials, can be used to treat a range of soil types. Lime treatment of soil facilitates the construction activity in three ways. First, a decrease in the liquid limit and an increase in the plastic limit results in a significant reduction in plasticity index. Reduction in plasticity index facilitates higher workability of the treated soil. Second, as a result of chemical reaction between soil and lime a reduction in water content occurs. This facilitates compaction of very wet soils. Further, lime addition increases the optimum water content but decreases the maximum dry density and finally immediate increase in strength and results in a stable platform that facilitates the mobility of equipment (Balasingam M. and Farid S. 2008; Teferra A., and Leikun M. 1999).

3.2.2.2 Cement stabilization

Earlier studies have shown that cement is a suitable stabilizer for use with soil in the production of compressed stabilized soil Block.

Portland cement hydrates when water is added; the reaction produces a cementitious gel that is independent of the soil. This gel is made up of calcium silicate hydrates; calcium aluminate hydrates and hydrated lime. The first two compounds form the main bulk of the cementitious gel, whereas the lime is deposited as a separate crystalline solid phase. The cementation process results in deposition between the soil particles of an insoluble binder capable of embedding soil particles in a matrix of cementitious gel. Penetration of the gel throughout the soil hydration process is dependent on time, temperature and cement type.

The lime released during hydration of the cement reacts further with the clay fraction forming additional cementations bonds. Soil-cement mixes should be compacted immediately after mixing in order not to break down the newly created gel and therefore reduce strengthening. The basic function of cementation is to make the soil water-resistant by reducing swelling and Increasing its compressive strength.

3.2.2.3 Bitumen stabilization

There are two ways whereby bitumen can stabilize soil. The first way is a binding process that increases soil strength particularly in granular soils. Generally, small amounts of bitumen (2% to 6%) give the soil cohesion. When these percentages are exceeded the bitumen tends to act as a lubricant separating the particles and thus reducing the strength.

The second way is when the bitumen acts as a water repellent. The two mechanisms usually occur together in any soil but to different degrees, depending on the type of soil. Soils suitable for bituminous stabilization are sandy soils. Clays need large amounts for good results [3].

The main disadvantages of bituminous materials as stabilizers are

- ✓ They are not a traditional building material in most developing countries,
- ✓ Bituminous materials are expensive to import,
- ✓ Preparation costs are high (heating, storing and mixing),
- ✓ Heat can have an adverse effect on their binding properties, particularly in hot countries.

3.2.2.4 Gypsum stabilization

Gypsum is a traditional material found in many Mediterranean and Middle Eastern countries. The earliest civilizations used gypsum for building purposes, mainly for plasters and mortars. The advantage that gypsum has over Portland cement and lime is that it requires a low calcinations temperature (about 1/7th of that needed for cement and 1/5th of that needed for lime). Besides its agricultural and chemical uses, the main use of gypsum in
Ethiopia is in the production of Portland cement where it retards the setting of the cement.
Gypsum is a good stabilizer for sandy soils.

3.2.2.5 Pozzolanas stabilization

Pozzolanas are fine silica and alumina rich materials which when mixed with hydrated lime produce cementitious materials suitable for stabilization and construction needs. Pozzolanas are found in their natural state as volcanic ash or pumice or it can be manmade.

3.2.3 Soil stabilization by geotextiles and fabrics

Geotextiles are porous fabrics made of synthetic materials such as polyethylene, polyester, nylons and polyvinyl chloride. Woven, non woven and grid form varieties of geotextiles are available. Geotextiles have high strength and they are adopted as reinforcement when the requirements of low extensibility are not very high. When properly embedded in soil it contributes to its stability. It is used in the construction of unpaved roads over soft soils and also required to perform other functions simultaneously, such as facilitate drainage, separation or filtration. Reinforcing the soil for stabilization by metallic strips into it and providing an anchor or tie back to restrain a facing skin element.

3.3 previous studies

Asmamaw T., (2007) studied compressed cement stabilized soil blocks as an alternative wall making material on soil from Addis Ababa, Kara area. Index properties, compaction characteristics, water absorption test and compressive strength of soil-cement blocks were determined.

The conclusion and findings drown from the study are;

- ✓ Increase in cement content results in an increase in the compressive strength value of blocks made at the same constant compaction pressure.
- ✓ Increase in the cement content of block results into a reduction of its water absorption capacity.
- ✓ Increase in cement content could be a more effective method of increasing compressive strength values than an increase in compaction pressure and the final wet strength reached by a block is much more sensitive to variations in the cement content than to densification

Fernando Galindez; (2009) studied compressed earth blocks with no added cement in Argentina. The experimental study involved Atterberg limit test, moisture-density relation, water absorption test, water abrasion test, linear shrinkage and compressive strength test of soil blocks Two main advantages gained from removing the cement

- An economic benefit, because the price of cement makes the cost of the block much higher.
- An environmental benefit due to impact of the cement manufacturing process.

The conclusion and findings drown from the study are;

- ✓ Results obtained from test pieces of the same type of soil compressed at different pressure show that Compression strength increases with the increase in compaction pressure.
- ✓ Results obtained from test pieces with different soil types also show compression strength increases with the plasticity of soil.
- ✓ Water proofing the blocks by surface oil treatment, to stabilize the clays water reaction, gave better results in low plasticity clays.
- ✓ CEBs made from medium plasticity clayey sand earth, properly compacted and water proofed with used vehicle oil produce a viable building block.
- ✓ The strength of compressed earth blocks without cement can be improved by
- ✓ Increasing soil compaction or by using higher plasticity soil.

Habtemariam M., (2012) studied stabilized mud blocks as an alternative building material and development of models on soil from Addis Ababa, Yeka area. The conclusion and findings drown from the study are;

- ✓ Increase in cement content results in an increase in the compressive strength value of blocks by increasing the cement content from 2% to 5% yields 58.3% increment in compressive strength of the block.
- ✓ Increase in straw fibre content results in an increase in the compressive strength of the blocks. By increasing the straw fibre content from 3% to 6% yields 6.33% increment in the compressive strength.
- ✓ Increase in the cement content of block results into a reduction of its water absorption capacity an increment in cement content from 2% to 5% results in to a reduction in water absorption to 14%.

CHAPTER FOUR

MATERIALS AND METHODS

4.1 Introduction

In this chapter the materials used and methods adopted for the research are described with respect to their sources and their physical properties. All laboratory investigations on materials are carried out in AAiT geotechnical and material laboratory and Gia engineering laboratory.

4.2 MATERIALS

4.2.1 SOIL

The soil sample used for this research work is collected from Adama, Boku area from one test pit. The soil is low plastic and brown silty clay and disturbed sample is collected.

4.2.2 VOLCANIC ASH (PUMICITE)

The volcanic ash (pumicite) is collected from Bulbula around Bulbula river at $7^0$43’16.78’’N and 38^0 40’51.4’’E which is located in East Showa Zone of Oromia regional state.

Fig 4.1.volcanic ash (pumicite)

4.2.3 Straw fiber

The straw fiber used in this study was purchased from the open market.

4.3 METHODS

4.3.1 Sample preparation

Prior to treatment and testing, the sample was prepared in accordance with the method described in AASHTO T87-86. This method involves

- ✓ Air drying of samples and/or oven drying at 60ºC or less;
- ✓ Breaking up the soil aggregates by rubber covered mallet.

Then, sieve analysis is performed to separate the dried soils into groups.

4.3.3 Atterberg Limits Testing

The test includes the determination of the liquid limits, plastic limits and the plasticity index for the natural soil and the pumicite (volcanic ash). The tests are conducted in accordance with AASHTO T89-90 and T90-96 testing procedures.

4.3.3.1 Liquid Limit

Liquid limit is defined as the minimum moisture content at which the soil will flow under the application of very small shear force. At this moisture content the soil is assumed to behave practically as a liquid. The soil sample for liquid limit is air dried and 100g of the material passing through No. 40 sieve was obtained and thoroughly mixed with water to form a homogeneous paste on a flat glass plate. A portion of the soil water mixture is then placed in the cup of the Casagrande apparatus, leveled off parallel to the base and divided by drawing the grooving tool along the diameter through the centre of the hinge. The cup is then lifted up and dropped by turning the crank until the two parts of the soil come into contact at the bottom of the groove. The number of blows at which that occurred was recorded and a little quantity of the soil was taken and its moisture content determined. The test is performed for well–spaced out moisture content from the drier to the wetter states. The values of the moisture content (determined) and the corresponding number of blows is then plotted on a semi–logarithmic graph and the liquid limit is determined as the moisture content corresponding to 25 blows. The same procedure is also carried out for the pumicite (volcanic ash).

4.3.3.2 Plastic Limit

Plastic limit may be defined as the minimum moisture content at which the soil remains in plastic condition. A portion of soil used for the liquid limit test is retained for the determination of plastic limit.

The ball of soil is molded between the fingers and rolled between the palms of the hand until it dried sufficiently, even though the soil is already relatively drier than the ones used for liquid limit. The sample is rolled into a thread between the first finger and the thumb. The thread is then rolled between the tip of the fingers of one hand and the glass. This continued until the diameter of the thread is reduced to about 3mm. The movement continued until the thread shears both longitudinally and transversely. The crumbled soil is then put in the moisture container and the moisture content determined. The same procedure is also carried out for the pumicite.

4.3.3.3 Plasticity Index

The plasticity index of soil is the difference between the liquid limit and plastic limits. It indicates the presence of clay in a given soil. The plasticity indexes of the samples are calculated as

PI =LL –PL

4.3.4 Particle Size Distribution

The test includes the determination of the particle size distribution for the natural soil. The tests are conducted in accordance with AASHTO T88-93 testing procedures.

Approximately, 50gm of dry soil passing No. 200sieve is treated with a dispersing agent and a hydrometer analysis is then performed to measure the amount of silt and clay size and particles. And by screening a known weight of soil through a stack of sieves of progressively finer mesh size and Sieve analysis is performed to measure the amount of gravel and sand size and particles.

4.3.5 Specific Gravity

Specific gravity which is the measure of heaviness or denseness of the soil particle is determined by the method of pychnometer using a soil sample passing through sieve No. 10 and oven dried. This test includes the determination of the specific gravity for the soil and the pumicite (volcanic 0ash). The test is conducted in accordance with AASHTO T100-93 testing procedure.

4.3.6 Classification

The soil is classified using the unified soil classification system. Using the particle size distribution and the Atterberg limits, UCS designates a group name for each soil. A visual-manual procedure can also be used to identify soils easily in the field. However, all classifications provided in this research are based on the laboratory testing procedure.

4.3.7 Compaction

The test includes the determination of the maximum dry density and the optimum moisture content for the soil and the soil-volcanic ash mixture. The tests are conducted by blending pumicite and soil at different percentage in accordance with AASHTO T99-94 testing procedures.

4.3.7.1 Maximum Dry Density

The maximum dry density is conducted for soil, volcanic ash and different soil-volcanic ash mixture by varying the moisture content. The sample is then compacted into the 944cm^3 mold in three layers of approximately equal mass with each layer receiving 25 blows. The blows are uniformly distributed over the surface of each layer. The collar is then removed and the compacted sample leveled off at the top of the mould with a straight edge. The mould containing the leveled sample is then weighed.

One small representative sample is then taken from the compacted soil for the determination of moisture content. The same procedure is repeated until minimum of five sets of samples are taken for moisture content determination. The values of the dry densities are plotted against their respective moisture contents and the dry densities. MDD is deduced as the maximum point on the resulting curves.

4.3.7.2 Optimum Moisture Content

The corresponding value of moisture contents at maximum dry densities, which is deduced from the graph of dry density against moisture content, gives the optimum moisture content.

4.3.8 Unconfined compressive strength

In this method the unconfined compressive strength of cohesive soils in the undisturbed, remolded or compacted condition using strain controlled application of the axial load. This method is applicable only to cohesive materials which will not expel water during loading.

In this research the sample is remolded using optimum moisture content and dry density obtained from standard compaction. After the samples were extracted from the mold they were covered with plastic membrane and cured in water for seven up to twenty eight days.

4.4 Tests on blocks

The tests include the wet and dry compressive strength tests and the water absorption test. Although the wet and dry compressive strength tests and the water absorption tests are both now standard performance tests widely described and used for stabilized soils.

4.4.1 Compressive strength

The compressive strength of the blocks is perhaps their most important property. It is the amount of pressure that the blocks can resist without collapsing and depends on the soil type, type and amount of stabilizer. Maximum strengths are obtained by proper mixing, proper compacting and curing.

The compressive strength values give an overall picture of the quality of the blocks. The main aim of the compressive strength tests was to determine the wet compressive strength values of the blocks. It is the wet compressive strength value, which is normally lower than the dry compressive strength, which is used in the structural design of buildings. The compressive strength test done is a standard test based on ASTM standards.

After the 7, 14 and 28 days curing period, the blocks are measured and weighed. The main compression equipment used was the Concrete Testing Machine with a maximum load of 100KN.

The tensile strength of a block is about 90% lower than its compressive strength [6] and the blocks carry a vertical load. For this reason, the block sample subjected to compression force only in the test.

Equipments for compressive strength test are scale and compressive testing machine.

Fig4.2. compressive testing machine

The composition of sample is prepared based on volume ratio of each material as given below.

1. 8%pumicite +92% soils (8P)
2. 10%pumicite +90% soils (10P)
3. 12%pumicite +88% soils (12P)
4. 10% pumicite + 3% straw fibre +87% soils (10P3S)
5. 10% pumicite + 6% straw fibre +84% soils (10P6S)
6. 10% pumicite + 9% straw fibre +81% soils (10P9S)
7. Only soil (S)

Each block samples were covered with soft paper and sprinkled with water twice a day for seven up to twenty eight days. The samples were then carefully placed within the set marking pins of the compression-testing machine. The average compressive strength values for 7, 14 and 28 days curing of pumicite are presented in table 5.7.

4.4.2 Water absorption test

The aim of the water absorption test was to determine the percentage moisture absorption capacity of the block samples. Block samples were weighed in the laboratory dry condition(Wd) and, immersed in water for 24 hours, removed and weighed again (Ww). An accurate electronic weighing machine was used in case, to an accuracy of 0.05g.

The percentage moisture absorption by weight was calculated from the formula:

$$Mc = \frac{Ww - Wd}{Wd} \times 100\ (\%) \qquad [4.1]$$

Where: Mc = percentage moisture absorption (%)

Ww= mass of wetted sample (g)

Wd = mass of dry sample (g)

Through the water absorption test, it should be possible to determine the ability and extent to which blocks can absorb moisture. Knowledge of the water absorption levels of blocks could serve as useful criteria for setting limits and for investigating possible ways of reducing the same in order to improve on the durability of blocks.

The apparatus consisted of an accurate weighing balance, a stop watch and a water trough with a capacity to hold up to 2 fully immersed blocks. The entire test took two days to complete mainly due to the overnight soaking of the block samples in water. This test helps to investigate the effect of water absorption of stabilized soil blocks during the rainy season.

CHAPTER FIVE

TEST RESULTS AND DISCUSSIONS

5.1 Introduction

This chapter presents the results of laboratory tests and a discussion pertinent to the results.

The relevant engineering property of the soil is evaluated both for natural and pumicite (volcanic ash) samples separately. The tests include Atterberg limits, gradation, specific gravity determination, moisture density relationship (compaction) , unconfined compressive strength test (UCS) on the soil sample and compressive strength test and water absorption tests on the block samples.

Unconfined compressive strength test (UCS) and compressive strength tests are conducted for 7, 14 and 28 days cured soil samples.

5.2 Properties of Material Used in the Study

5.2.1 Natural Soil

The results of the tests conducted for identification or determination of properties of the natural soil are presented in Table 5.1. The soil is brown silty clay. As shown in Figure 5.1 on the particle size distribution curve almost 85.1% of the soil is passing through No. 10 sieve and about 2.56% of the soil is passing through sieve No.200; it exhibits a liquid limit of 38%, a plastic limit of 34% and plasticity index of 4. Liquid limit less than 35% indicates low plasticity, between 35% and 50% intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity (Whitlow, R., 1995). Hence, these values indicate that the soil is intermediate plastic clay.

The soil has a maximum dry density of 1.38g/cm3, optimum moisture content of 28.35%,

Table 5.1 Geotechnical properties of the natural soil

Property	Quantity
Percentage passing No. 10 sieve, %	85.1
Percentage passing No. 200 sieve, %	2.56
Plastic limit, %	34
Liquid limit, %	38
Plasticity index	4
Specific gravity	2.52
Unified soil classification	MS
Maximum dry density, g/cm^3	1.38
Optimum moisture content, %	28.35
Unconfined compressive strength, Kpa	37

Grain size distribution curve

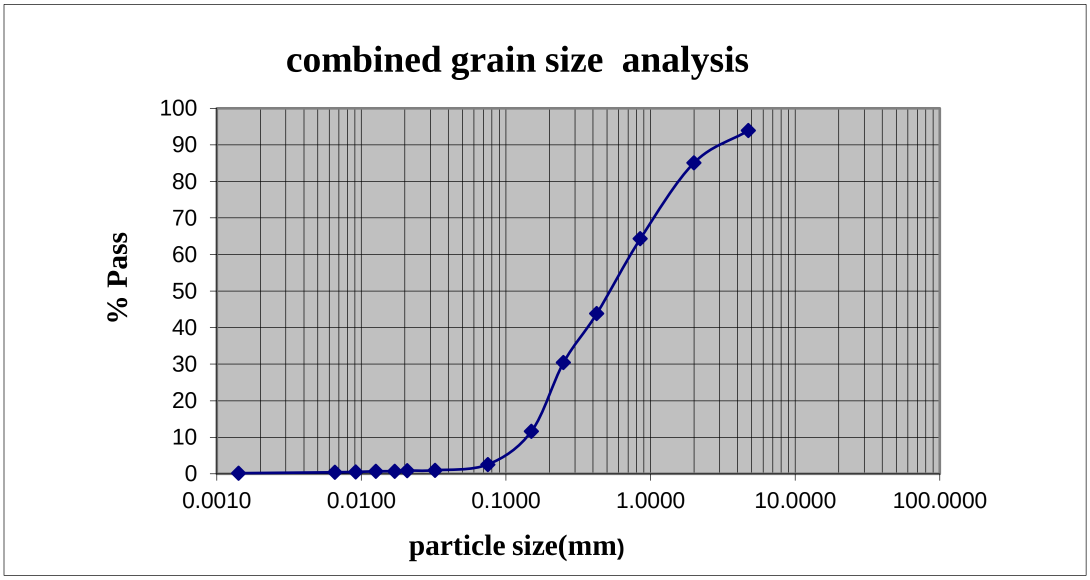


Figure 5.1: Particle size distribution curve of the expansive soil

5.2.2. Volcanic ash (pumicite)

The pumicite is dark grey in color. In liquid limit test the volcanic ash (pumicite) closes in 7 or 8 blows for repeated trials. According to AASHTO T 089-96 testing procedure no trial requiring more than 35 blows or less than 15 blows shall be recorded. And in the plastic limit test the volcanic ash starts to crumbles before it rolls to into a thread of 3.2mm diameter. AASHTO T 090-96 recommended to report a material non plastic when the plastic limit or liquid limit cannot be determined. Therefore the pumicite is non plastic material.

Property	Quantity
Liquid limit, %	NP
Plastic limit, %	NP
Specific gravity	2.49
Maximum dry density, g/cm^3	1.10
Optimum moisture content, %	40.72
Unconfined compressive strength, Kpa	51

Table 5.2 properties of the pumicite

5.3. Effect of volcanic Ash (pumicite) on compaction characteristics of natural soil

Maximum Dry Density

The effect of pumicite on the maximum dry density of the natural soil is shown in Figure 5.2 for the soil sample. As shown in the figure, maximum dry density increases from 1.48g/cm3 to 1.56g/cm3 for the soil samples with increased pumicite content from 0% to 10% and decreases from 1.56g/cm3 to 1.41g/cm3 with increased pumicite content from 10% to 24%.

Pumicite(%)	MDD(g/cc)	OMC(%)
2	1.48	26.4
4	1.51	26.9
6	1.52	28.4
8	1.53	26.6
10	1.54	25.9
12	1.53	26.7
14	1.52	26.1
16	1.5	27.3
18	1.49	30.2
20	1.46	31.6
22	1.43	34.5
24	1.41	36.2

Table 5.3: Variation of MDD and OMC with application of different pumicite contents

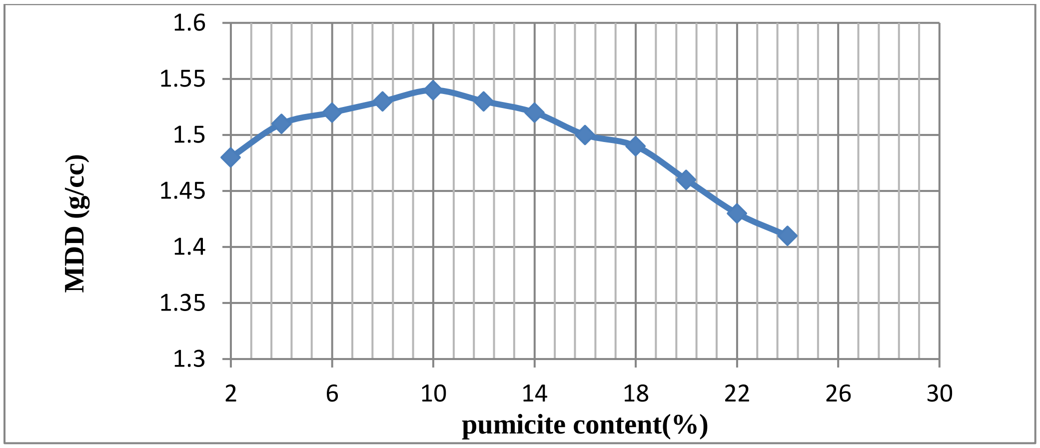


Figure 5.2: Variation of MDD with application of different pumicite contents

The decrease in the maximum dry density is mainly due to;

- the partial replacement of comparatively heavy soils with the light weight pumicite
- comparatively lower specific gravity value (2.49) of pumicite than that of replaced soil(2.52)
- It may also be attributed to coating of the soil by the pumicite which result to large particles with larger voids and hence less density.

Optimum Moisture Content

The effect of pumicite on the optimum moisture content for the soil pumicite mixtures are shown in Figure 5.3. The optimum moisture content increases from 25.9% to 36.2% for soil samples with increased pumicite content from 10% to 24%

Enough moisture content is essential not only for hydration process to proceed but also for efficient compaction. Insufficient moisture content will cause binders to compete with soils in order to gain some amount of moisture

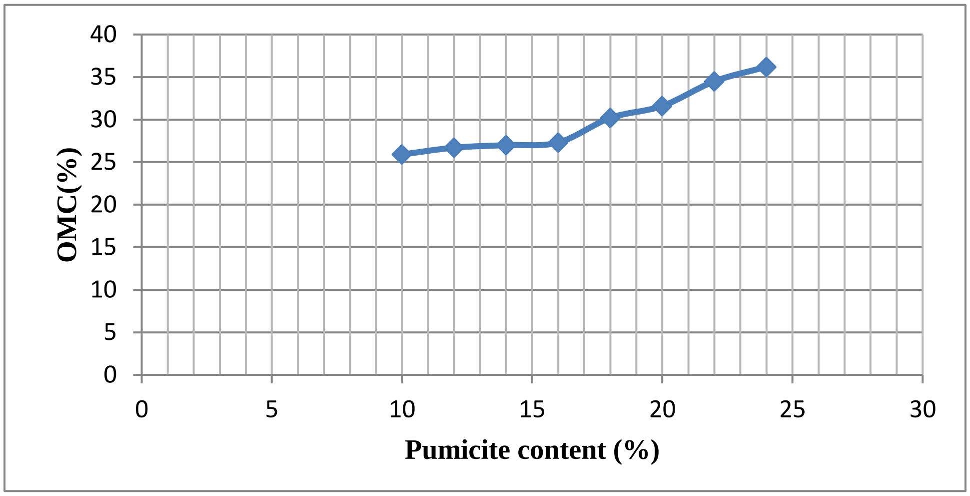


Figure 5.3: Variation of OMC with application of different pumicite contents

The increase in the optimum moisture content was mainly due to;

- The optimum moisture content of soil increases with an increase pumicite/volcanic ash, because volcanic ash is finer than the soil. The more fines the more surface area, so more water is required to provide well lubrication.
- The increase of water content may also be attributed by the pozzolanic reaction of pumicite with the soil.
- The increase in OMC due to addition of pumicite caused by the absorption of water by pumicite. This implies that more water is needed in order to compact the soil with pumicite mixture. So pumicite effectively dries wet soils and provides an initial rapid strength gain, which is useful during construction in wet, unstable ground conditions. In general it can be utilized in improving the workability of wet in soils.

The summaries of compaction curves shown in Figures 5.4 for samples of different pumicite content. Details of the maximum dry density and optimum moisture content results are shown in the Appendix B.

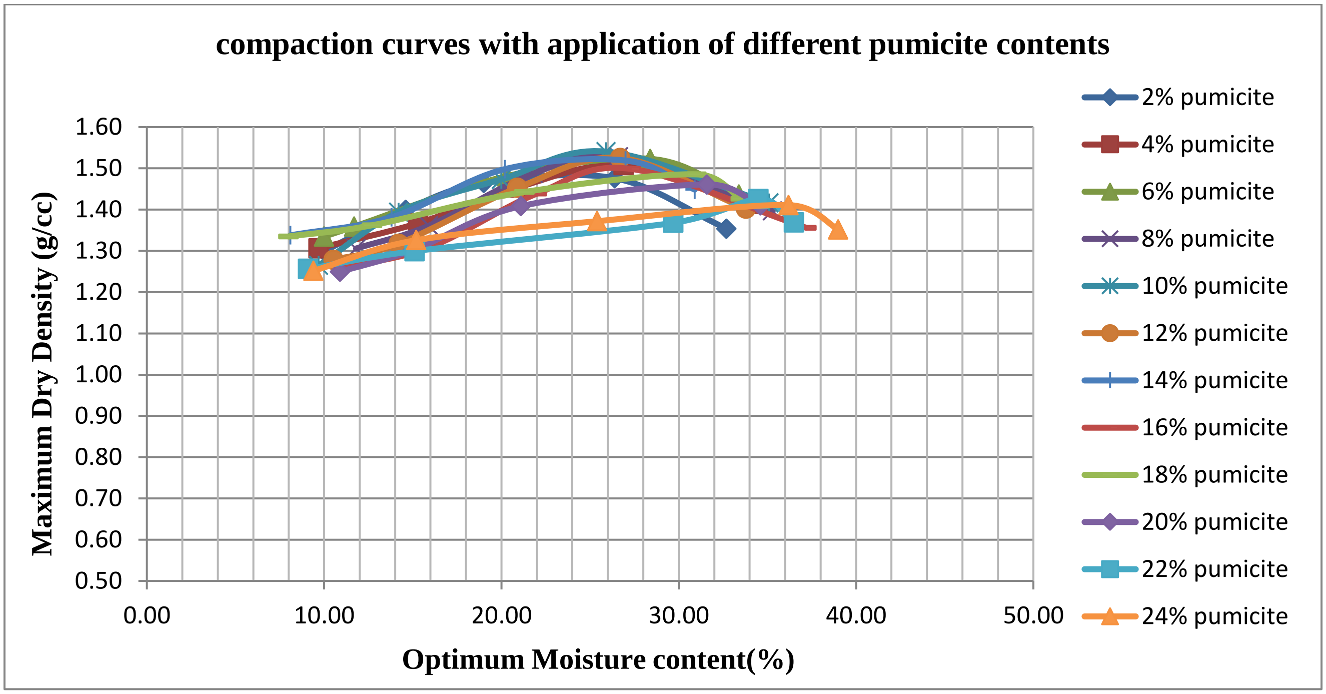


Figure 5.4: Summary of compaction curves with application of different pumicite contents

5.4 Effect of pumicite on unconfined compressive strength and Compressive strength tests

5.4.1 Unconfined compressive strength

The effect of pumicite on the unconfined compressive strength values of the soil pumicite mixtures are shown in Figure 5.5. When the natural soil mixed at 10% volcanic ash (pumicite) content the sample gives a peak UCS value of 35.72Kpa, 39.68Kpa and 49.34Kpa for 7 days, 14 days and 28 days curing periods respectively. UCS value for the natural soil is 37Kpa. The UCS of the natural soil increased with pumicite contents up to 10%. The optimum UCS value of soil treated with pumicite is when the pumicite content is 10% and curing period of 28 days. This shows that the load bearing capacity of the sample increased significantly with pumicite treatment and also curing has some effect on the UCS values. The reason for this improvement is due to the pozzolanic reactions of pumicite with soil. Detailed test results are given in Appendix C.

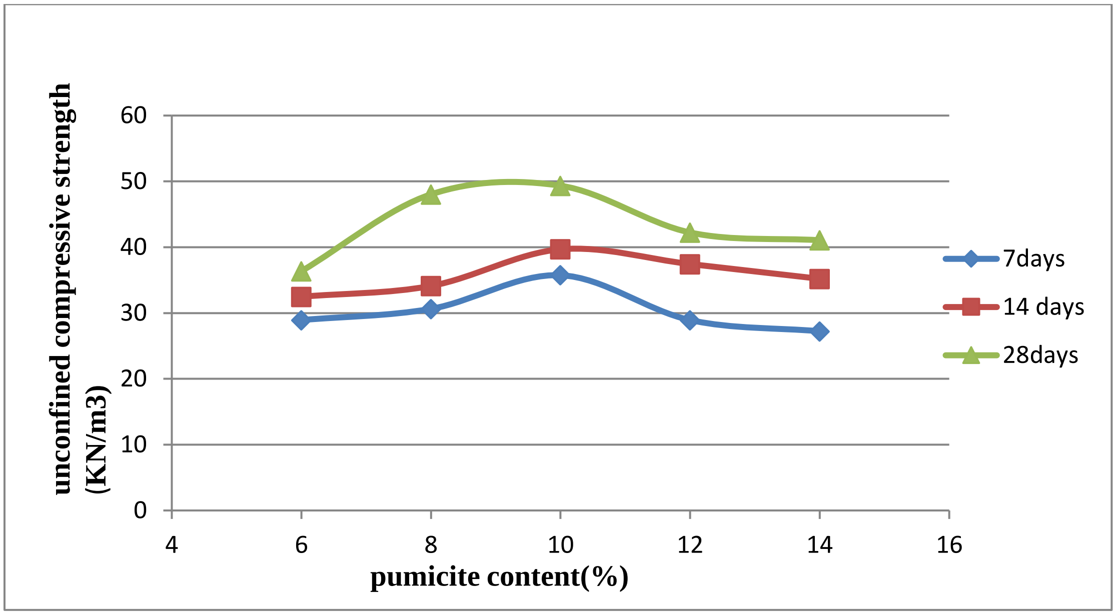


Figure 5.5: Variation of unconfined compressive strength with application of different pumicite contents and curing dates

5.4.2 Compressive strength

Compressive strength of compressed earth blocks is strongly related to dry density achieved in compaction. Compressive strength of individual blocks consistently increases as dry density increases,

In practical, compressive strength value for stabilized earth building blocks may be less than4MPa.When building loads are small (e.g. in the case of single story constructions), a compressive strength value from 2MPa to 4MPa may be sufficient for building purposes. Many building authorities around the world their recommend values are within this range. The minimum British Standard requirements for precast earth blocks and load bearing fired clay blocks is above 2.8MPa [19]. The effect of pumicite on the Compressive strength of the natural soil is shown in Figure 5.6 for the block sample.

	Mean compressive strength			
Mix code	7 days	14 days	28 days	
E	0.75	0.96	1.18	0.96
8P	1.15	1.24	1.38	1.26
10P	1.58	1.67	1.75	1.67
12P	1.45	1.57	1.68	1.57
E3S	1.22	1.36	1.45	1.34
E6S	1.31	1.42	1.48	1.40
E9S	1.35	1.5	1.56	1.47
10P3S	1.6	1.73	1.79	1.71
10P6S	1.65	1.75	1.82	1.74
10P9S	1.71	1.79	1.9	1.80

Table5.4 Mean compressive strength of soil blocks samples

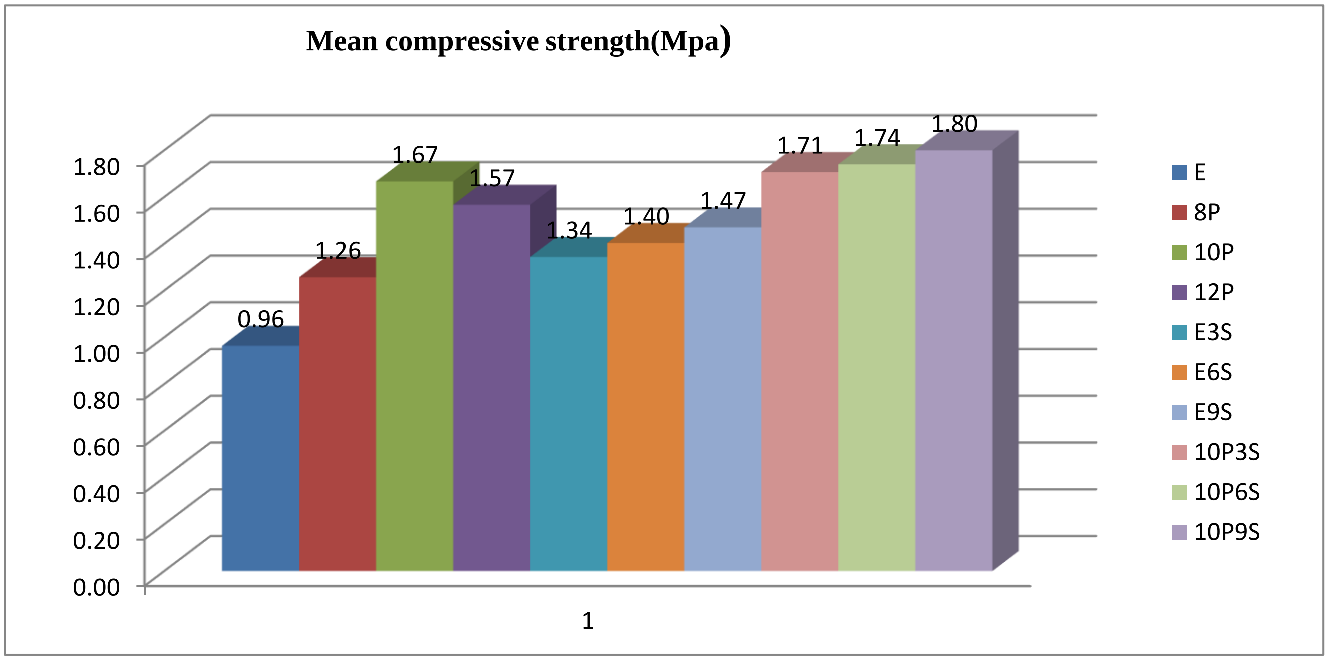


Fig 5.6 Mean compressive strength for all block samples

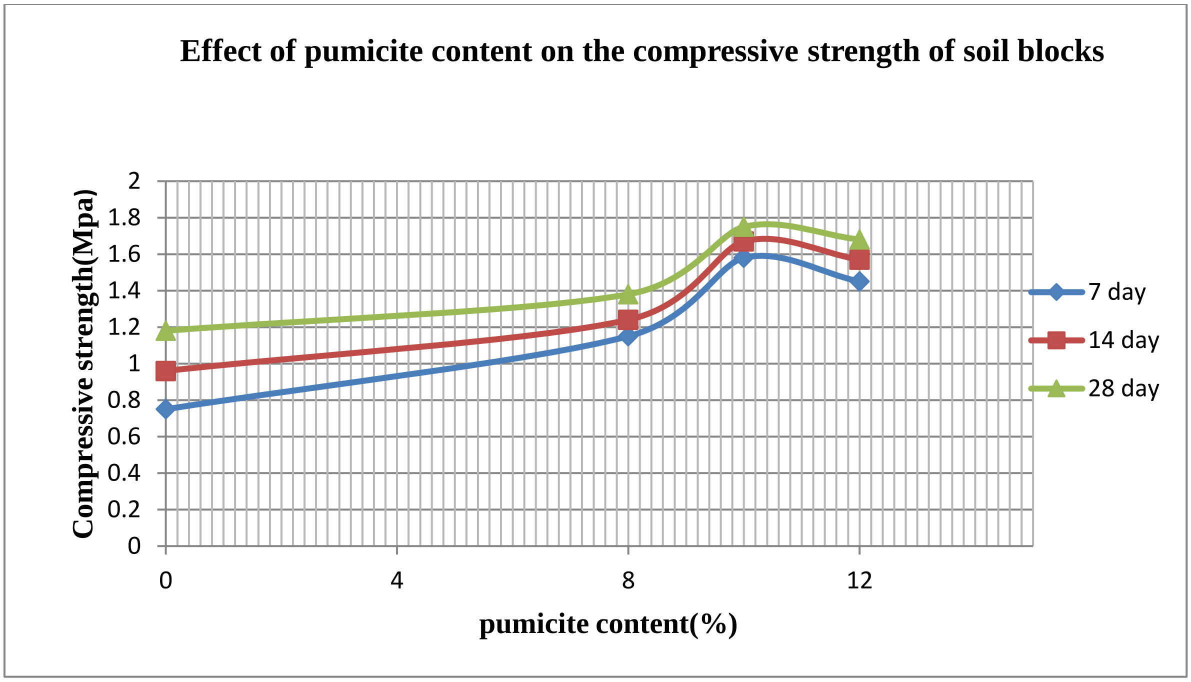


Fig 5.7 effect of pumicite on the compressive strength of soil block sample with only pumicite

As the results shown all the block specimens exhibited continuous increase in compressive strength with increase in curing age. It was found that increasing the pumicite in the soil blocks increase the compressive strength as there is an increase in the formation of compounds possessing cementious properties that binds with the particles together. This occurs due to the presence of silica and other compounds present in the pumicite**.**

Table 5.4 show that the compressive strength of the blocks decreases with the addition of pumicite beyond 10%. The main reason is that the addition of pumicite to the soil blocks increases the water required for the mix to get a suitable workability and as a result, the strength decreases.

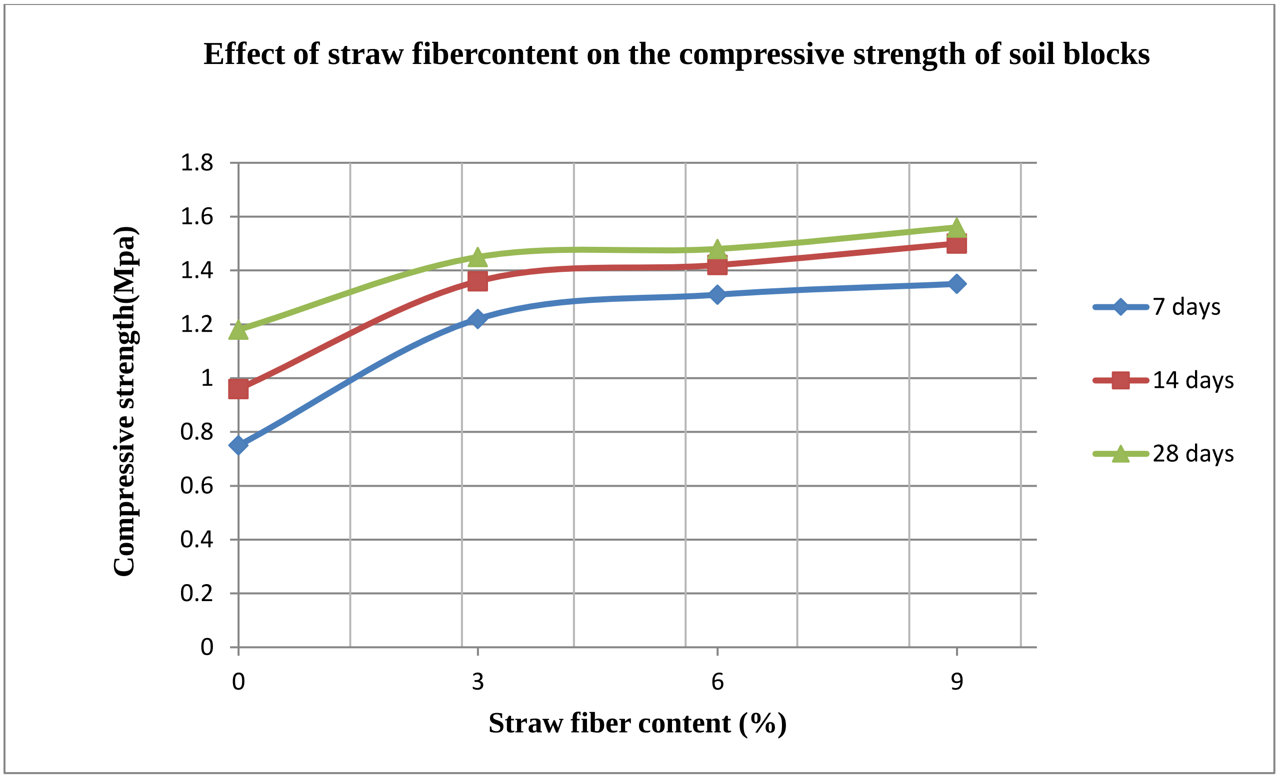


Fig 5.8 effect of straw fiber on the compressive strength of soil block samples with straw fiber only

The amount of straw in the mixture has effect on the shape and the width of cracks that is created during compressive strength test. The increase of straw fiber decreases the size and the number of cracks. This is because the straw fibers have good plastic property that keeps the composite particle close together.

5.5 Water absorption

In practice, water can gain access to the block either in liquid phase in the case of rainwater infiltration or suction from a wet surface, or in the vapor phase in the case of condensation or adsorption, but leaves the block almost exclusively in the vapor phase through evaporation. Therefore the water content of the wall should be determined not only by its contact to water sources but also with its water vapor balance i.e., evaporation minus condensation and adsorption.

Given that the block undergoes seasonal cycle with maximum water content in the rainy season and minimum water content in the dry season, such cycles constitute an added complexity in analyzing the moisture balance and therefore any remedial steps that could be taken.

The value of the total water absorption (TWA) of a block is important because it can be used for:

- Approximation of the voids content of a block
- Quality checks on blocks

Generally, the less water a block absorbs and retains the better is its performance likely to be. Reducing the TWA capacity of a block has often been considered as one of the ways of improving its quality and durability. Strength reduces as moisture content increases due to the softening of binders by water and development of pore water pressures.

Total water absorption test was conducted on all the ten sample types and the value for each sample and their average value is shown in table 5.5. The experimental results of the water absorption test show the effect of pumicite and straw fiber content on the water absorption capacity of the blocks. According to the tabulated results in Table 5.5, the mean water absorption values for the various samples tested range from 11.66% for the 10% pumicite and 9% straw fiber content samples (10P9S) to 18.94% for the soil (E) samples. From the literature the recommended maximum water absorption value for suitable blocks is below 15%.

Types of sample	Sample	Wet mass(g)	Dry mass(g)	Water Absorption(%)	Average total water Absorption(%)
E	1	2498	2093	19.35	18.94
	2	2520	2126	18.53	
8P	1	2420	2100	17.62	15.68
	2	2450	2110	16.11	
10P	1	2400	2095	14.56	14.90
	2	2420	2100	15.24	
12P	1	2510	2180	15.14	15.07
	2	2530	2200	15.00	
10P3S	1	2260	2000	13.00	13.31
	2	2277	2004	13.62	
10P6S	1	2340	2090	11.96	12.53
	2	2375	2100	13.10	
10P9S	1	2445	2180	12.16	11.66
	2	2440	2195	11.16	
E3S	1	2370	2000	18.50	18.68
	2	2375	1998	18.87	
E6S	1	2460	2100	17.14	17.33
	2	2490	2119	17.51	
E9S	1	2537	2175	16.64	16.43
	2	2545	2190	16.21	

Table 5.5 Total water absorption for stabilized earth block

According to Table 5.5, an increase in straw fiber content has the effect of reducing the water absorption value of the blocks. An increment of the straw fiber content in the mixture from 3% to 6%, results into a reduction in water absorption value of 18.68% to 17.33%.

This shows that the increase in straw fiber content results in reduction of water absorption. Therefore, from the result the four samples (10P, 10P3S, 10P6S and 10P9S) fulfill the recommended value i.e. 15%.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

1) Stabilization of soil with pumicite significantly improved the compressive strength of soil blocks although blocks produced were suitable as masonry wall units. Increasing the quantity of pumicite to some extent increased the compressive strength of the soil blocks.

2) Production of stabilized soil block using pumicite and straw fiber as a stabilizer fulfills a number of objectives which are necessary to attain a durable structure from locally available soil. Some of these are: better mechanical property (better compressive strength), and better cohesion between particles (reducing porosity which reduces changes in volume due to moisture fluctuations).

3) The addition of pumicite/volcanic ash led to an improvement of the maximum dry density up to 10% pumicite on the natural soil.

4) The addition of pumicite in combination with straw fibre improved the Compressive strength, unconfined compressive and compaction characteristics of natural soil. The improvement is more significant when the sample is cured. Hence, combination of pumicite and straw fibre can improve the strength of the soil.

5) Increase in straw fiber content results in an increase in the compressive strength value of blocks. For instance, by increasing the straw fiber content from 3% to 6 % yields 6 % increment in compressive strength of the block. When the amount of straw fiber increases, its stiffness decreases.

6) The average water absorption value for the four samples (10P, 10P3S, 10P6S and 10P9S) were less than 15% satisfying the IS recommendation

7) Reducing and monitoring deforestation is a vital issue at this time so replacing wooden mud houses by only mud blocks is reliable method for monitoring deforestation, therefore soil blocks are well suited to solve economical, social and environmental related problems in our country.

6.2. RECOMMENDATION

1) The process of manufacturing clay bricks requires high energy to burn due to the emission of CO_2 gas from the manufacturing process. Therefore to control and minimize the emission of CO_2 and to restore the ecological balance stabilized soil blocks should be used as an alternative wall making material.
2) Promoting stabilized earth block through advertising and pilot housing, so that many people could have better knowledge about this technology so that it can solve the country housing problems with economical and environmentally friendly way.
3) Suitable soil selection using laboratory tests may be expensive for small-scale production. Adoption of simple field test methods and trial block production should be produced.
4) Stabilized earth block production technology is not common in Ethiopia. This technology opens ways for small-scale entrepreneurs who do not require high investments and skills. The accessory which is used in earth block production can be manufactured in local work shop by small business groups (entrepreneurs).
5) The use of stabilized soil block as a walling material in Ethiopia has shown different defects. These defects include time related loss of quality of the block under direct or indirect influence of environment. This can be reduced by proper quality control during production; Plastering of the first two courses of the wall and increasing the overhangs of the roof.

7. REFERENCES

1. Asmamaw Tadege; Study of compressed cement stabilized soil block as an alternative wall making material A thesis submitted to Construction Technology and Management Department School of Graduate Studies of Addis Ababa University
2. Dr.-Ing. Abebe Dinku, Associate Professor of Civil Engineering, A text book of Building Construction, Addis Ababa University, 2007
3. Doctor. E.A.Adam in collaboration with Professor A.R.A.Agib, Compressed stabilized Earth Block Manufacture in Sudan, UNESCO, Paris, July 2001
4. Appropriate Building Materials for Low Cost Housing African region, proceedings of a symposium held in Nairobi Kenya from 7 to 14 November 1983, E.&F.N.Spon Ltd, London 1985
5. Kevin D. Hale; A field investigation of composite mud brick compressive strength 2015
6. Anthony Geoffrey kerali; Durability of compressed and cement-stabilized building blocks, September 2001
7. Grace Yung Yu Chen; Analysis of stabilized adobe in rural east Africa 2009
8. Habtemariam Molla; Study of stabilized soil block as an alternative building material and development of models A thesis submitted to Mechanical Engineering Department School of Graduate Studies of Addis Ababa University
9. A. Angelsen and D. Kaimowitz; Agricultural technologies and tropical deforestation, Mar. 1999
10. A.K.LAL, Hand book of Low Cost Housing, New Age International (p) Ltd. March 1995
11. 16. Craig, R.F, Soil mechanics, E & FN Spon, 1997.
12. Kusuma Dhammadamrong : Mud house ,school of architecture, king mongut’s institute of technology ladkrabang, Bangkok, Thailand 2004
13. Peter Davich,Joseph F. Labuz,Bojan Guzina and Andrew Drescher: Small Strain and Resilient Modulus Testing of Granular Soils 2004
14. Quintilio Piattoni, Enrico Quagliarini , Stefano Lenci: Construction and Building Materials , Sept 2010
15. Svetlana Brzev and Marcial Blondet:Earthquake-Resistant Construction of Adobe Buildings,March 2003

16. Vasilios Maniatidis & Peter Walker: A Review of Rammed Earth Construction May,2003
17. Cebtex, Compressed Earth Block Construction Http://Cebtex.Com
18. Joseph Exelbirt; characterizing compressed earth bricks based on hydrothermal aging and wind-driven rain erosion A thesis presented to the graduate school of the university of Florida 2011
19. Becky Little and Tom Morton, building with earth in Scotland: innovative design and sustainability 2001

APPENDIX A

SOIL INDEX PROPERTIES TEST RESULTS

Table A1.1 Specific Gravity Test for soil

Method used ASTM D 854

Trial No	1	2	3
Mass of Pycno.	60.00	59.90	59.50
Mass of Pyc+Dry soil	70.80	70.40	70.50
Mass of Pyc+soil+water	165.50	165.60	165.80
Mass of Pyc+Water	159.00	159.40	159.00
Specific gravity	2.51	2.44	2.62
Average specific gravity	**2.52**		

Table A1.2 Specific Gravity Test for pumicite

Method used ASTM D 854

Trial No	1	2	3
Mass of Pycno.	59.80	59.50	60.00
Mass of Pyc+Dry soil	70.80	70.50	69.90
Mass of Pyc+soil+water	165.70	165.30	164.90
Mass of Pyc+Water	159.00	158.80	159.00
Specific gravity	2.56	2.44	2.48
Average specific gravity	**2.49**		

Table A1.3 Plastic Limit Determination

Method used ASTM D 2216-92

Determination Number		
1	2	3
1	2	3
15.70	14.90	14.2
17.80	18.00	16.8
17.20	17.40	16.1
0.60	0.60	0.7
1.50	2.50	1.9
40.00	24.00	36.84
AVERAGE PLASTIC LIMIT		34

Table A1.4 Liquid Limit Determination

Method used ASTM D 2216-92

	Determination Number			
	1	2	3	4
Can no.	A	B	C	D
Wt. of can(g)	15.7	15.80	15.45	15.50
Wt.can + wet soil(g)	35.8	33.00	35.90	31.50
Wt can + dry soil (g)	30.5	28.25	30.10	26.90
Wt. water(g)	5.30	4.75	5.80	4.60
Wt. of dry soil (g)	14.80	12.45	14.65	11.40
No.of blows N	30	22	18	16
Moisture content(%)	35.81	38.15	39.59	40.35

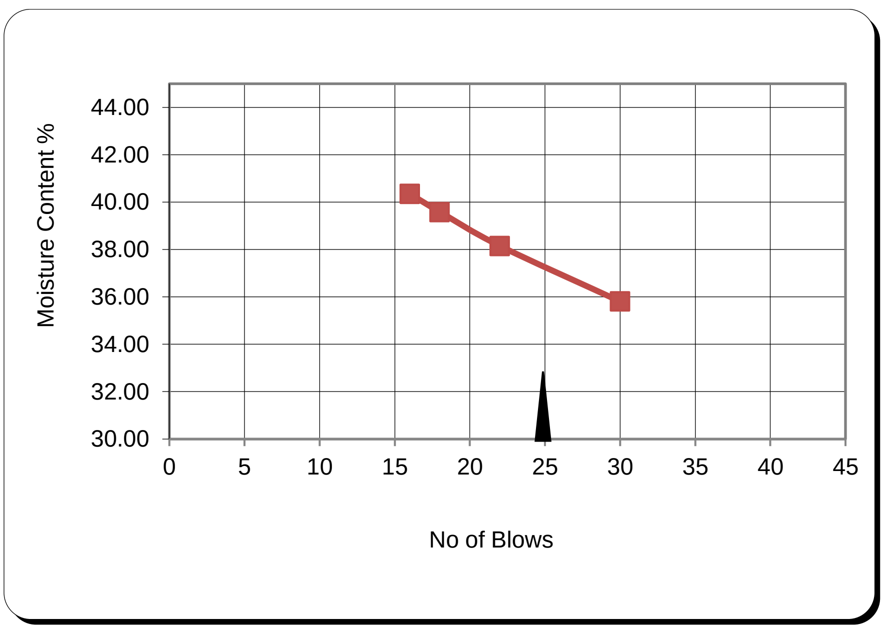


Table A1.5 Hydrometer Analysis

Method used ASTM D 422

Types of Hydrometer analysis used 151H

Specific gravity of soil =2.52

Weight of oven dry Sample = 50gm

Amount of Dispersing agent used 40gm/Liter

Time(min.)	Actual Hydrometer Reading	Temp.(ºC)	Hyd. Correction for meniscus	Effe. Depth of Hydrometer(L)	Values of K	temp. correction fac	Correction factor(a)	Diameter of soil Particle	Corrected Hyd. Reading Rc	% finer,P	adjusted % finer PA
2	20.5	21	21.5	10.6	0.014048	0.2	1.032	0.032341	18.20	37.56	0.97
5	19	21	20	11	0.014048	0.2	1.032	0.020837	16.70	34.47	0.89
8	16	21	17	11.8	0.014048	0.2	1.032	0.017061	13.70	28.28	0.73
15	15	21	16	12.1	0.014048	0.2	1.032	0.012617	12.70	26.21	0.68
30	12	21.4	13	12.9	0.01398	0.28	1.032	0.009167	9.78	20.19	0.52
60	10	21.9	11	13.4	0.013895	0.38	1.032	0.006567	7.88	16.26	0.42
1440	5.5	20.6	6.5	14.55	0.014116	0.12	1.032	0.001419	3.12	6.44	0.17

Table A1.6 Sieve analysis/ Grain size analysis

Method used ASTM D 422

Method of sieving = dry sieving
Weight of air dry Sample = 1000gm

Sieve no.	Sieve size, mm.	Sieve weight(gm)	weight of sieve + soil retianed(gm)	weight retained(gm)	% retained	% passing
	9.5	-	-	-	-	0.000
No.4	4.75	427.20	488.20	61.00	6.10	93.90
No.10	2.00	540.60	628.60	88.00	8.80	85.10
No.20	0.85	344.00	551.80	207.80	20.78	64.31
No.40	0.43	293.40	498.00	204.60	20.46	43.85
No.60	0.250	461.70	596.00	134.30	13.43	30.42
No.100	0.150	460.50	648.40	187.90	18.79	11.62
No.200	0.075	257.20	347.80	90.60	9.06	2.56
Pan	Pan	246.20	271.80	25.60	2.56	0.00
				999.80		

APPENDIX-B

MOISTURE-DENSITY RELATION BY STANDARD PROCTOR TEST

Table B-1 Moisture-Density relations for soil only

Pumicite Content = 0%

Moisture-Density (Compaction) Test
Data Sheets
Test Method: Standard Proctor, Method A (ASTM 698)

Water Content Determination:										
Compacted Soil - Sample no.	1		2		3		4		5	
Water content - Sample no.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
Moisture can number - Lid number	C1	C2	D1	D2	E1	E2	F1	F2	G1	G2
MC = Mass of empty, clean can + lid (grams)	15.5	14.6	16	15.7	15.6	15.5	15.7	15.5	15.4	15.5
MCMS = Mass of can, lid, and moist soil (grams)	29.5	27.8	34.9	28.8	34.6	36.2	40.7	37.6	35.5	38.3
MCDS = Mass of can, lid, and dry soil (grams)	27.5	25.9	31.8	26.6	30.9	32.3	35.2	32.7	30.5	32.6
MS = Mass of soil solids (grams)	12	11.3	15.8	10.9	15.3	16.8	19.5	17.2	15.1	17.1
MW = Mass of pore water (grams)	2	1.9	3.1	2.2	3.7	3.9	5.5	4.9	5	5.7
w = Water content, w%	16.7	16.8	19.6	20.2	24.2	23.2	28.2	28.5	33.1	33.3

Density Determination:					
Mold Volume=944 cm3					
Compacted Soil - Sample no.	1	2	3	4	5
w = Assumed water content, w%	8	12	16	20	24
Actual average water content, w%	16.74	19.90	23.70	28.35	33.22
Mass of compacted soil and mold(grams)	4513.1	4572.9	4702.9	4833.4	4723.8
mass of mold(grams)	3161.5	3118	3118	3161.5	3161.5
wet mass of soil in mold(grams)	1351.6	1454.9	1584.9	1671.9	1562.3
wet density,	1.432	1.541	1.679	1.771	1.655
dry density	1.23	1.29	1.36	1.38	1.24

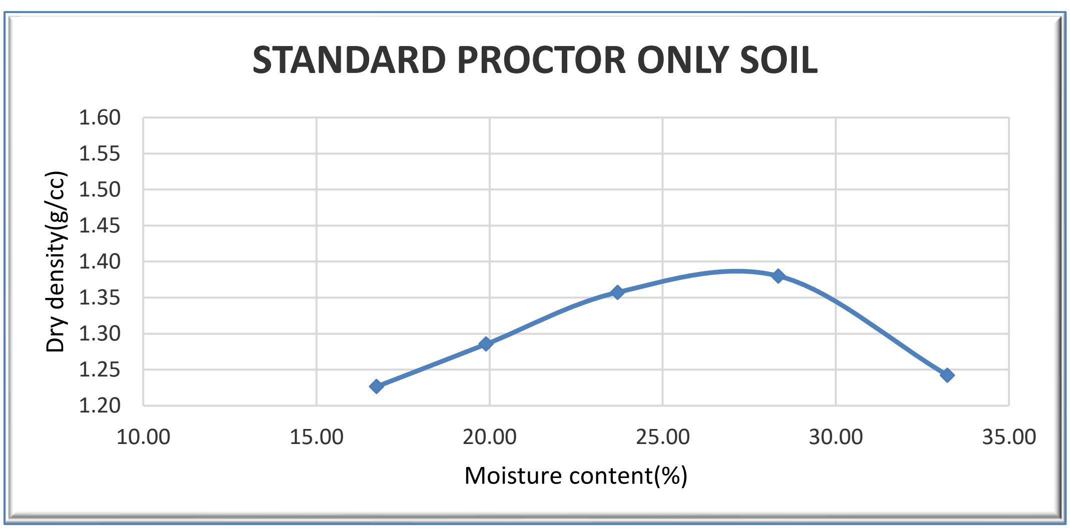


Figure C- 1: Moisture-Dry density curve for Soil only

Table B-2 Moisture-Density relations for soil with 2% pumicite

Pumicite Content = 2%

Water Content Determination:

	1	2	3	4	5
Compacted Soil - Sample no.	1	2	3	4	5
Water content - Sample no.	1A	2A	3A	4A	5A
Moisture can number - Lid number	C1	C2	D1	D2	E1
MC = Mass of empty, clean can + lid (grams)	22.1	23.3	21.5	21.9	21.7
MCMS = Mass of can, lid, and moist soil (grams)	162.4	173.7	166	174.9	231.6
MCDS = Mass of can, lid, and dry soil (grams)	149.6	154.5	142.9	142.9	179.9
MS = Mass of soil solids (grams)	127.5	131.2	121.4	121	158.2
MW = Mass of pore water (grams)	12.8	19.2	23.1	32	51.7
w = Water content, w%	10.0	14.6	19.0	26.4	32.7

Density Determination:
Mold Volume=944 cm3

Compacted Soil - Sample no.	1	2	3	4	5
w = Assumed water content, w%	8	12	16	20	24
Actual average water content, w%	10.00	14.60	19.00	26.40	32.70
Mass of compacted soil and mold(grams)	6838	7003	7134	7250	7185
mass of mold(grams)	5489	5489	5489	5489	5489
wet mass of soil in mold(grams)	1349	1514	1645	1761	1696
wet density,	1.429	1.604	1.743	1.865	1.797
dry density	1.30	1.40	1.46	1.48	1.35

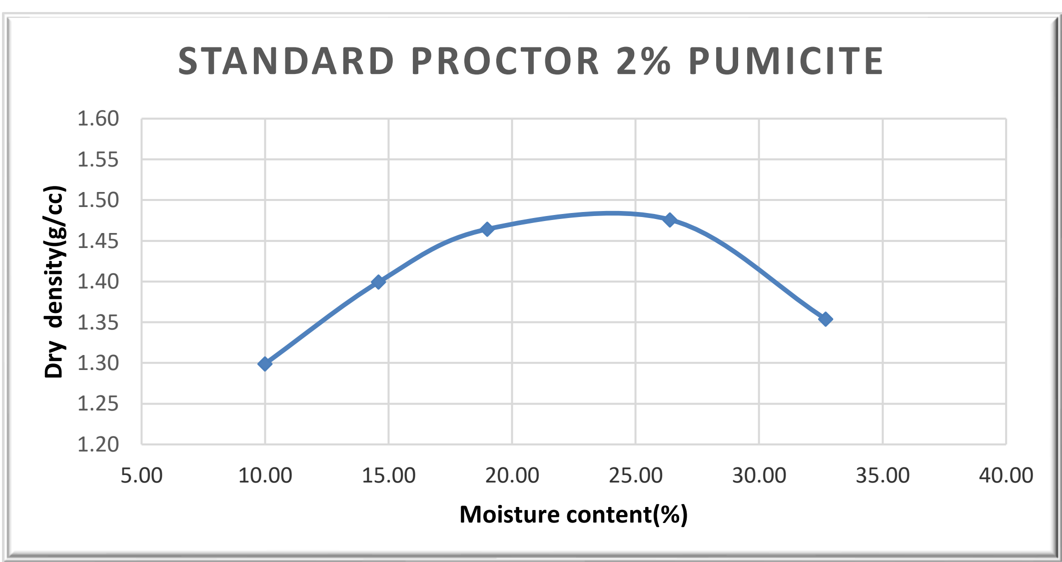


Figure C- 2: Moisture-Dry density curve for soil with 2 % pumicite

Table B-3 Moisture-Density relations for soil with 4% pumicite

Pumicite Content = 4%

Water Content Determination:

Compacted Soil - Sample no.	1	2	3	4	3
Water content - Sample no.	1A	2A	3A	5	5A
Moisture can number - Lid number	C1	C2	D1	D2	E1
MC = Mass of empty, clean can + lid (grams)	21.6	21.6	22	21.8	21.9
MCMS = Mass of can, lid, and moist soil (grams)	131.6	143.5	157.4	175.5	218.7
MCDS = Mass of can, lid, and dry soil (grams)	121.9	127.3	134	140.7	168.8
MS = Mass of soil solids (grams)	100.3	105.7	112	118.9	146.9
MW = Mass of pore water (grams)	9.7	16.2	23.4	34.8	49.9
w = Water content, w%	9.7	15.3	20.9	29.3	34.0

Density Determination:
Mold Volume=944 cm3

Compacted Soil - Sample no.	1	2	3	4	5
w = Assumed water content, w%	8	12	16	20	24
Actual average water content, w%	9.70	15.30	20.90	29.30	34.00
Mass of compacted soil and mold(grams)	6842	6977	7148	7328	7278
mass of mold(grams)	5489	5489	5489	5489	5489
wet mass of soil in mold(grams)	1353	1488	1659	1839	1789
wet density,	1.433	1.576	1.757	1.948	1.895
dry density	1.31	1.37	1.45	1.51	1.41

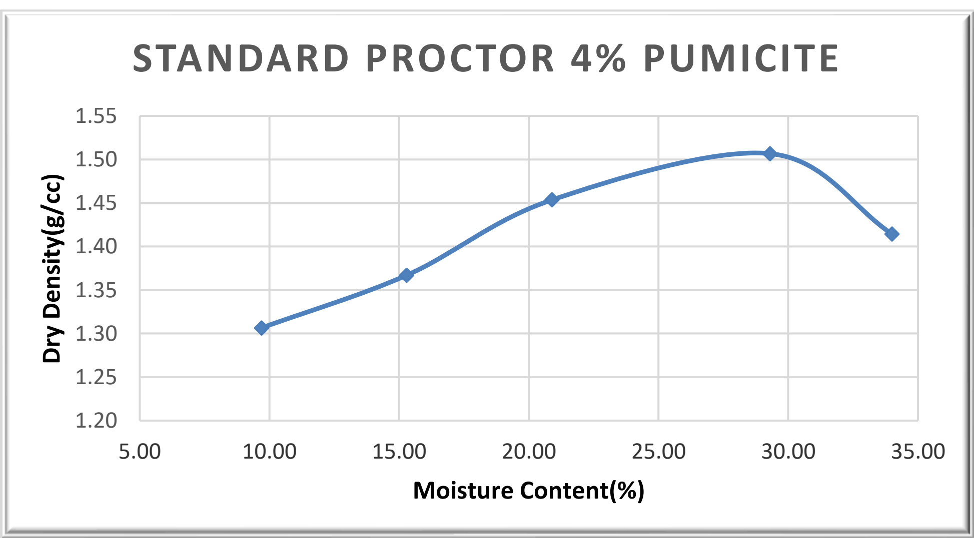


Figure C- 3: Moisture-Dry density curve for soil with 4 % pumicite

Table B-4 Moisture-Density relations for soil with 6% pumicite

Pumicite Content = 6%

Water Content Determination:

Compacted Soil - Sample no.			1	2	3	4	5
Water content - Sample no.			1A	2A	3A	4A	5A
Moisture can number - Lid number			C1	C2	D1	D2	E1
MC = Mass of empty, clean can + lid (grams)			21.7	23.3	21.8	22	21.9
MCMS = Mass of can, lid, and moist soil (grams)			162.5	170.7	182.6	148.1	200.1
MCDS = Mass of can, lid, and dry soil (grams)			149.7	155.3	155.5	120.2	155.5
MS = Mass of soil solids (grams)			128	132	133.7	98.2	133.6
MW = Mass of pore water (grams)			12.8	15.4	27.1	27.9	44.6
w = Water content, w%			10.0	11.7	20.3	28.4	33.4

Density Determination:
Mold Volume=944 cm3

Compacted Soil - Sample no.		1	2	3	4	5
w = Assumed water content, w%		8	12	16	20	24
Actual average water content, w%		10.00	11.70	20.30	28.40	33.40
Mass of compacted soil and mold(grams)		6875	6922	7171	7335	7298
mass of mold(grams)		5489	5489	5489	5489	5489
wet mass of soil in mold(grams)		1386	1433	1682	1846	1809
wet density,		1.468	1.518	1.782	1.956	1.916
dry density		1.33	1.36	1.48	1.52	1.44

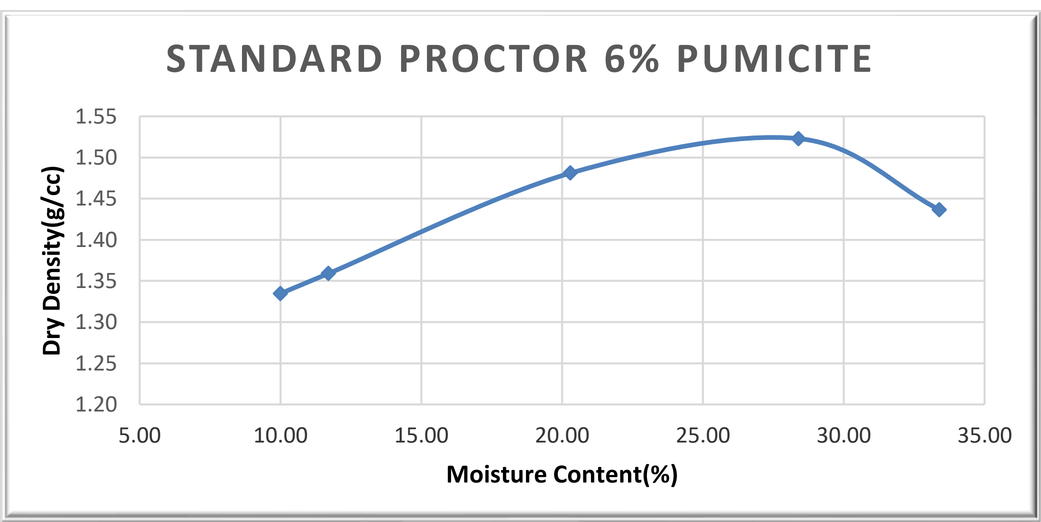


Figure C- 4: Moisture-Dry density curve for soil with 6 % pumicite

Table B-5 Moisture-Density relations for soil with 8% pumicite

Pumicite Content = 8%

Water Content Determination:

Compacted Soil - Sample no.	1	2	3	4	5
Water content - Sample no.	1A	2A	3A	4A	5A
Moisture can number - Lid number	C1	C2	D1	D2	E1
MC = Mass of empty, clean can + lid (grams)	21.8	21.9	23.4	21.9	21.6
MCMS = Mass of can, lid, and moist soil (grams)	152	154.8	175.3	152.9	228.2
MCDS = Mass of can, lid, and dry soil (grams)	138.3	136.6	148.1	125.4	174.3
MS = Mass of soil solids (grams)	116.5	114.7	124.7	103.5	152.7
MW = Mass of pore water (grams)	13.7	18.2	27.2	27.5	53.9
w = Water content, w%	11.8	15.9	21.8	26.6	35.3

Density Determination:
Mold Volume=944 cm3

Compacted Soil - Sample no.	1	2	3	4	5
w = Assumed water content, w%	8	12	16	20	24
Actual average water content, w%	11.80	15.90	21.80	26.60	35.30
Mass of compacted soil and mold(grams)	6867	6978	7199	7315	7273
mass of mold(grams)	5489	5489	5489	5489	5489
wet mass of soil in mold(grams)	1378	1489	1710	1826	1784
wet density,	1.460	1.577	1.811	1.934	1.890
dry density	1.31	1.36	1.49	1.53	1.40

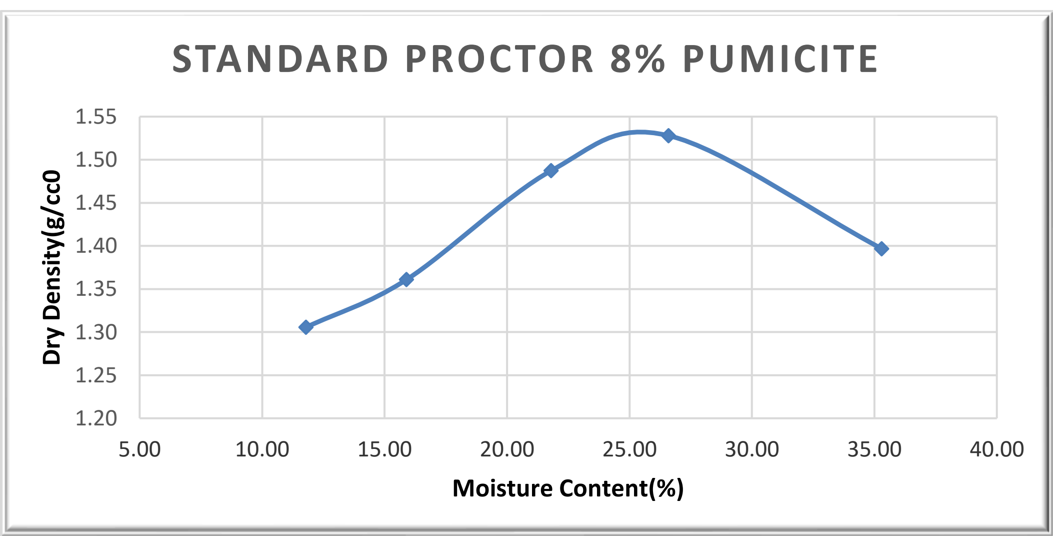


Figure C- 5: Moisture-Dry density curve for soil with 8 % pumicite

Table B-6 Moisture-Density relations for soil with 10% pumicite

Pumicite Content = 10%

Water Content Determination:

Compacted Soil - Sample no.			1	2	3	4	5
Water content - Sample no.			1A	2A	3A	4A	5A
Moisture can number - Lid number			C1	C2	D1	D2	E1
MC = Mass of empty, clean can + lid (grams)			22.1	21.8	21.9	21.6	21.6
MCMS = Mass of can, lid, and moist soil (grams)			158.5	172	163.7	193.1	238.9
MCDS = Mass of can, lid, and dry soil (grams)			146.4	153.3	140.1	157.2	182.4
MS = Mass of soil solids (grams)			124.3	131.5	118.2	135.6	160.8
MW = Mass of pore water (grams)			12.1	18.7	23.6	35.9	56.5
w = Water content, w%			9.7	14.2	20.0	25.6	35.1

Density Determination:
Mold Volume=944 cm3

Compacted Soil - Sample no.		1	2	3	4	5
w = Assumed water content, w%		8	12	16	20	24
Actual average water content, w%		9.70	14.20	20.00	25.90	35.10
Mass of compacted soil and mold(grams)		6799	6992	7158	7320	7295
mass of mold(grams)		5489	5489	5489	5489	5489
wet mass of soil in mold(grams)		1310	1503	1669	1831	1806
wet density,		1.388	1.592	1.768	1.940	1.913
dry density		1.27	1.39	1.47	1.54	1.42

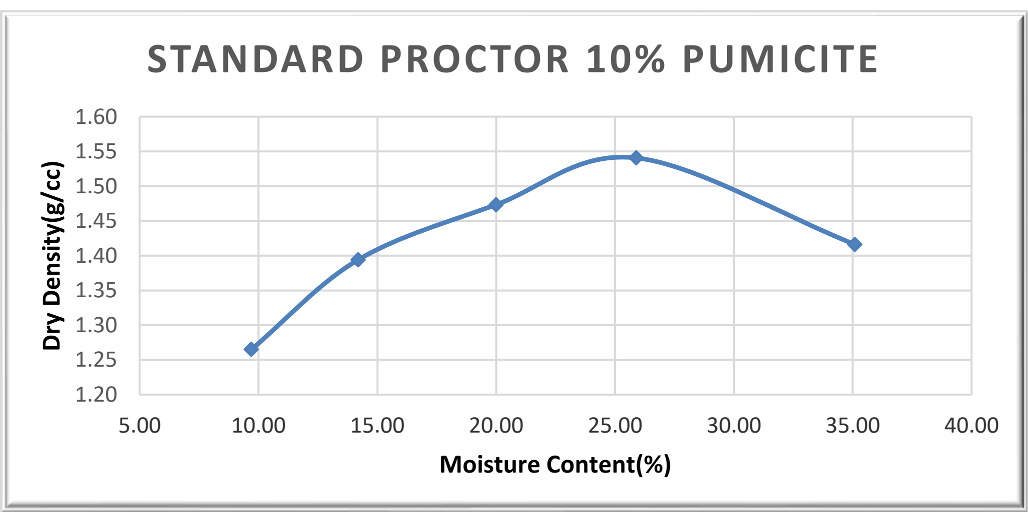


Figure C- 6: Moisture-Dry density curve for soil with 10 % pumicite

Table B-7 Moisture-Density relations for soil with 12% pumicite

Pumicite Content = 12%

Water Content Determination:

Compacted Soil - Sample no.			1	2	3	4	5
Water content - Sample no.			1A	2A	3A	4A	5A
Moisture can number - Lid number			C1	C2	D1	D2	E1
MC = Mass of empty, clean can + lid (grams)			22	21.8	22	21.7	24.8
MCMS = Mass of can, lid, and moist soil (grams)			165.6	144.7	165.2	172.6	260.7
MCDS = Mass of can, lid, and dry soil (grams)			151.9	129.4	140.4	140.8	201.1
MS = Mass of soil solids (grams)			129.9	107.6	118.4	119.1	176.3
MW = Mass of pore water (grams)			13.7	15.3	24.8	31.8	59.6
w = Water content, w%			10.5	14.2	20.9	26.7	33.8

Density Determination:
Mold Volume=944 cm3

Compacted Soil - Sample no.		1	2	3	4	5
w = Assumed water content, w%		8	12	16	20	24
Actual average water content, w%		10.55	14.20	20.90	26.70	33.80
Mass of compacted soil and mold(grams)		6823	6909	7147	7313	7260
mass of mold(grams)		5489	5489	5489	5489	5489
wet mass of soil in mold(grams)		1334	1420	1658	1824	1771
wet density,		1.413	1.504	1.756	1.932	1.876
dry density		1.28	1.32	1.45	1.53	1.40

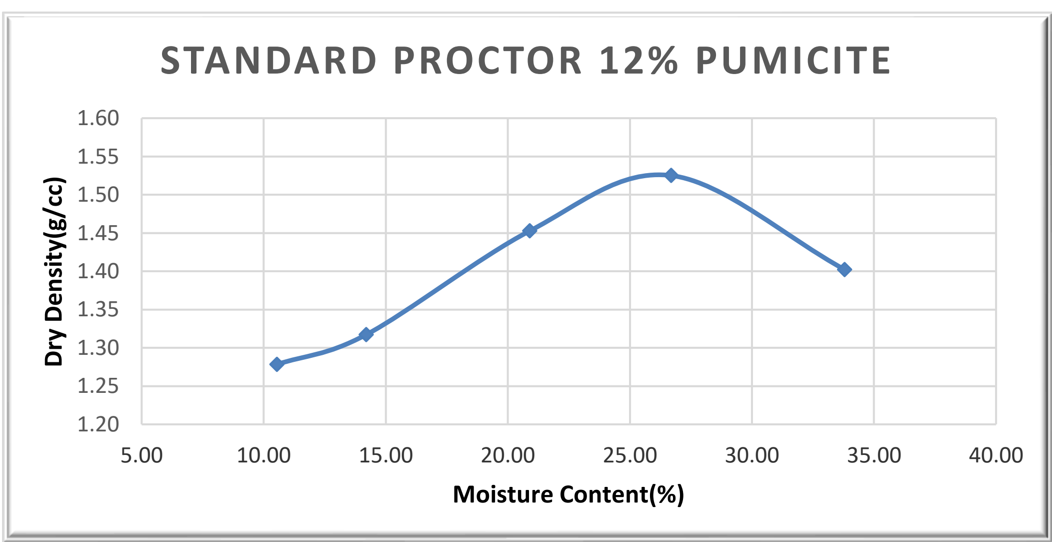


Figure C- 7: Moisture-Dry density curve for soil with 12 % pumicite

Table B-8 Moisture-Density relations for soil with 14% pumicite

Pumicite Content = 14%

Water Content Determination:

	1	2	3	4	5
Compacted Soil - Sample no.	1	2	3	4	5
Water content - Sample no.	1A	2A	3A	4A	5A
Moisture can number - Lid number	C1	C2	D1	D2	E1
MC = Mass of empty, clean can + lid (grams)	21.7	21.7	21.9	21.9	21.8
MCMS = Mass of can, lid, and moist soil (grams)	162.4	165.9	166.7	198.5	220.3
MCDS = Mass of can, lid, and dry soil (grams)	151.8	148.4	142.4	161.9	173.5
MS = Mass of soil solids (grams)	130.1	126.7	120.5	140	151.7
MW = Mass of pore water (grams)	10.6	17.5	24.3	36.6	46.8
w = Water content, w%	8.1	13.8	20.2	26.1	30.9

Density Determination:
Mold Volume=944 cm3

Compacted Soil - Sample no.	1	2	3	4	5
w = Assumed water content, w%	8	12	16	20	24
Actual average water content, w%	8.10	13.80	20.20	26.10	30.90
Mass of compacted soil and mold(grams)	6854	6973	7189	7300	7279
mass of mold(grams)	5489	5489	5489	5489	5489
wet mass of soil in mold(grams)	1365	1484	1700	1811	1790
wet density,	1.446	1.572	1.801	1.918	1.896
dry density	1.34	1.38	1.50	1.52	1.45

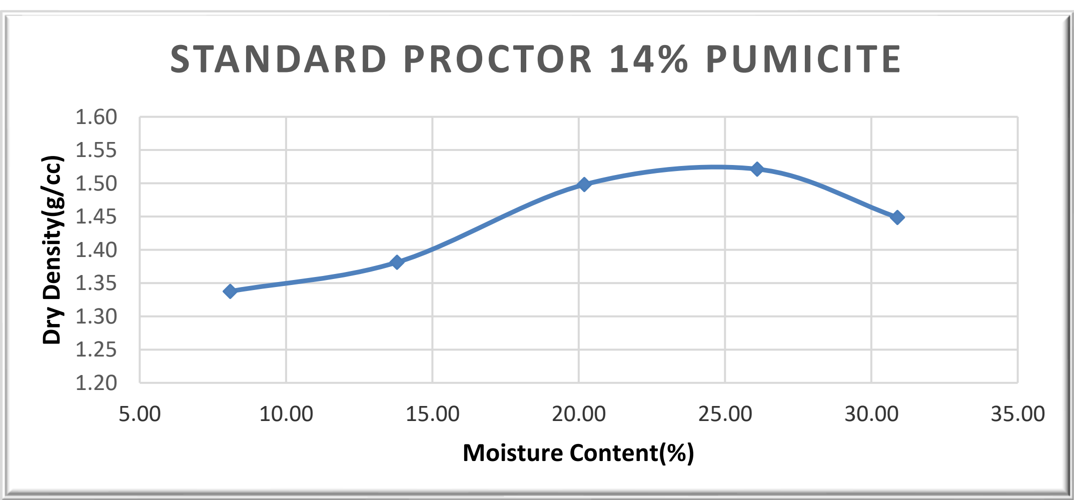


Figure C- 8: Moisture-Dry density curve for soil with 14% pumicite

Table B-9 Moisture-Density relations for soil with 16% pumicite

Pumicite Content = 16%

Water Content Determination:

Compacted Soil - Sample no.	1	2	3	4	5
Water content - Sample no.	1A	2A	3A	4A	5A
Moisture can number - Lid number	C1	C2	D1	D2	E1
MC = Mass of empty, clean can + lid (grams)	23.3	21.7	21.8	21.4	21.8
MCMS = Mass of can, lid, and moist soil (grams)	153.5	138.3	152	173	197.2
MCDS = Mass of can, lid, and dry soil (grams)	140.64	122.2	128.53	140.5	149.68
MS = Mass of soil solids (grams)	117.34	100.5	106.73	119.1	127.88
MW = Mass of pore water (grams)	12.86	16.1	23.47	32.5	47.52
w = Water content, w%	11.0	16.0	22.0	27.3	37.2

Density Determination:
Mold Volume=944 cm3

Compacted Soil - Sample no.	1	2	3	4	5
w = Assumed water content, w%	8	12	16	20	24
Actual average water content, w%	11.00	16.00	22.00	27.30	37.20
Mass of compacted soil and mold(grams)	6807	6923	7146	7290	7245
mass of mold(grams)	5489	5489	5489	5489	5489
wet mass of soil in mold(grams)	1318	1434	1657	1801	1756
wet density,	1.396	1.519	1.755	1.908	1.860
dry density	1.26	1.31	1.44	1.50	1.36

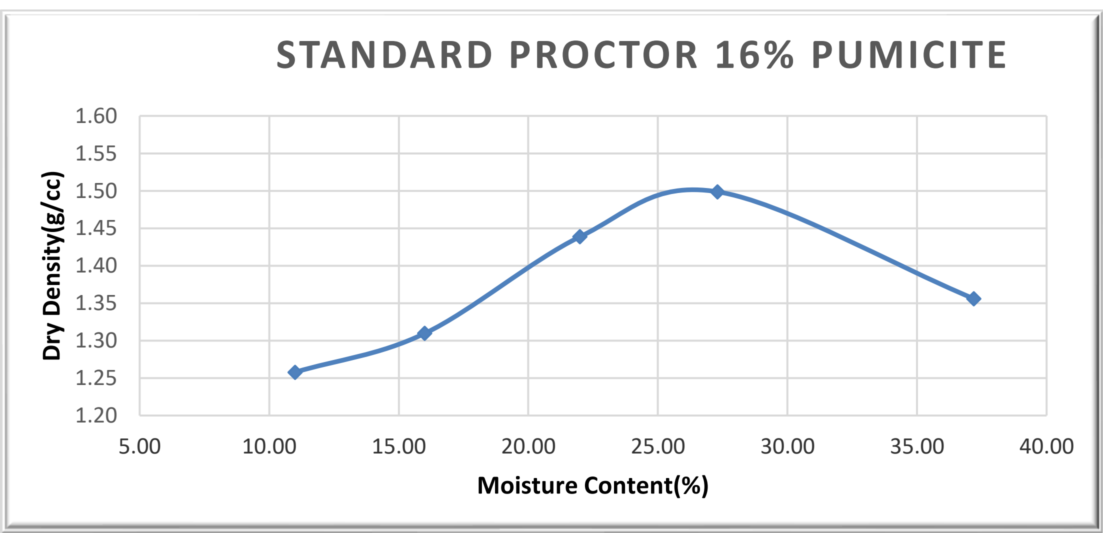


Figure C- 9: Moisture-Dry density curve for soil with 16% pumicite

Table B-10 Moisture Moisture-Density relations for soil with 18% pumicite

Pumicite Content = 18%

Water Content Determination:

Compacted Soil - Sample no.			1	2	3	4	5
Water content - Sample no.			1A	2A	3A	4A	5A
Moisture can number - Lid number			C1	C2	D1	D2	E1
MC = Mass of empty, clean can + lid (grams)			24.7	21.8	22.1	21.7	21.3
MCMS = Mass of can, lid, and moist soil (grams)			182.1	158.5	166	174.2	229.9
MCDS = Mass of can, lid, and dry soil (grams)			170.5	143.1	140.9	138.1	177.5
MS = Mass of soil solids (grams)			145.8	121.3	118.8	116.4	156.2
MW = Mass of pore water (grams)			11.6	15.4	25.1	36.1	52.4
w = Water content, w%			8.0	12.7	21.1	31.0	33.5

Density Determination:
Mold Volume=944 cm3

Compacted Soil - Sample no.		1	2	3	4	5
w = Assumed water content, w%		8	12	16	20	24
Actual average water content, w%		8.00	12.70	21.30	31.00	33.50
Mass of compacted soil and mold(grams)		6850	6938	7141	7326	7287
mass of mold(grams)		5489	5489	5489	5489	5489
wet mass of soil in mold(grams)		1361	1449	1652	1837	1798
wet density,		1.442	1.535	1.750	1.946	1.905
dry density		1.33	1.36	1.44	1.49	1.43

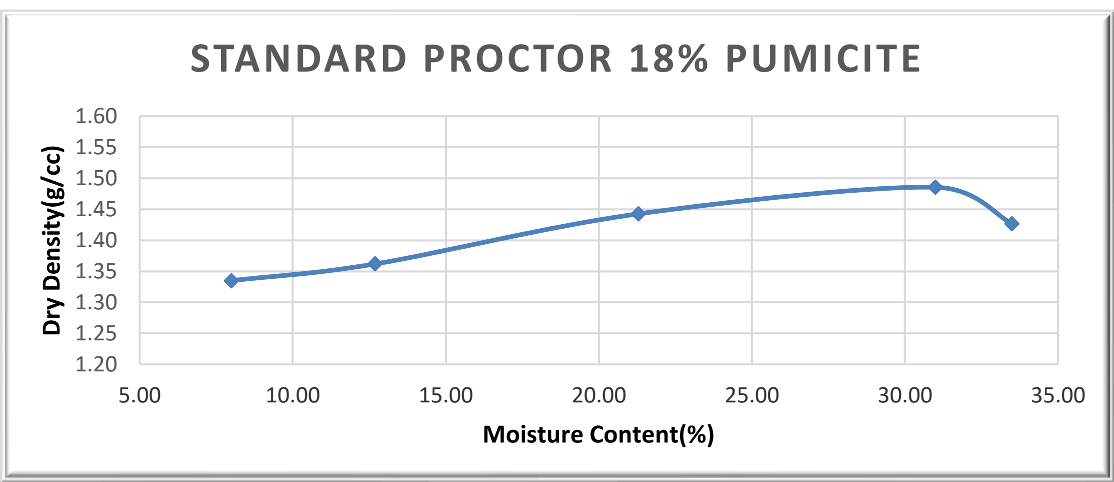


Figure C- 10: Moisture-Dry density curve for soil with 18% pumicite

Table B-11 Moisture-Density relations for soil with 20% pumicite

Pumicite Content = 20%

Water Content Determination:

Compacted Soil - Sample no.			1	2	3	4	5
Water content - Sample no.			1A	2A	3A	4A	5A
Moisture can number - Lid number			C1	C2	D1	D2	E1
MC = Mass of empty, clean can + lid (grams)			21.5	21.7	21.9	21.8	21.6
MCMS = Mass of can, lid, and moist soil (grams)			144.2	141.9	143.4	167.3	189.9
MCDS = Mass of can, lid, and dry soil (grams)			132.1	126.23	122.27	132.35	146.6
MS = Mass of soil solids (grams)			110.6	104.53	100.37	110.55	125
MW = Mass of pore water (grams)			12.1	15.67	21.13	34.95	43.3
w = Water content, w%			10.9	15.0	21.1	31.6	34.6

Density Determination:
Mold Volume=944 cm3

Compacted Soil - Sample no.		1	2	3	4	5
w = Assumed water content, w%		8	12	16	20	24
Actual average water content, w%		10.90	15.00	21.10	31.60	34.60
Mass of compacted soil and mold(grams)		6797	6902	7099	7304	7281
mass of mold(grams)		5489	5489	5489	5489	5489
wet mass of soil in mold(grams)		1308	1413	1610	1815	1792
wet density,		1.386	1.497	1.706	1.923	1.898
dry density		1.25	1.30	1.41	1.46	1.41

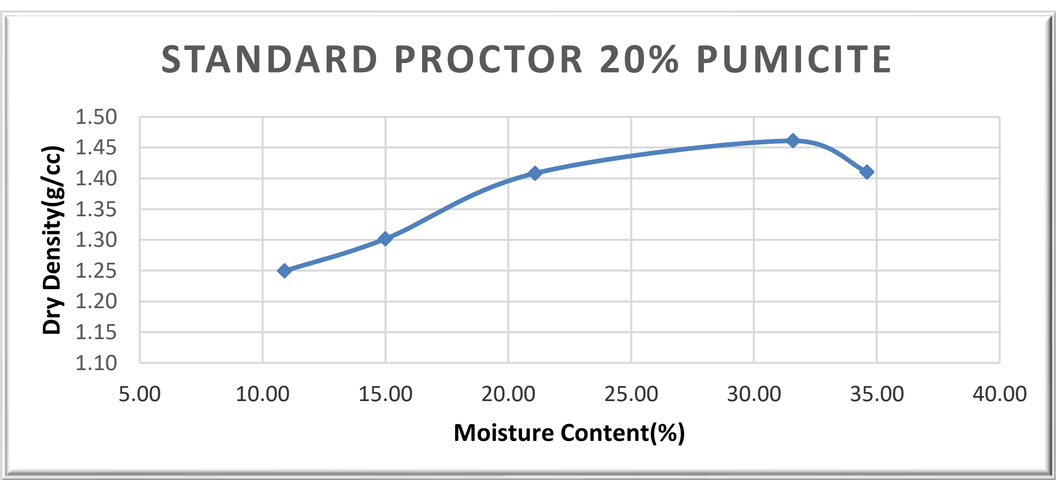


Figure C- 11: Moisture-Dry density curve for soil with 20% pumicite

Table B-12 Moisture-Density relations for soil with 22% pumicite

Pumicite Content = 22%

Water Content Determination:

Compacted Soil - Sample no.	1	2	3	4	5
Water content - Sample no.	1A	2A	3A	4A	5A
Moisture can number - Lid number	C1	C2	D1	D2	E1
MC = Mass of empty, clean can + lid (grams)	21.8	22	21.5	21.8	21.9
MCMS = Mass of can, lid, and moist soil (grams)	160.4	161.1	180.1	184	252.7
MCDS = Mass of can, lid, and dry soil (grams)	148.8	142.9	143.8	142.4	191
MS = Mass of soil solids (grams)	127	120.9	122.3	120.6	169.1
MW = Mass of pore water (grams)	11.6	18.2	36.3	41.6	61.7
w = Water content, w%	9.1	15.1	29.7	34.5	36.5

Density Determination:
Mold Volume=944 cm3

Compacted Soil - Sample no.	1	2	3	4	5
w = Assumed water content, w%	8	12	16	20	24
Actual average water content, w%	9.10	15.10	29.70	34.50	36.50
Mass of compacted soil and mold(grams)	6783	6901	7164	7299	7253
mass of mold(grams)	5489	5489	5489	5489	5489
wet mass of soil in mold(grams)	1294	1412	1675	1810	1764
wet density,	1.371	1.496	1.774	1.917	1.869
dry density	1.26	1.30	1.37	1.43	1.37

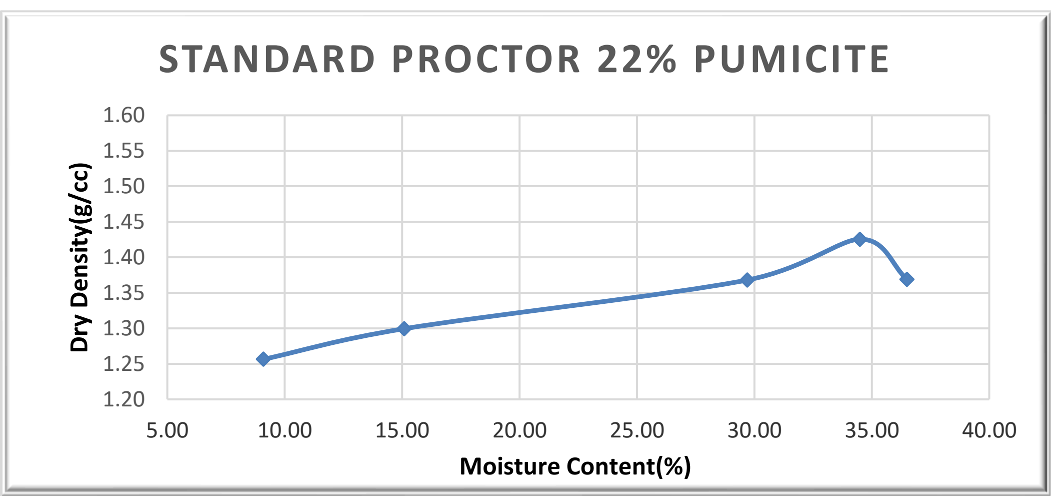


Figure C- 12: Moisture-Dry density curve for soil with 22% pumicite

Table B-13 Moisture-Density relations for soil with 24% pumicite

Pumicite Content = 24%

Water Content Determination:

Compacted Soil - Sample no.	1	2	3	4	5
Water content - Sample no.	1A	2A	3A	4A	5A
Moisture can number - Lid number	C1	C2	D1	D2	E1
MC = Mass of empty, clean can + lid (grams)	21.7	21.8	21.7	21.9	21.9
MCMS = Mass of can, lid, and moist soil (grams)	146.7	151.5	162.2	169.8	176.4
MCDS = Mass of can, lid, and dry soil (grams)	135.95	134.4	132.72	130.5	133.05
MS = Mass of soil solids (grams)	114.25	112.6	111.02	108.6	111.15
MW = Mass of pore water (grams)	10.75	17.1	29.48	39.3	43.35
w = Water content, w%	9.4	15.2	26.6	36.2	39.0

Density Determination:
Mold Volume=944 cm3

Compacted Soil - Sample no.	1	2	3	4	5
w = Assumed water content, w%	8	12	16	20	24
Actual average water content, w%	9.41	15.20	25.40	36.20	39.00
Mass of compacted soil and mold(grams)	6782	6931	7113	7303	7263
mass of mold(grams)	5489	5489	5489	5489	5489
wet mass of soil in mold(grams)	1293	1442	1624	1814	1774
wet density,	1.370	1.528	1.720	1.922	1.879
dry density	1.25	1.33	1.37	1.41	1.35

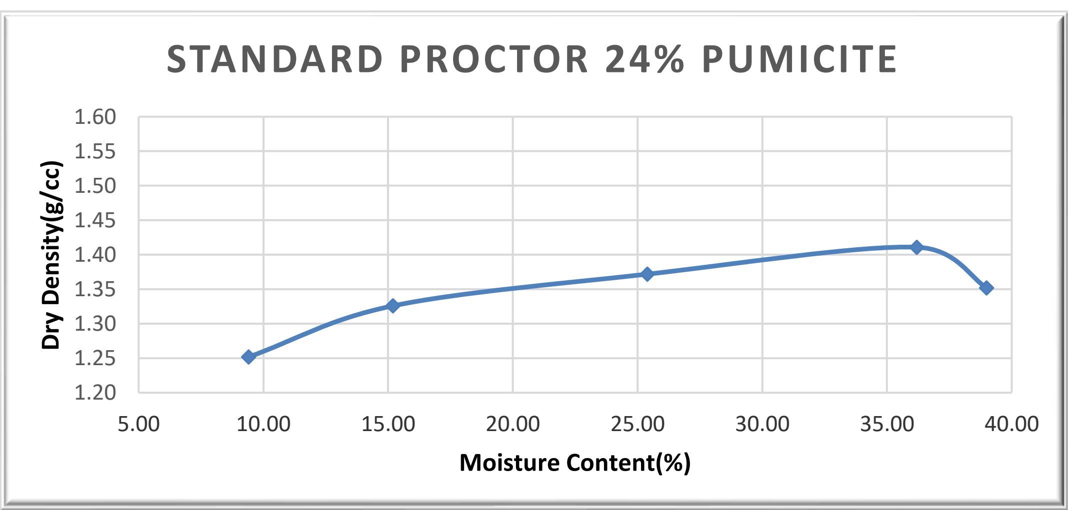


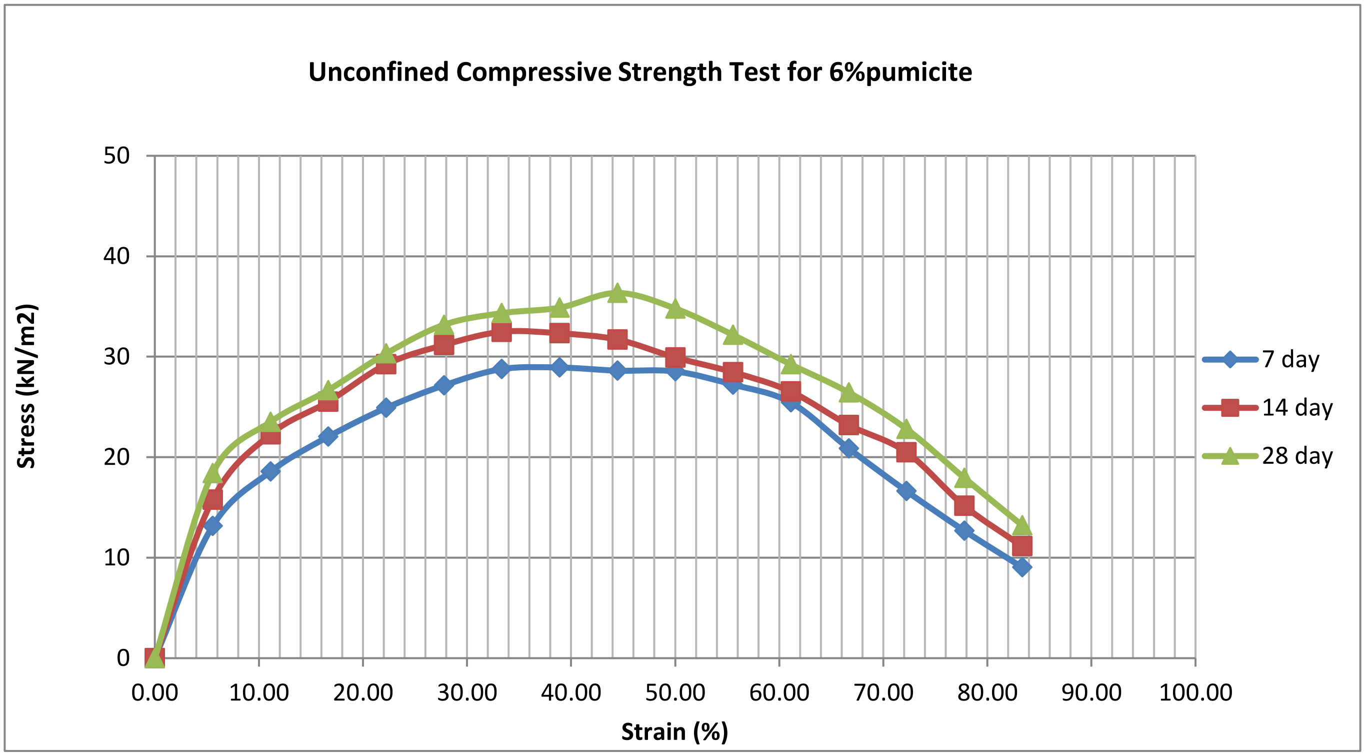
Figure C- 13: Moisture-Dry density curve for soil with 24% pumicite

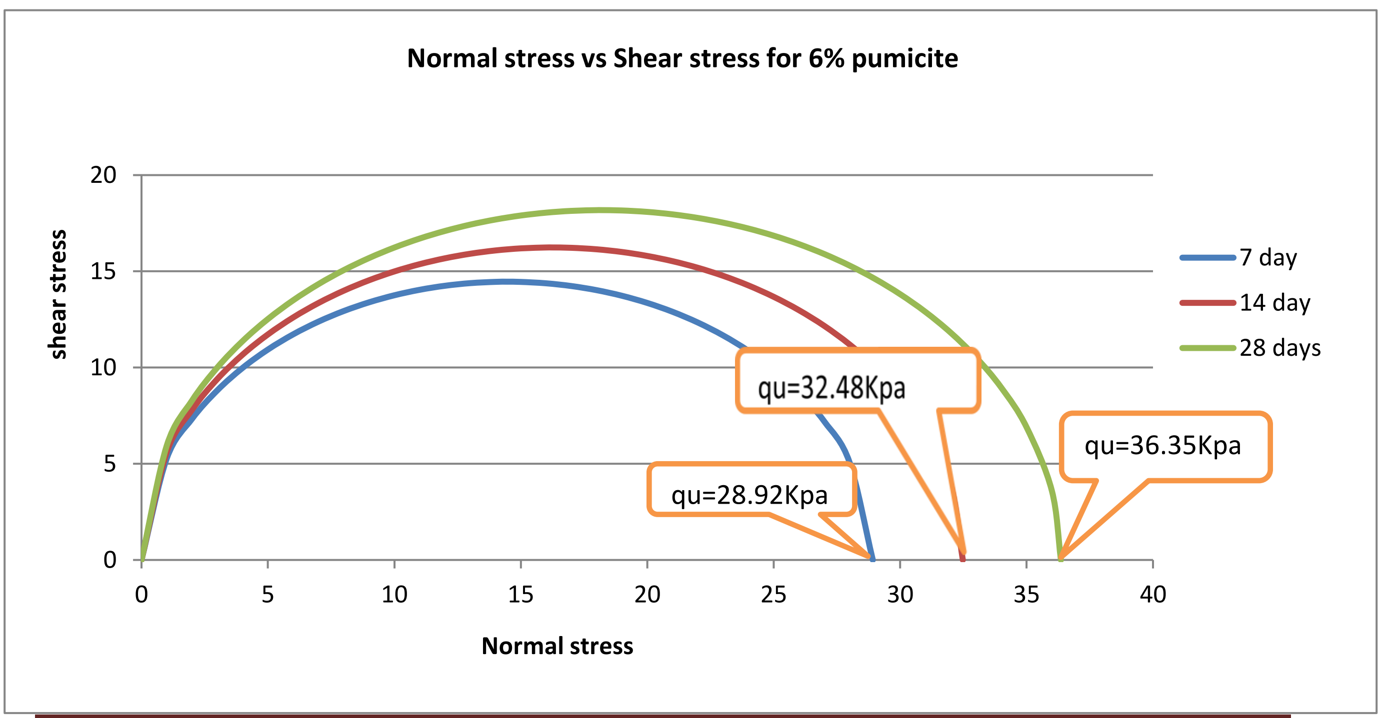
APPENDIX C

UNCONFINED COMPRESSIVE STRENGTH RESULTS

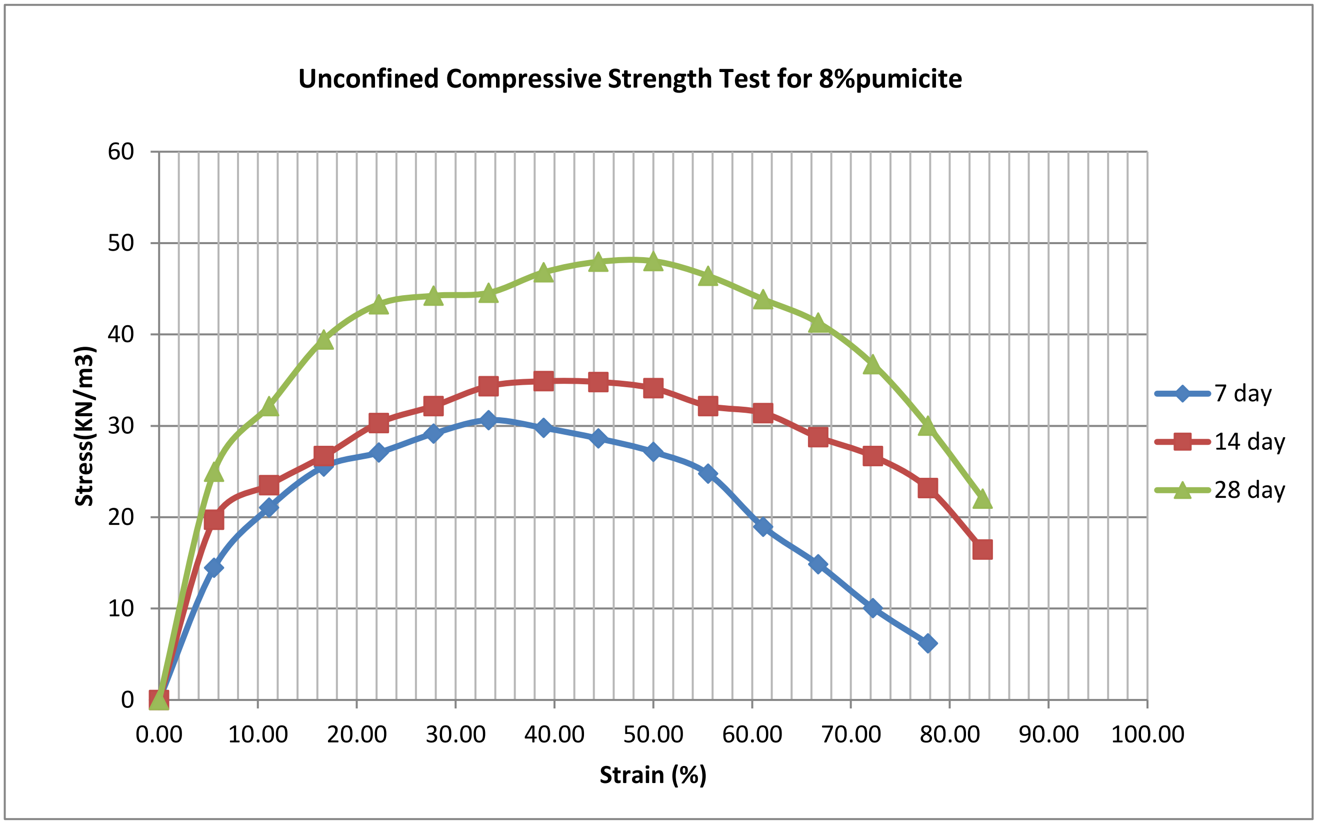
Table C-1 unconfined compressive strength curves with varying percentage of pumicite

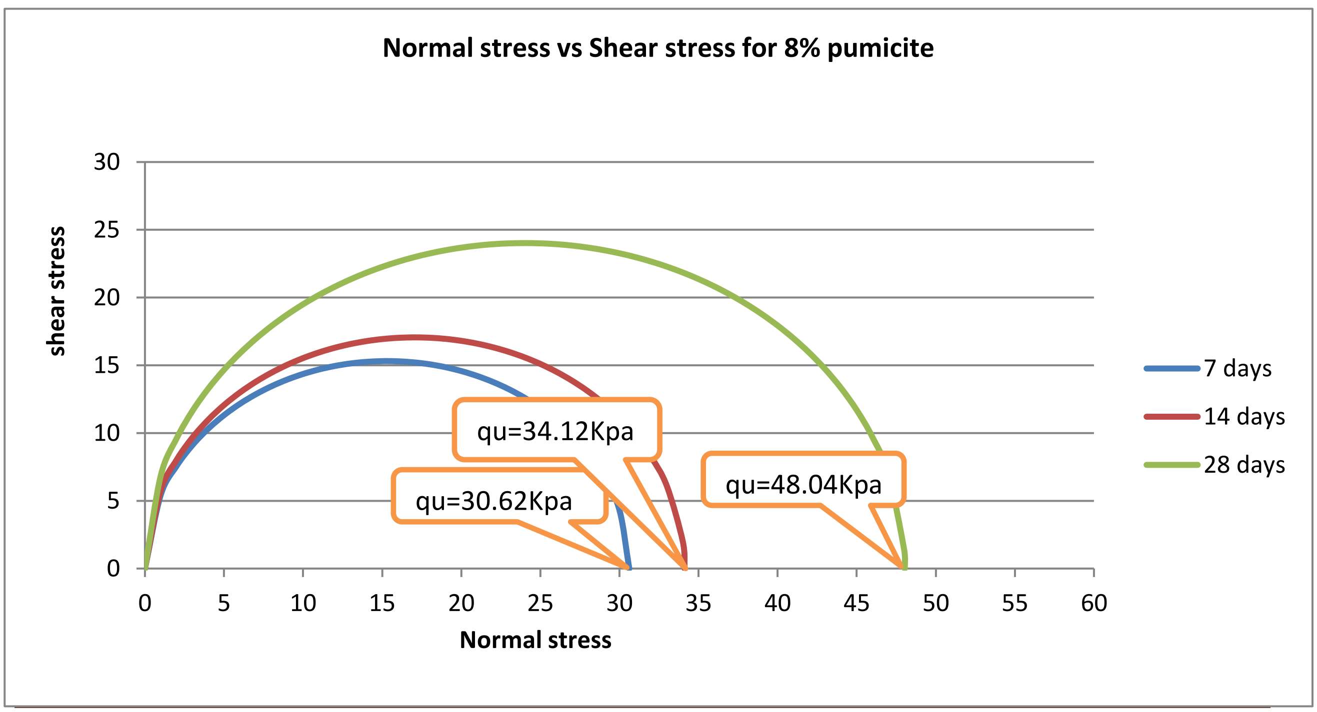
A. pumicite Content = 6%



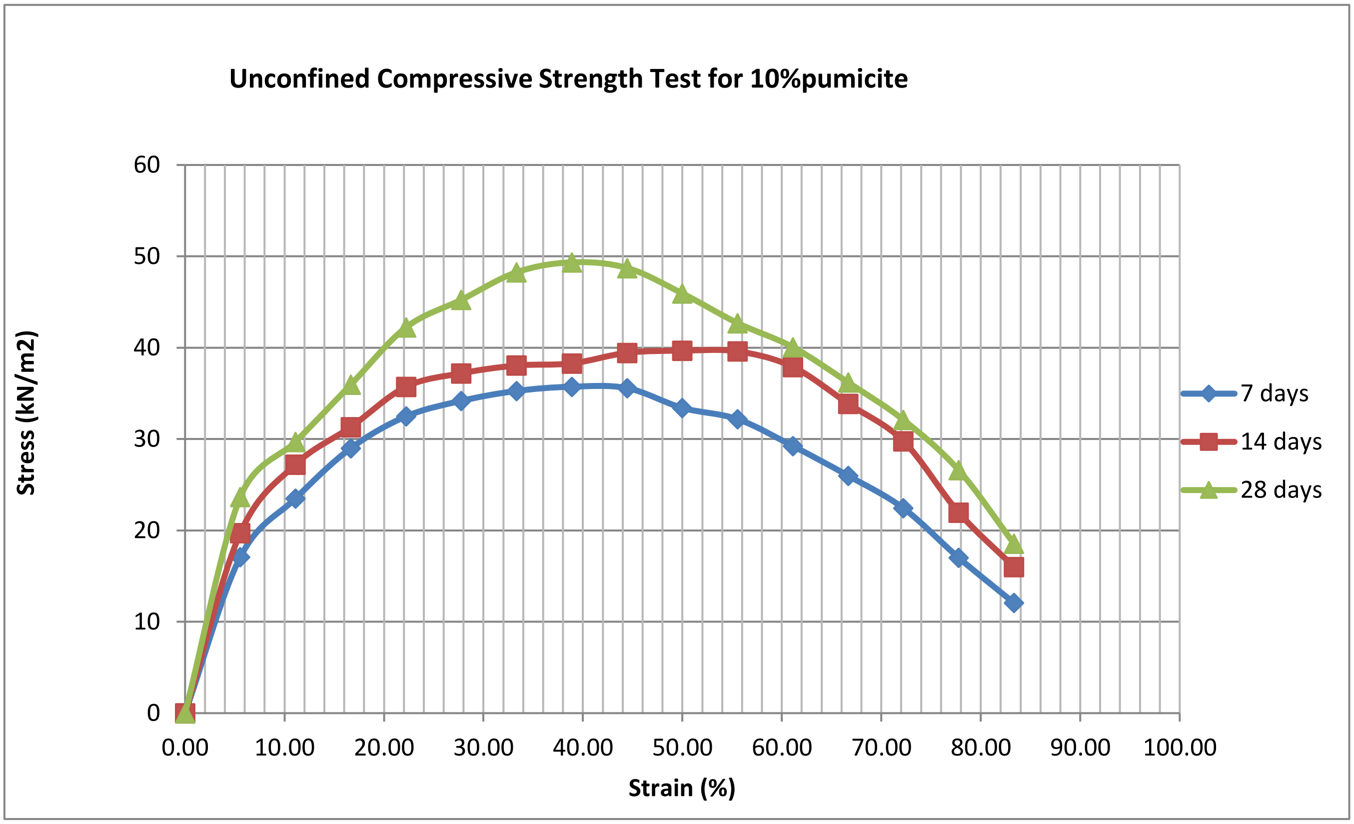


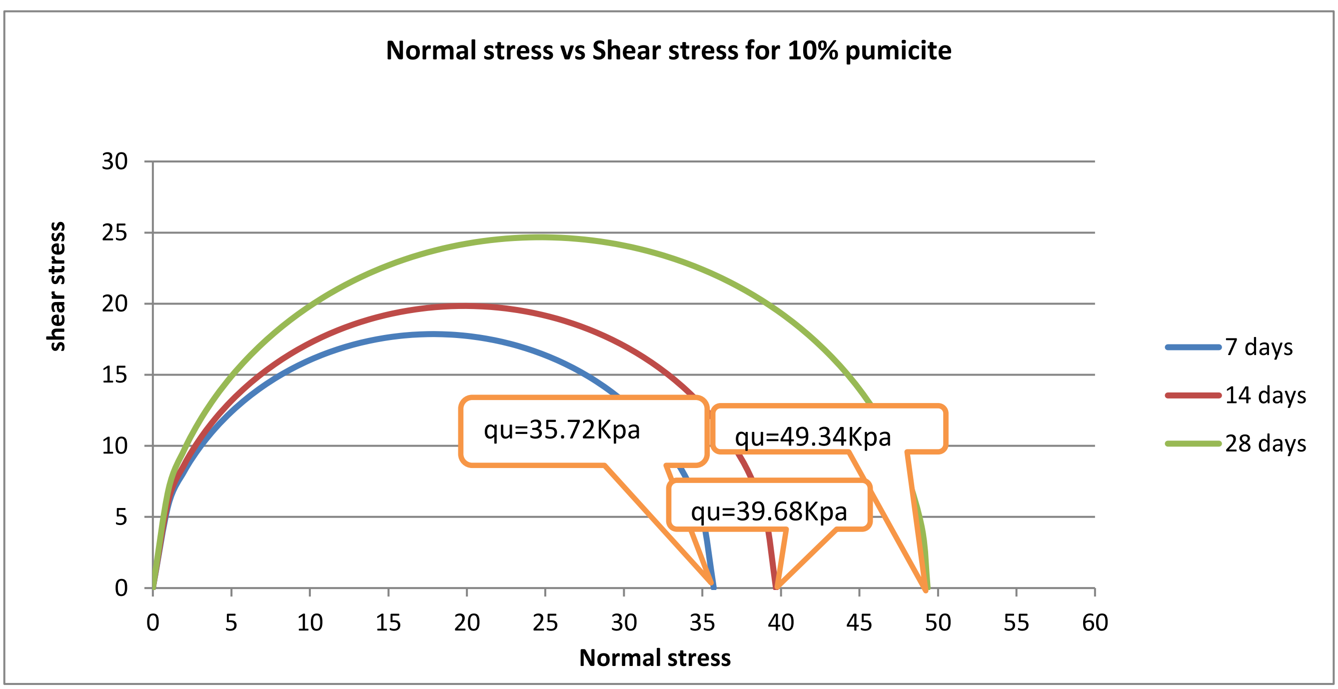
B. pumicite Content = 8%



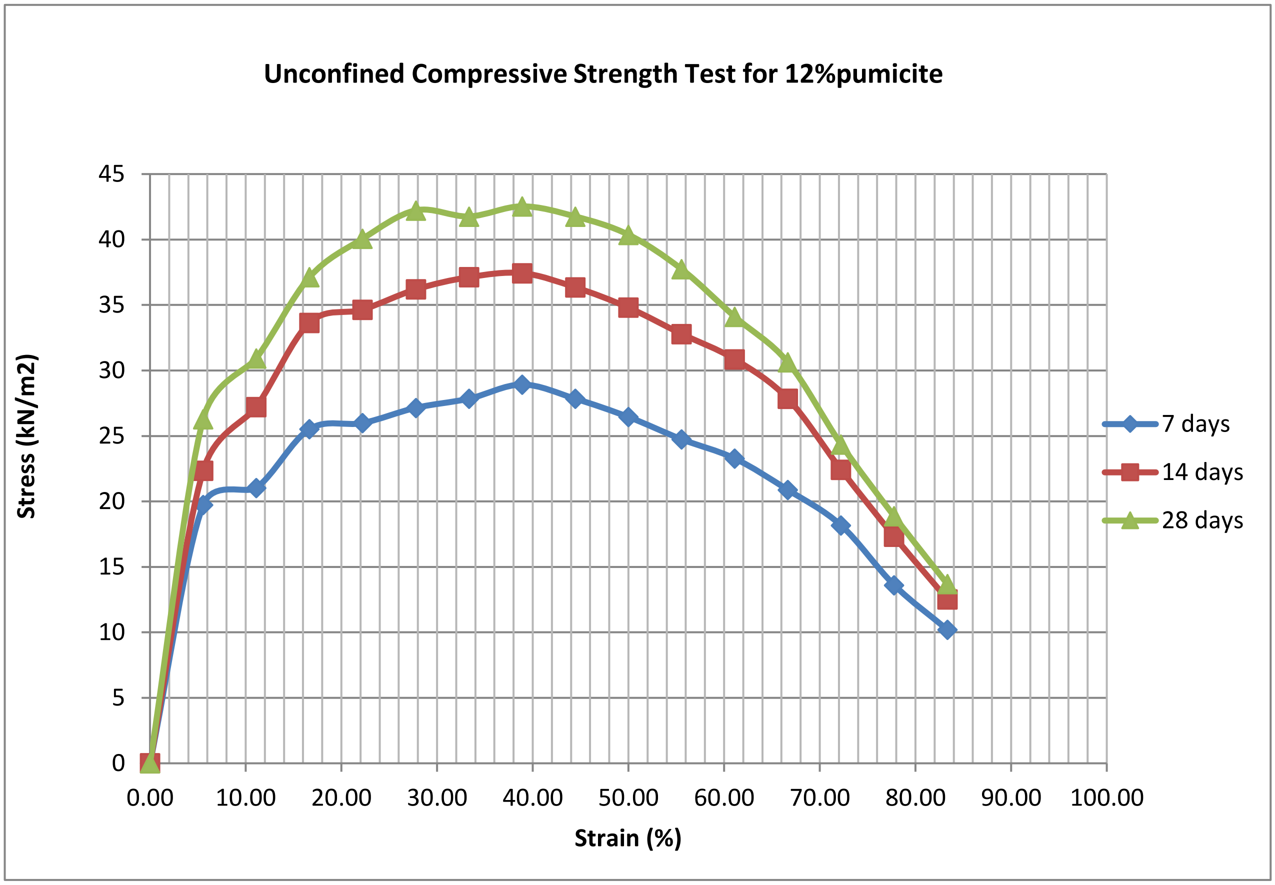


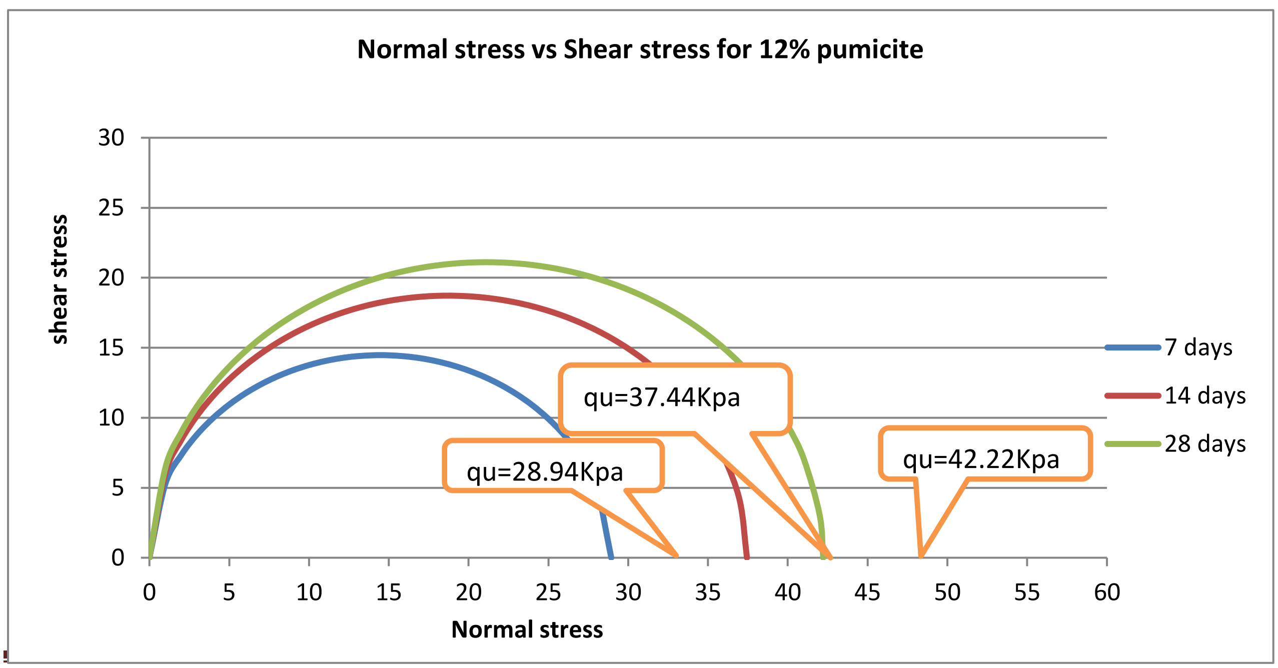
C. pumicite Content = 10%



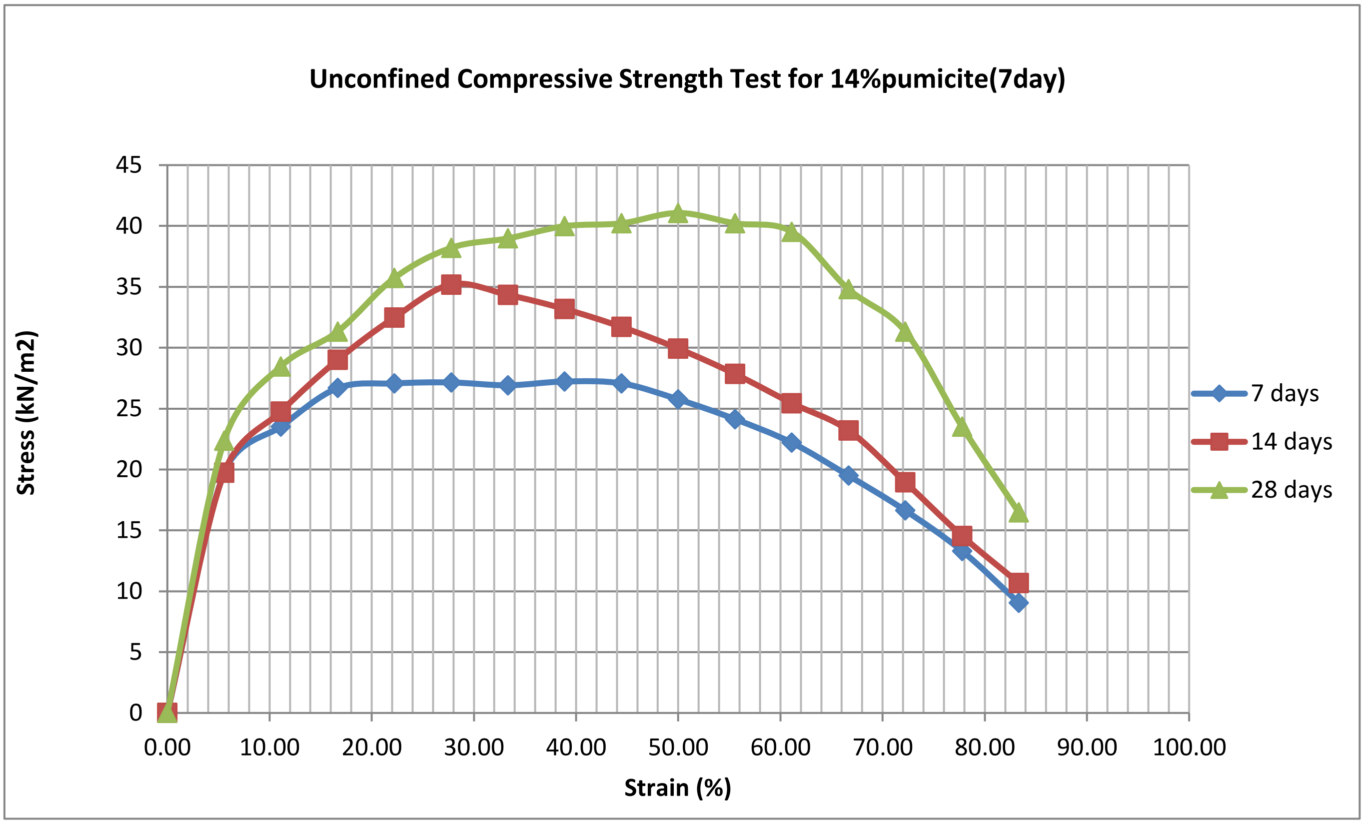


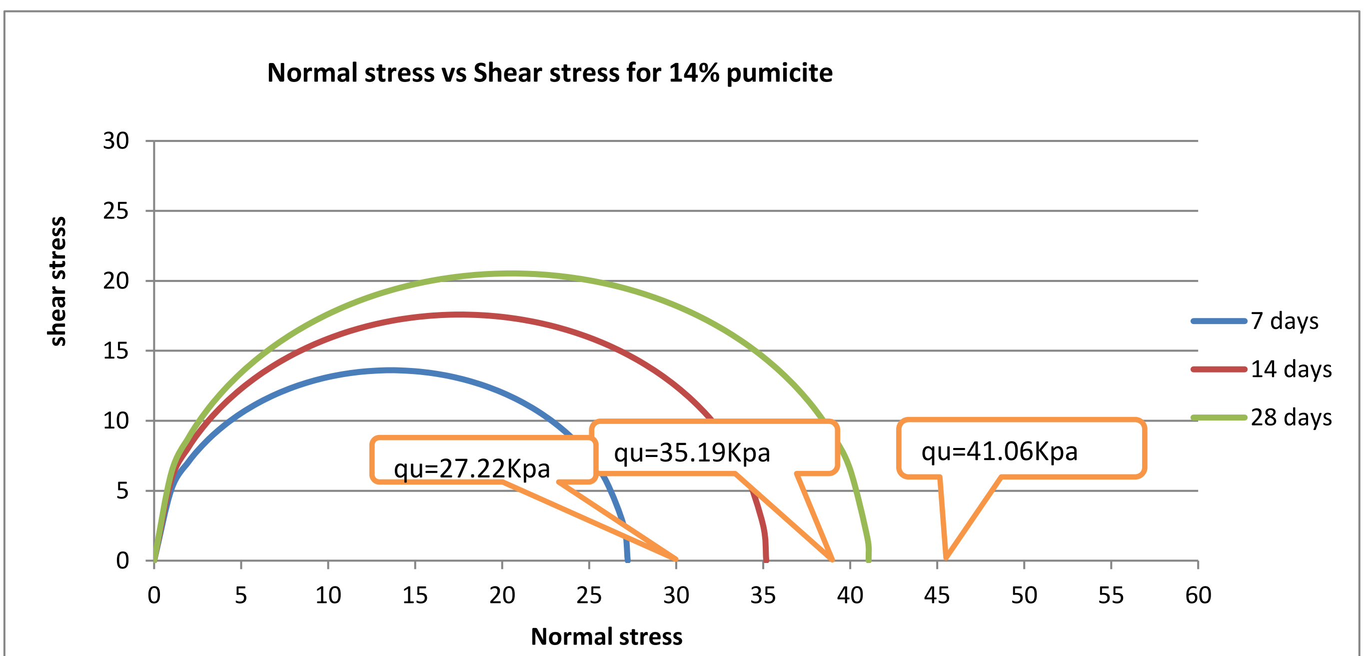
D. pumicite content 12%





E. pumicite content 14%





APPENDIX D

COMPRESSIVE STRENGTH TEST RESULTS

Table D-1 Blocks Compressive Strength Tests Result of soil only (E)

Curing Time (days)	Sample	Dimension (LxWxH)	Area(cm2)	Maximum force(KN)	Compressive strength(Mpa)	Average compressive strength(Mpa)
7 Days	1	20.5x13.5x8.6	276.8	19.37	0.7	0.75
	2	20.6x13.5x8.6	278.1	22.25	0.8	
14 Days	1	20.6x13.5x8.6	278.1	29.48	1.06	0.96
	2	20.4x13.5x8.6	275.4	23.68	0.86	
28 Days	1	20.5x13.5x8.6	276.8	31.00	1.12	1.19
	2	20.6x13.5x8.6	278.1	34.76	1.25	

Table D-2 Blocks Compressive Strength Tests Result using 8% pumicite (8P)

Curing Time (days)	Sample	Dimension (LxWxH)	Area(cm2)	Maximum force(KN)	Compressive strength(Mpa)	Average compressive strength(Mpa)
7 Days	1	20.6x13.5x8.6	278.1	33.93	1.22	1.15
	2	20.4x13.5x8.6	275.4	29.74	1.08	
14 Days	1	20.6x13.5x8.6	278.1	35.87	1.29	1.25
	2	20.5x13.5x8.6	276.75	33.21	1.2	
28 Days	1	20.5x13.5x8.6	276.8	37.36	1.35	1.38
	2	20.6x13.5x8.6	278.1	38.93	1.4	

Table D-3 Blocks Compressive Strength Tests Result using 10% pumicite (10P)

Curing Time (days)	Sample	Dimension (LxWxH)	Area(cm2)	Maximum force(KN)	Compressive strength(Mpa)	Average compressive strength(Mpa)
7 Days	1	20.5x13.5x8.6	276.8	44.28	1.6	1.58
	2	20.4x13.5x8.6	275.4	42.69	1.55	
14 Days	1	20.4x13.5x8.6	275.4	45.44	1.65	1.67
	2	20.5x13.5x8.6	276.75	46.77	1.69	
28 Days	1	20.6x13.5x8.6	278.1	50.06	1.8	1.75
	2	20.5x13.5x8.6	276.75	47.05	1.7	

Table D-4 Blocks Compressive Strength Tests Result using 12% pumicite (12P)

Curing Time (days)	Sample	Dimension (LxWxH)	Area(cm2)	Maximum force(KN)	Compressive strength(Mpa)	Average compressive strength(Mpa)
7 Days	1	20.5x13.5x8.6	276.8	39.58	1.43	1.46
	2	20.6x13.5x8.6	278.1	41.16	1.48	
14 Days	1	20.6x13.5x8.6	278.1	43.11	1.55	1.57

	2	20.4x13.5x8.6	275.4	43.79	1.59	
28 Days	1	20.5x13.5x8.6	276.8	46.22	1.67	1.68
	2	20.6x13.5x8.6	278.1	47.00	1.69	

Table D-5 Blocks Compressive Strength Tests Result using 10% pumicite and 3% straw fiber (10P3S)

Curing Time (days)	Sample	Dimension (LxWxH)	Area(cm2)	Maximum force(KN)	Compressive strength(Mpa)	Average compressive strength(Mpa)
7 Days	1	20.4x13.5x8.6	275.4	43.51	1.58	1.6
	2	20.5x13.5x8.6	276.75	44.83	1.62	
14 Days	1	20.5x13.5x8.6	276.75	47.05	1.7	1.74
	2	20.6x13.5x8.6	278.1	49.22	1.77	
28 Days	1	20.5x13.5x8.6	276.8	49.26	1.78	1.79
	2	20.6x13.5x8.6	278.1	50.06	1.8	

Table D-6 Blocks Compressive Strength Tests Result using 10% pumicite and 6% straw fiber (10P6S)

Curing Time (days)	Sample	Dimension (LxWxH)	Area(cm2)	Maximum force(KN)	Compressive strength(Mpa)	Average compressive strength(Mpa)
7 Days	1	20.5x13.5x8.6	276.8	44.28	1.6	1.65
	2	20.6x13.5x8.6	278.1	47.28	1.7	
14 Days	1	20.5x13.5x8.6	276.75	47.60	1.72	1.76
	2	20.4x13.5x8.6	275.4	49.57	1.8	
28 Days	1	20.6x13.5x8.6	278.1	51.17	1.84	1.82
	2	20.4x13.5x8.6	275.4	49.57	1.8	

Table D-7 Blocks Compressive Strength Tests Result using 10% pumicite and 9% straw fiber (10P9S)

Curing Time (days)	Sample	Dimension (LxWxH)	Area(cm2)	Maximum force(KN)	Compressive strength(Mpa)	Average compressive strength(Mpa)
7 Days	1	20.5x13.5x8.6	276.8	47.05	1.7	1.72
	2	20.6x13.5x8.6	278.1	48.11	1.73	
14 Days	1	20.6x13.5x8.6	278.1	48.67	1.75	1.79
	2	20.4x13.5x8.6	275.4	50.12	1.82	
28 Days	1	20.5x13.5x8.6	276.8	52.03	1.88	1.90
	2	20.6x13.5x8.6	278.1	53.40	1.92	

Table D-8 Blocks Compressive Strength Tests Results on soil with 3% straw fiber (E3S)

Curing Time (days)	Sample	Dimension (LxWxH)	Area(cm2)	Maximum force(KN)	Compressive strength(Mpa)	Average compressive strength(Mpa)
7 Days	1	20.5x13.5x8.6	276.8	33.21	1.2	1.22
	2	20.6x13.5x8.6	278.1	34.48	1.24	
14 Days	1	20.5x13.5x8.6	278.1	38.10	1.37	1.36
	2	20.4x13.5x8.6	275.4	37.18	1.35	
28 Days	1	20.6x13.5x8.6	276.8	40.68	1.47	1.46
	2	20.4x13.5x8.6	278.1	40.32	1.45	

Table D-9 Blocks Compressive Strength Tests Results on soil with 6% straw fiber (E6S)

Curing Time (days)	Sample	Dimension (LxWxH)	Area(cm2)	Maximum force(KN)	Compressive strength(Mpa)	Average compressive strength(Mpa)
7 Days	1	20.4x13.5x8.6	276.8	35.98	1.3	1.32
	2	20.5x13.5x8.6	278.1	36.99	1.33	
14 Days	1	20.5x13.5x8.6	278.1	40.05	1.44	1.42
	2	20.6x13.5x8.6	275.4	38.56	1.4	
28 Days	1	20.5x13.5x8.6	276.8	41.51	1.5	1.48
	2	20.6x13.5x8.6	278.1	40.32	1.45	

Table D-10 Blocks Compressive Strength Tests Results on soil with 9% straw fiber (E9S)

Curing Time (days)	Sample	Dimension (LxWxH)	Area(cm2)	Maximum force(KN)	Compressive strength(Mpa)	Average compressive strength(Mpa)
7 Days	1	20.5x13.5x8.6	276.8	36.53	1.32	1.35
	2	20.4x13.5x8.6	278.1	38.38	1.38	
14 Days	1	20.4x13.5x8.6	278.1	42.27	1.52	1.51
	2	20.5x13.5x8.6	275.4	41.31	1.5	
28 Days	1	20.6x13.5x8.6	276.8	42.62	1.54	1.56
	2	20.5x13.5x8.6	278.1	43.66	1.57	