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ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

EXPERMENTAL CHARACTERIZATION OF SISAL FIBER REINFORCED ADOBE BRICKS

A Thesis in Structural Engineering

By: Mesay Haileyesus Workinhe

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A Thesis

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The undersigned have examined the thesis entitled '**Sisal Fiber Reinforced Adobe Bricks**' presented by **Mesay Haileyesus**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

Prof. Girma Zerayohannes	for [signature]	12/04/2023
Advisor	Signature	Date
Dr. Abraham Gebre	[signature]	April 12 2023
Internal Examiner	Signature	Date
Dr.Ing. Adil Zekaria	[signature]	12/04/2023
External Examiner	Signature	Date
Dr. Abraham Gebre	[signature]	April 12 2023
Chair person	Signature	Date

Abrham Gebre (Dr.)
Dean, School of Civil &
Environmental Engineering

Addis Ababa University
Institute of Technology
Director of Postgraduate Program

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Signature of Student

Mesay Haileyesus

ABSTRACT

The paper presents the result of a research aimed at comprehensively characterizing the physical, chemical and mechanical performance of adobe bricks produced by blending soils from termite mound, clay obtained from brick producing companies and by reinforcing using sisal fiber. Adobe is a traditional building material made of soil mixed with or without fiber or it is a mud bricks baked using sun light. Due to it is less impact on the environment, the use of adobe bricks is getting more scientific attention.

It is the fact that provision of adequate and affordable house is one of the greatest challenges of the Ethiopian government. In terms of the quality of construction material, over 50% of the housing units are categorized as substandard and poor quality. Specific to the use of wall material in urban areas over 70.8% are made of "Chika," Wood plastered with mud mortar. It is practically possible to use traditional building material for at least domestic use so as to contribute by producing adobe bricks for the construction of affordable housing units. Unfortunately, the mechanical characteristics of the adobe bricks produced by local material and reinforced with sisal fiber as well as the use of termite mound blending with clay soil for production of adobe bricks not addressed yet. The target of this experimental investigation is to fill the gap in terms of experimental data on the material, show the possible use of termite mound for production of adobe bricks and minimize the possible formation of cracks by incorporating sisal fiber on the adobe bricks.

The outcomes of this research depicted that the use of termite mound blended with red clay for the production of adobe brick soil gives improved compressive strength and the use of sisal fiber mixed with soil matrix can enhance deformation properties and facilitate the drying process.

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LIST OF ABBREVIATIONS

ASTM	American Society of Testing Materials
AASHTO	American Association of Highway and Transportation Officials
SFRAB	Sisal Fiber Reinforced Adobe Bricks
ESA	Ethiopian Standard Authority
LL	Liquid Limit
PL	Plastic Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plasticity Index
AMU	Alternative masonry unit
CMU	Concrete masonry unit
LVDT	Linear variable differential transducers
T:R=1:3	Termite to Red at 1 to 3 ratio
T:R=3:1	Termite to Red at 3 to 1 ratio
T:R=1:1	Termite to Red at 1 to 1 ratio
R:W=1:3	Red to White at 1:3 ratio
R:W=1:1	Red to White at 1:3 ratio
R:W=3:1	Red to White at 1:3 ratio
T:W=1:3	Termite to White at 1:3 ratio
T:W=1:1	Termite to White at 1:1 ratio

T:W=3:1	Termite to White at 3:1 ratio
l	Liter
Kg	Kilogram
min	Minute
ml	Milliliter
mm	Millimeter
MPa	Mega pascal
ρ	rho

CHAPTER 1 INTRODUCTION

1.1 Introduction

The existing pressure on earth surface through human activity is clearly visible. In this era of global warming and declining biodiversity, it is clear that we must find new ways to live so that future generations will also have accessible opportunities for a healthy life. The search for alternative building materials especially, those of the low energy, low cost and minimally dependent on non-renewable natural resource types are the order of the day in the post- Koyoto climate protocol era. [1]

Now a days, in our country Ethiopia the population is increasing at alarming rate, as per the report of world population review[2] the growth rate of population is estimated to be 2.61% which is 113,023,619 and with this growth rate it is expected to double this figure by the year 2050 G.C. Therefore, it’s rational to believe that our government will not address one of the basic needs shelter, with this struggling construction industry and economy of the country.

Disregarding the modern house building, there are different types of houses in Ethiopia, based on climate conditions and altitude, House of the low lands, House of the uplands and House of the highlands, and all houses use eucalyptus tree as their primary material to build homes except for nomads. It’s worth mentioning that we can’t continue to build homes at this rate indefinitely. So, how to help our society to build homes using alternative building materials or how to let them remember the ancient way of Ethiopian construction in a scientific way? Beside the construction of modern newly building areas great attention shall be given to build up traditional easy residents as a necessary step to remove the lack of house in a shorter period. For those houses a cheap clayish building raw material is enough which can be provided with a low expenditure. This material have been used extensively in Ethiopia and applied for plastering, mixed with several dried plant material, and for stabilization of wooden, stone less walls for those easy house. Higher demands on the quality of this raw material are not required, the application is basing on sun-dried effect. Because of the above mentioned reasons, soils can be one of the potential building materials after it is pertinent properties regarding physical and mechanical studied carefully. Due to invention of new building materials like concrete, steel and others, The use of adobe or ‘mud bricks’ to construct a house becomes an expression for the backwardness of a country, which interns wrong perspective, if we give enough time to investigate thoroughly and invest on the science of adobe, it’s possible to use as a replacement for modern construction of members, at least for domestic use. Irrespective of it is backwardness Ethiopians extensively uses “chika mortar and adobe blocks for different day to day activities as well as home buildings. Thus, clear understanding of the physical and mechanical behavior of adobe bricks; enable us to enhance its strength and deformational properties.

1.2 Statement of the problem

Traditional building of homes involves different preliminary jobs; one of them is a collection of materials. Among the different materials eucalyptus is the major one, which is cut into pieces about 5-8 cm thick as per required. This trend resulted in conversion of high forest area into bare land. Thus, deforestation becomes major concern of Ethiopia, clearing of lands for agriculture and cutting and preparation of trees for fuel as well as to supply the world market for furniture, changes the forest coverage and still causing problems. One way to reduce this problem is to use environmentally friendly and alternating building material like adobe bricks and mortar after their strength and ductility is enhanced and verified as per standards. But at present there are no experience and standards at suitability of using clay soil for production of adobe blocks, due to its softness and nature, the use of adobe is ignored in the modern countries because of development of new building materials like, concrete, steel, timber and others, which all of them take their share on causing undeniable greenhouse effect. In a nut shell, the following two main points are identified as a problem that needs solutions. The first one is experimental investigation of mechanical and physical properties of adobe brick, reinforced with sisal fiber is lacking. The second one is the use of termite mound soils blended with other locally available soils not covered yet.

1.3 Objective of the research

1.3.1 General objective

The objective of this research is to investigate the physical and mechanical properties of adobe bricks produced using soil of different mineralogical content reinforced with sisal fiber. This includes, determining individual behavior of both adobe bricks made of different soil type with or without sisal fiber separately, with respect to tensile and compressive strength.

1.3.2 Specific objectives

- Optimizing the ingredients of adobe bricks that are clay, silt, and sand so as to increase the compressive strength of adobe bricks and to compare the obtained result with the existing trend.
- Investigating the physical properties of soil extracted and formed by termites, clay soil collected from Ethio bricks.
- Preparing mix design and production procedure for production of adobe bricks that can be produced from soil with different mineralogical content.
- Investigating the existing mechanism for testing adobe bricks.
- Checking the effect of addition of sisal fiber on both tensile and compressive strength of adobe bricks.

1.4 Scope of the research

- Review and research of the properties of the earth as an alternative building material
- This study is to investigate the mechanical characterization of Adobe bricks and Sisal fiber reinforced adobe bricks and also examining correlation between testing methods for Adobe bricks.
- Review and research suitability of soil results from termites' hills or "Qoisa Soil" for the production of adobe bricks for masonry construction.
- Examining the behavior of adobe bricks produced by blending soils from termite mound and Red clay and white clay.
- Review the current trades of production of earth building materials and further prepare the structure for production of Adobe bricks at the industrial level.

- Analysis the test results and recommendation for further research area.

1.5 Significance of the study

The successful investigation of adobe brick reinforced with sisal fiber will be two fold one in providing sustainable building material for more than one half of our society which is currently enforced to live below the standard and second reducing the environmental impact imparted by production of modern building materials and their ingredients. In addition to the above mentioned importance, the production of adobe bricks will open a job opportunity for majority of youth in Ethiopia and we can also be able to modernize our way of building a house without departing from our culture. Finally, this research is expected to be a stepping stone for further investigation on sisal fiber reinforced adobe bricks.

1.6 Thesis structure

The body of the thesis grouped into six chapters. Here under, the main topics which are included in each chapter are highlighted. The second chapter presents previous work conducted on earth building materials, the different tests conducted on the adobe bricks by different researchers. The third chapter briefly describe about the different materials used and their corresponding properties from existing literature as well as from different experiment conducted at A.A.i.T material laboratory. Chapter four explains the experimental methods and procedure used in this research. Chapter five discuss the result of the experiments followed by interpretations. The final part of the research is presented in chapter 6 with the conclusion about the thesis finding, and puts recommendations for future work. Some results involving reputation of charts and tables are presented in the appendix part of the research.

CHAPTER 2 LITERATURE REVIEW

2.1 An Over View of Masonry

Masonry is not a building material like that of Wood or steel; it is a combination of bricks and mortar. It is considered as a composite consisting of the units and mortar. Primary function of masonry wall is for constructing walls, as load bearing or partitioning wall and infill between columns and beams. Also occurs as a roofing material in case of vaulting [3]. One of the motives which enforce the ancient human for building house was, and is still, the desire for better living condition, fear of wild animals, the desire for protection against different weather condition, and may be to have a place where everything belongs to the family. This and other infinite needs which have gradually presented results in the use of nearby materials like Stone, sand , earth, grass , skin, etc. was originally used in their crude form to construct their space. The use of earth in their original form for construction has been known for 9000 years. Evidence of masonry, dating back as far as 8000 BC, is Adobe (mud) brick masonry can be witnessed in the present-day Israel, Jordan, Syria, Iraq, Iran, Turkey, and Egypt. Load-bearing exterior walls were constructed from hand formed earth blocks as a part of their earthen house; this can be seen in oldest house found in Turkey and town of Jericho, near Jerusalem[4]**.**

Another permanent earthen house can be found in present-day Egypt where their civilization and existence follows river Nile (Abay). The river takes fertile soil from Ethiopia, and got dried when it reaches the lands of Egypt; this dried soil when mixed with water it forms a mud, which can be shaped into different forms, including earth blocks. This is the basic root for the knowledge of production of sun dried earth block or mud bricks baked in the sun, where they used to construct their house and temples. The earth block could also be made stronger and durable by adding additives such as sand or plant fibers, to even further boost the strength firing could also be applied to the finished earth block [5]**.**

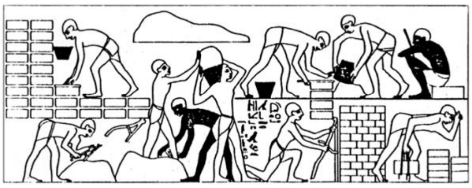


Figure 2-1: Production of earth blocks in Ancient Egypt, around 1500 BC; depiction in the tomb of Vizier Rekhmire,

2.2 Housing in Ethiopia

Disregarding the modern house building, one way of classification of house in Ethiopia is based on climate condition and altitude. These are, House of the lowlands (less than 1400m), House of the uplands (1400-2700m) and House of the highlands (2700m and above), for almost all houses the walls are constructed from either stones or trees and jointed with earth mortar (chika) and reinforced with grass except for house of the nomads, where the climatic condition and their way of life enforce them to build a house that can easily move to a new place when they change their settlement.

It is the fact that provision of adequate and affordable housing is one of the greatest challenges both in urban and ruler area of Ethiopia. In terms of the quality of construction material over 50% of the housing units are categorized as substandard and poor quality. Specific to the use of wall material in urban areas over 70.8% are made of chika wood plastered with mud. One of the pertinent factors for the current housing condition is poverty in terms of high cost of standard construction material. Above all the current building regulation discourages the use of traditional housing construction from earth material. Looking the data of Low Cost Housing construction, Since 1997 E.C. the Ethiopian government has awarded over 175,000 still more than 60% of the overall population is still living in informal settlements[6], and this number is steadily increasing due to the fact that the population is increasing at alarming rate. To satisfy this basic needs house with reduced building and material cost shall be constructed without rest and still satisfying some basic requirements such as water penetration, deflection limits and maintenance requirements. Studies for using alternative building material for at least domestic use still lacking, and the government are trying to construct accelerated building from readymade material for 10,000 citizen at a project cost of 80 billon Birr., which in turn incomparable with the actual need and the population growth.

2.2.1 Masonry unit types

Masonry usually means a construction of stone or brick wall (natural or artificial stone) joined with or without mortar. The stones or bricks may be of either regular or irregular shape. All kinds of artificial stone are regular form. Masonry, in which the stones are joined without mortar, is called dry stone wall. For ordinary building work, bricks are undoubtedly one of the easiest forms of construction known for walls on account of the size in which they are made. They always ensure easy erection. To ensure their use for wall making material, now a days they are produced in a variety of forms and the strength of the brickwork as a mass or wall depends on the individual strength of the units, the bond between the brick and its cementing material.

The clay brick is one of the ancient building materials in the history of world. In Ethiopia both clay bricks and concrete masonry units are used as walling system, the most common building walling system is concrete masonry units, the reason of using this construction material as walling system can be listed as follows

- Economical
- Socially acceptable
- Standard code for design, construction and maintenance are available
- Good Thermal and sound resistance

According to compulsory Ethiopian standard, hollow concrete blocks classified into three classes, Class A, Class B and Class C. This standard also covers inspection and methods of test as well as properties such as, shape, appearance, dimensions, water absorption, etc. The Ethiopian compulsory standard gives the minimum compressive strength requirement for each class of hollow concrete shown in the table below.

Table 2-1 Minimum Compressive Strength [7]

Class	Average of 6 units	Individual units
	N/mm^2	N/mm^2
A	4.2	3.8
B	4.0	3.2
C	2.0	1.8

2.2.2 Environmental Issue of Concrete Blocks and Fired Bricks

For the walling system, the existing trend is using concrete masonry units and fired clay bricks materials, which both have a disadvantage with respect to their negative impact on the environment. Thus, the construction industry takes it is share on growing concern over greenhouse effect. So to lower the negative impact of construction industries on environment different steps have been conducted and few papers are available on the production of eco-friendly material. The manufacture of fired clay bricks are energy intensive material with high temperature necessary for their production. Natural gas, propane, coal or firewood is generally used as the fuel source [8] **.**

The discovery of cement also facilitated the use of concrete masonry units for the construction of buildings. While concrete masonry units are widely used in low cost housing and many other applications, fired clay bricks are still used throughout the world. However, fired clay bricks have an energy consumption that is nearly 300 % to that of Concert masonry units[9]. Using both of these materials has a negative impact on the environment. Therefore, looking for eco-friendly material is the call of nature.

2.3 Alternative Masonry Units (AMU)

In Ethiopian context the most popular masonry units that are used as an input for construction are hollow concrete blocks and fired clay bricks. They are not environmentally sustainable because one use cement extensively the other consume excessive amount of energy for production, due to this the cost to purchase single unit is expensive. Hence, it is mandatory to search and produce environmentally friendly masonry units from natural resource that can be recycled and with minimal impact on the environment so that it is possible to replace both concrete masonry and fired clay bricks with time at least for the construction of low cost house.

Johannes Fourie investigated different types of AMU [10], and give a list of research done to produce sustainable masonry units.

- Strengthening the quality of clay bricks by the introduction of recycled wastes into the mix. These wastes include sugar-cane baggase ash, clay waste, sewage sludge, waste glass from structural wall and other industry sludge.
- Producing bricks with only waste materials with no natural resource such as gravel and sand. Materials that were used to create these bricks include straw fibers, waste treatment sludge, fly ash and other wastes.

The first category of the research uses intensive amount of energy for the production of clay bricks though it is reduction of clay amount by partial replacement of waste materials. Whereas the second category focuses on masonry from waste materials here again due to the increasing number of population and there by the need of housing, it is practically unable to supply the need of construction material.

The study of Kassahu Admassu investigated alternative methods to create compressed earth block [1]. The main focus is the addition of natural minerals such as pumice, scoria and diatomite to the soil mix to produce compressed block. These additions serve as to practice the usage of naturally available resource for the production of compressed earth block. The alternative units discussed so far uses either minerals or wastes partially or fully on the soil mix. Masonry units produced from different wastages are limited, especially for large scale production. The other main types of that were studied so far are adobe blocks and compressed blocks, which are different variation of blocks, made of soils. These two types of blocks are examined in section 2.4 and 2.5 respectively.

2.4 Compressed Stabilized Earth Blocks

The compressed earth block is the modern decedent of the adobe block. With technological advancement came the mechanization of the adobe block with pressure being applied to the block, through manual or mechanical means. This was further advanced with the addition of stabilizers to the mix design, creating the compressed stabilized earth block (CSEB).

2.5 Adobe

Adobe is a strategy which comprises in making mud blocks utilizing moulds however without compaction and let them dry in the sun. Adobe blocks have been utilized for a very long time and are likely the main man caused development [11]**.**These earthen materials to have different invaluable characteristics, including minimal expense, neighborhood accessibility, recyclability, good warm and acoustic properties and diminished energy when changed into building materials[12]. The main forms earth construction categorized into four categories; wattle and daub, rammed earth, adobe and compressed earth blocks, with numerous variety in each category. Adobe and compressed earth blocks are both formed into blocks in a mould, whereas the rammed earth is compacted directly into walls. Wattle and daub involves squeezing earth into a woven lattice of wooden strips [13]. This study, since focus on masonry blocks, only adobe and compressed earth blocks are investigated.

2.5.1 Composition of Soil for Adobe brick

Soil particles are usually classified as gravel, sand, silt or clay according to size. The durability of adobe brick is affected by excessive presence of gravel and clay. Basically, the clay portion of adobe is responsible for shrinkage, expansion and absorption of moisture. The sundried adobe bricks contains mixture of clay, silt, sand, water and possibly straw. According to published works, typical range of element proportion in soil suitable for brick production is Clay 12-25% Sand 55-75% Silt 10-30%. Clay and Silt are cohesive elements in nature, from the mixture in which the sand particles enclosed. Thus, clay is supposed to provide strength to dried material. A correct balance between expandable clay minerals i.e. semctite, provide strength but responsible for undesirable cracks and nonexpendable clay minerals Kaolinite responsible for less shrinkage problem and cohesion is required[14]. For this study, sisal fiber is introduced to the adobe soil mixture at different percentage and mixed thoroughly with water, different authors set upper limit for the inclusion of fiber, and in this research also noticed that increasing the fiber content makes if difficult and requires additional amount of water.

2.5.2 Characterization of Adobe bricks

The characterization consisted of both physical and mechanical tests. The detailed explanation of the methods and reference used for this study are explained in the experimental program of this document. The existing results obtained by different researchers regarding the compressive strength of adobe specimens are in the range of 0.17MPa to 2.88MPa.

CHAPTER 3 MATERIAL AND METHODOLOGY

Introduction

The main raw materials used for brick production consists of termite mounds from Adama city, both Red and white clay collected from Ethio bricks factory, sisal fiber and water.

3.1 TERMITE MOUND SOIL

Termite mound soils were collected from Adama town, from Boku area. The soil is taken from mound built by termites.

3.2 RED AND WHITE CLAY SOIL

The term clay is applied to the fraction of grains whose equivalent diameter is less than 0.002mm. The individual grains are fragments of a single mineral i.e. a solid compound with a definite chemical composition and unique crystalline structure. The clay used for the production of bricks after blending with termite mound is obtained from Ethio-Bricks Company located 11 km north-west of piazza on the Ambo Road in Gulale District. The material bed rock is trachayt ignibrite, after weathering of the parent rock the pink-white kaolinite at the bottom and red-brown montmoriollonitic soil at the top is formed. The mixture that is used in the production of bricks is 75% of the red-brown soil and 25% of pink-white kaolinite. The geotechnical properties of the termite mound, red clay and white clay soils are shown in Table 5-1 of the result and discussion part of this thesis.

The main groups of clay crystalline materials that make up clays are the minerals kaolinite, illite and montmorillonite.

The chemical composition of the termite mound, red clay and white clay soils are shown in Table 3-1

Table 3-1 : Chemical Composition of Soil Samples

Soil Samples	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
Termite mound	61.18	8.74	5.92	5.24	2.08	2.28	2.12	0.10	0.154	0.33	5.41	7.63
Red Clay	64.90	14.78	5.92	<0.01	<0.01	1.80	2.48	<0.01	0.20	0.29	2.05	6.34
White Clay	59.84	21.63	7.08	<0.01	0.08	1.74	3.00	<0.01	<0.10	0.13	2.26	5.38

3.4 SISAL FIBER

Sisal fibers are one of leaf fibers, obtained from the sisal plant, see Figure 3-1. Sisal plant grows in tropical and sub-tropical regions of the world. Sisal plant is one of the most cultivated plants all over the world, because it is easy to cultivate and it can grow in all kinds of environment [15]. The major producer of sisal plants are: Mixico, Kenya, Madagascar, China, Perannu and India. In the case of Ethiopia production of finished sisal fiber rarely found because fiber producing companies tends to other plants. But, the climatic condition of Ethiopia and the nature of sisal fiber can easily cultivated at a company level.

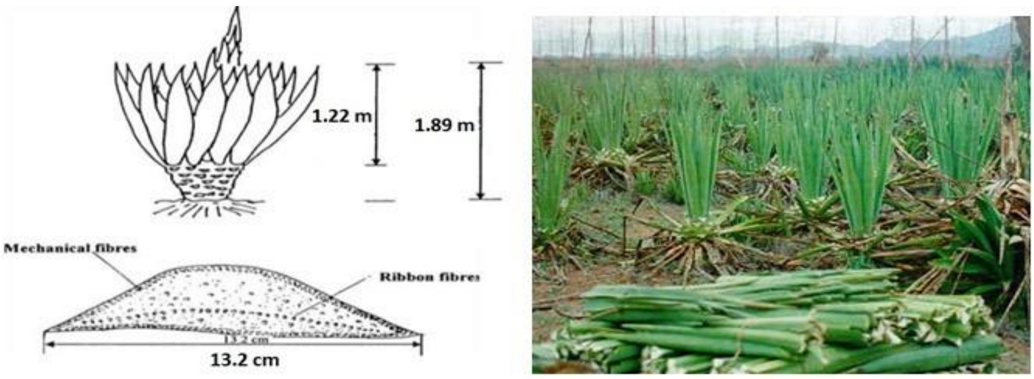


Figure 3-1 : (a) Dimensions Sisal plant and leaf (Y. R. Suryawanshi, 2013), (b) Harvested Sisal leaves, [www.arc.agric.za]

As mentioned above, the microstructure, shape and properties (physical and mechanical) of plant fibers vary within the same plant/tree. It depends from which part of the plant the fibers are obtained and the growth condition of the fibers. Furthermore, the extraction process affects also the microstructure, shape and properties of plant fibers[16].

Figure 3-2 : Extraction and production of Sisal Fiber

3.5 WATER

The water used for this research is underground water found in the Addis Ababa Institute of Technology. The amount of water for a unit mix is obtained by trial and error and approach, since there is no fixed amount stated for the production of adobe units. Initial water content has directly taken from the test conduct for determination of maximum dry density and optimum moisture content.

CHAPTER 4 EXPERMENTAL PROGRAM

The first goal of this research is to perform an experimental study to investigate the mechanical characterization of sisal reinforced adobe bricks prepared by blending of three different soil types and primarily focus on the material properties of the adobe brick. Secondly, to investigate experimentally the possible application of termite mound for production of Adobe bricks. Finally, to check the different testing method adopted for testing compressive strength of modern masonry material for Adobe bricks and to develop correlation among methods. All the experimental study are performed at the Construction Material and Geo technique laboratory.

Three different types of adobe bricks were prepared with three different percentage compositions of three different soil types, where the soils are obtained from termite mound, but red and white soil from brick producing company. The ratio of blending of each type of soil is performed by considering ratio of 1:1, 1: 3 and 3:1 whenever combination of each soil type is considered. Following this, the whole experiment is repeated by adding sisal fiber with 1%, 3% and 5% by weight of the adobe brick composite inclusion.

4.1 Physical Characterization of Adobe

The methodologies for this study are consisting of sample collection, preparation, characterization, mixing, brick production, testing adobe bricks. All the above listed methods are described briefly as follows:

4.1.1 Sample collection and preparation of the raw material

Termite mound for this study were collected from Adama town which is located 90km from Addis Ababa. The sample was collected from “Food security and distribution compound” by simply taking from the hill formed by termites, and it was packed in 50 kg plastic bag. Then this was brought to Addis Ababa Institute of Technology for laboratory demonstration and preparation of brick and mortar from the collected sample. The second soil specimen, which is used as a reference as well as for blending with the termite mound collected from Ethio brick manufacturing company. It is one of the oldest brick manufacturing companies located around Asko area. The last material, which is the sisal fiber was also collected from Ferensay Legasion area. All the samples were collected by the researcher.

Prior to treatment and production of bricks, all the soil samples were prepared in accordance with the method described in AASHTO T87-86, this involves air drying of the sample using oven at a temperature of 60^0C or less and breaking up the sample by rubber cover mallet.

The size reduction of the dried sample carried out using laboratory electrical mill until the size of the soil particle is passing sieve number 10 or 2 mm in diameter. This was performed for the termite mound as well as for the clay material collected from ethio bricks. Then the samples were stored in airtight polyethylene bag and kept in the storage area for further laboratory analysis.

4.2 Characterization of clay sample

The classification of soil or classification test to determine the grain size and type, the maximum dry density and corresponding optimum moisture content, the specific gravity of the sample was performed as per the ASTM standards.

4.2.1 Atterberg limit test

The aim is investigate the liquid limit and plastic limit of fine grained soil.

4.2.1.1 Liquid limit test

The liquid limit is determined from an apparatus Figure 4-1 that consists of a semispherical brass cup that is repeatedly dropped onto a hard rubber base from a height of 10 mm by a cam-operated mechanism. A dry powder of the soil is mixed with distilled water into a paste and placed in the cup to a thickness of about 13mm. The soil surface is smoothed and a groove is cut into the soil using a standard grooving tool. The crank operating the cam is turned at a rate of two revolutions per second, and the number of blows required to close the groove over a length of 13mm. is counted and recorded. A sample of soil from the closed portion is extracted for investigation of the water content. The liquid limit is defined as the water content at which the groove cut into the soil will close over a distance of 13mm. following 25 blows. This is difficult to achieve in a single test. Four or more tests at different water contents are usually required for terminal blows (number of blows to close the groove over a distance of 13mm.) usually ranging from 10 to 40. The results are presented in a plot of water content (ordinate, arithmetic scale) versus terminal blows (abscissa, logarithmic scale) as shown in Figure 4-2.

The best fit straight line to the data points, usually called the low line, is drawn. We will call this line the liquid state line to distinguish it from low lines used in describing the flow of water through soils. We read the liquid limit from the graph as the water content on the liquid state line corresponding to 25 blows.

Figure 4-1: Casagrande Liquid Limit Device

4.2.1.2 Plastic limit test

The plastic limit of a soil is the lowest water content at which the soil remains plastic; the plastic limit of a soil is determined by taking a quantity of soil weighing about 20 grams from thoroughly mixed portion of the material passing the No 40 sieve. Place the air dried soil in an evaporating dish and thoroughly mix with distilled water until the mass becomes plastic enough to be easily shaped in to ball. Take a portion of this ball weighing about 8gm for the test sample, then roll this mass between the fingers and the ground glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout it is length. When the diameter of the thread becomes 3 mm; break the thread in to eight pieces. Squeeze the pieces together between the thumbs and fingers into a uniform mass roughly ellipsoidal in shape continue this step until the soil can no longer be rolled into a thread. Then gather the portion of crumbled soil together and place in suitable tarred container. Weigh the container and the soil and record the weight. Oven dries the soil in the container to constant weight at 110°C and weigh. Record this weight. Record the loss in weight as the weight of water[17].

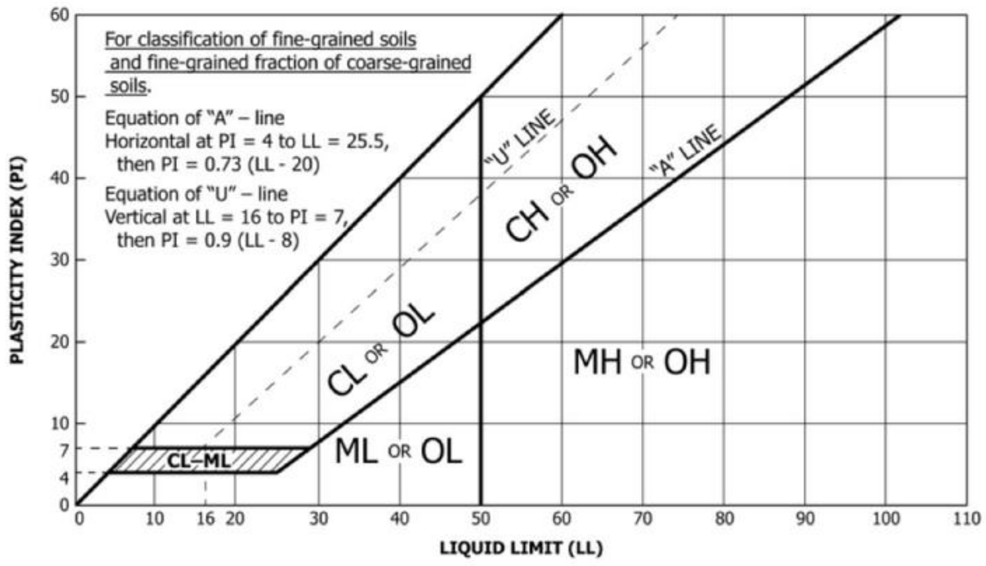


Figure 4-2 : Casagrande's Plasticity Chart

4.2.2 Particle Size Analysis

4.2.2.1 Sieve and Hydrometer Analysis

A 4kg of each soil sample is placed in a nest of sieves that are arranged in order of size of opening largest to smallest from top to bottom, and then shaken by rotary and up and down for about 10 minutes until all the grains have passed through all sieves possible according to size. Then measure the mass retained on each sieve, and determine percentage retained on each sieve accordingly.

Hydrometer Analysis

In this test a solution is added to neutralize the bonds between grains, and the sample is mixed in a 'milk shaker' apparatus to break up clumps of grains. Then the sample is placed in a jar and mixed to ensure that the grains are distributed uniformly in the jar, then the sample will be transferred a graduated cylinder and allowed to settle. Reading is taken with hydrometer to determine the density of the soil-water mixture. Using Stokes' law, it is possible to calculate the diameter D of a soil particle such that all coarser particles have already settled a distance L in time T, while all finer particles that

Originally were at the surface are still in suspension. The data from this experiment give the percent of particles finer than various particles diameter and allow the plotting of a grain – size distribution curve[18].

4.2.3 Standard compaction test

The test includes the determination of maximum dry density and optimum moisture content for the soil samples blended at different percentage.

4.2.3.1 Maximum Dry Density

For standard compaction test the diameter of the mould is 4 in and whose volume is 1/30 ft^3, and the prepared sample will be added in this mould and compaction start to be performed in three layer at a count of 25 using 5.5lb Hammer which is prepared for this purpose. Then, the soil which is above the level of the mould removed using a blade and the sample measured to obtain the weight, dividing this weight for the volume of the mould results in the Wet density of the specimen. Conversion of the wet density to dry density performed by determining the moisture content of each sample for each trial. Then using the expression it was calculated the dry density and moisture content for each test and the corresponding curve were plotted accordingly.

4.2.3.2 Optimum Moisture Content

Soil compacted without addition of water or compaction in a dry state can achieve certain dry density but when compaction of the same soil is performed by the adding water to the specimen with the same compaction effort will have higher dry density than the soil compacted in a dry state. The reason for this is the water will moisten each soil particle and facilitate cohesion between the particles beside the water also help to release the air, when the air is released form the sample more soil can take this place and can increase the dry density. But, once the air is released from the sample adding water will decrease the dry density because more water takes the space that shall be taken by the soil [19].

4.2.4 Specific gravity test

Specific gravity of a soil is the ratio of the mass of the soil to the mass of an equal volume of distilled water, involves adding 25 g of oven dried soil that pass sieve number 10 in the pycnometer and find it’s mass, add water until the pycnometer is about ¾ filled, apply the partial vacuum to the sample to remove any air, then fill with water to the calibration mark, and obtain it’s mass, finally using the expression the relative density of the soil was determined [20].

4.2.5 Organic Impurities test

The organic content is calculated as the ratio, expressed as a percentage, of the mass of organic content in a given mass of soil to the mass of the dry soil solids. The test involves taking a sample from moisture content experiment in a porcelain dish and places the porcelain dish in a muffle furnace, and always recorded the data using the procedure, and then finally using the mass of oven dried sample and the mass of the burned sample, the organic matter present in the soil can be determined [21].

4.2.6 Moisture Content

The water content is the ratio, expressed as a percentage of the mass of free water in a given mass of soil to the mass of the dry soil solids [22].

4.3 Analytical Instrument

The major instrument used to conduct the experiment described accordingly as per there specification below; casagrande Apparatus for classification of the soil, hydrometer analysis, the chemical composition of the soil was determined using X- ray fluorescence (XRF), specific gravity and maximum dry density and optimum moisture content was determined using standard proctor test, muffle furnace, grinding machine, desiccators, ASTM compression strength machine to measure compressive strength, and digital weighing balance were used.

4.4 Test types and Specimen

The ultimate purpose of this research work is investigation of physical and mechanical characterization of Adobe brick composite prepared with blending different soil whose properties are investigated experimentally and enhance the adobe brick composite with sisal fiber and determination of improved properties. The test start with granulometric classification, determination of the maximum dry density and optimum moisture content, specific gravity of the parent soil and the new soil obtained by blending the parent soils. Once the characterization of the soils completed, then uniaxial compression and three point bending tests are conducted on adobe brick composite. Additional tests that measure the performance of the Adobe bricks were also tested. All the compression tests are done on $240mm\,, 120mm\ and\ 60mm$ standard brick size in Ethiopia. For compressive strength test samples were extracted by cutting the adobe bricks into a size of $120mm$, $60mm$ and $60mm$. For three point bending test, sample with a size of $160mm$, $40mm$ and $40mm$ are produced. The adobe brick composite were labeled as Type TR, Type TW and Type RW depending on the soil used to produce each type. Type TR adobe brick is the combination of termite mound and red soil, Type TW is combination of termite mound and white soil and finally Type RW is formed by blending red soil and white soil. Each type of bricks (i.e, Type TR,Type TW and Type RW) are produced by blending red soil, white soil and termite mound, at a ratio of 1:3,1:1 and 3:1 as shown in the table below. Prior to the production of bricks from the individual soils characterization of each soil has been done with regards to physical properties as well as chemical properties, the observation and results are presented in chapter 5 of this thesis. For each soil the percentage of sand, silt and clay were derived using ASTM D422. Other governing physical properties were conducted at geotechnical laboratory. After completing characterization of individual soil samples, a total of 108 samples were produced by blending red soil and white soil, termite mound and red soil and termite mound and white soil. Each produced bricks were tested for mechanical characterization; this includes determination of uniaxial compressive strength and tensile strength. The effect of inclusion of sisal fiber on mechanical properties of adobe bricks were also examined by producing Type RWS, Type TRS and Type TWS adobe bricks using 1%,3% and 5% inclusion of sisal fiber. Type RWS is combination of red soil, white soil and sisal fiber, Type TRS adobe brick is formed by blending termite mound, red soil and sisal fiber, and finally Type TWS is a combination of termite mound, white soil and sisal fiber.

Table 4-1: Different tests conducted and reference codes

Test conducted	Number of Tests	Standard
Granulometry	3	ASTM D 422[18]
Moisture content	3	NT Build 333[23]
Density	3	NT Build 333[23]
Liquid limit, Plastic limit and Plasticity index		ASTM D 4318[17]
Compaction Characteristics of Soil		ASTM D 698 [19]

Specific Gravity		ASTM D 854-00 [20]
Organic Content		ASTM D 2974 [21]
Uniaxial compression	5air dried and 5 oven dried	BS EN 772-1 [24]
Three point bending test	4	EN 12390-5 [25]

4.5 Mix design

The volume of the adobe bricks was calculated by multiplying the length, width and height of the mold prepared for molding the Adobe bricks according to the standard size recommended by the Ethiopian Standard Authority, which is 260mmx120mmx60mm determined using Equation (4.1) and the density of the brick composite was calculated by method which allow the rule of law of mixing different components of the bricks and was obtained first by adding the volume of the red soil, white soil and water for type A brick, and similar approach is adopted for type B and type C bricks, the detailed calculation of the density of the composite is presented in the appendix B, here under sample calculation is presented for determination of density of type A brick composite. After obtaining the density of the composite using equation 2, then mass of the composite obtained by multiplying the density obtained from equation 2 with the volume of the brick obtained from equation 1. Finally, the mass fraction of each component of the Adobe brick is obtained by further multiplying the mass of the adobe brick composite with the ratio of each component of red, white and water. The density of red soil and white soil taken as 1.38 g/cm^3 and 1.31 g/cm^3 respectively obtained from laboratory experiment, whereas the density of water is 1 g/cm^3 at 4^0 C.

The mix design and method of production of adobe bricks with or without fiber is almost made to resemble that used in real life practice, so that skilled or unskilled worker able to produce as much as termite mound bricks composed with red, white and sisal fiber as needed. For this study duty the size of the unit and nature of the study some rectification of the units has been done using cut saw machine.

The mix design is based on the weight fraction of individual ingredient, and using the fact that the volume of the composite is the sum of the volume of individual items. A proper mix design and good method of production is important for improved results of compressive strength, shrinkage, and absorption and unit weight of adobe bricks. A step by step procedure for production of adobe bricks is shown below together with calculation for mix design, and the final mix proportion of each component shown in table 4.6.1 with techniques of adobe production shown in the figure 4.3.

4.5.1 Calculation to determine the density and mass of Adobe brick composite

Volume of the brick =$240mm \ x \ 120mm \ x \ 60mm$

$$= 1{,}872{,}000mm^3 = 1872 \ cm^3 \dots \dots . \dots. \qquad (4.1)$$

Density of the Red Soil and White soil in gm/cm^3

1. Dry density of Red Soil = 1.38 gm/cm^3
2. Dry density of White Soil = 1.33 gm/cm^3
3. Density of Water is 1 g/cm^3 at 4^0 C.

$$V_c = V_{red} + V_{white} + V_{water} + V_{air} \dots \dots \dots \dots. \qquad (4.2)$$

$$\frac{m_{composite}}{\rho_{composite}} = \frac{m_{red}}{\rho_{red}} + \frac{m_{white}}{\rho_{white}} + \frac{m_{water}}{\rho_{water}} \dots \dots \dots \dots. \qquad (4.3)$$

Here, the red and white soil blended at a ratio of $1:3$ or in terms of percentage 18.75 % and 56.25% of Mass of composite for red and white soil respectively. Water takes the remaining 25% by mass of the composite. Thus equation (4.3) further becomes,

$$\frac{m_c}{\rho_c} = \frac{0.1875 m_c}{\rho_{red}} + \frac{0.5625 m_c}{\rho_{white}} + \frac{0.25 m_c}{\rho_{water}}$$

$$\frac{1}{\rho_c} = \frac{0.1875}{1.38} + \frac{0.5625}{1.33} + \frac{0.25}{1} \ , \rho_c = 1.2364 \ gm/cm^3$$

Using the result of equation 4.1 and $m_c = \rho_c x v_c \dots \dots \dots \dots . (4.3)$

$$m_c = 1.2364 \ gm/cm^3 \text{ x } 1872 \ cm^3 = 2314.5408 gm = 2.314 \ kg$$

Similar calculations are adopted for the remaining eight compositions,

4.6 Experiments

4.6.1 Weight fraction of Red Soil, White Soil and Water in the brick composite.

Table 4-2 : Experiment 1 Type TR mix proportion of single adobe brick produced from termite mound soil and red clay.

Composition	Mix design 1 T:R = 1:3	Mix design 2 T:R = 1:1	Mix design 3 T:R = 3:1
	Mass (kg)	Mass(kg)	Mass(kg)
Water	0.5860	0.5822	0.5786
Termite mound	0.4395	0.8733	1.3019
Red Clay	1.3185	0.8733	0.4339
Total	2.344	2.3288	2.3144

Total number of experiment for uniaxial compressive strength of type TR specimen is 30, each mix design producing 10 adobe bricks.

Table 4-3 : Experiment 2:- Type TW mix proportion of single adobe brick produced from termite mound soil and white clay.

Composition	Mix design 1 T:W = 1:3	Mix design 2 T:W = 1:1	Mix design 3 T:W = 3:1
	Mass (kg)	Mass(kg)	Mass(kg)
Water	0.5705	0.5727	0.5734
Termite mound	0.4279	0.8591	1.2903
White Clay	1.2837	0.8591	0.4301
Total	2.2821	2.2909	2.2938

Total number of experiment for uniaxial compressive strength of type TW specimen is 30, each mix design producing 10 adobe bricks, of which 5 of the specimen are sun dried and tested after 28 days, where the remaining samples tested after dried in an oven of 105^0C until constant mass is reached between successive measurements.

Table 4-4: Experiment 3:- Type RW mix proportion of single adobe brick produced from Red and white clay.

Composition	Mix design 1 R:W = 1:3	Mix design 2 R:W = 1:1	Mix design 3 R:W = 3:1
	Mass (kg)	Mass(kg)	Mass(kg)
Water	0.5741	0.5792	0.5898
Red Clay	0.4305	0.8688	1.3272
White Clay	1.2917	0.8688	0.4424
Total	2.2965	2.3168	2.3594

4.6.2 Weight fraction of Red Soil, White Soil, Sisal and Water in the single brick composite.

The inclusion of fiber was added at 1%, 3% and 5% percentage by weight of the Adobe brick composite, prior to the addition of water in the mix, here the amount water required for the mix kept constant like that of Adobe brick without Sisal fiber.

From the calculation shown above the mass of single brick is

$m_c = 1.2364\ gm/cm^3 \text{ x } 1872\ cm^3 = 2314.5408 gm = 2.314\ kg$, where

$$m_{red} = 0.1875\ m_c = 0.1875 * 2.314\ kg = 0.4338kg$$

$$m_{white} = 0.5625\ m_c = 0.5625 * 2.314\ kg = 1.3016kg$$

$$m_{red} + m_{white} = 0.4338kg + 1.3016kg = 1.7354kg$$

To produce three brick the total mass becomes $5.2063kg$, now the inclusion of Sisal fiber is considered according to their percentage

1% $Sisal\ Fiber\ inclusion$

$$m_{sisal} = 0.01 * 5.2063kg = 0.05206kg$$

$$m_{Termite} + m_{white} = 5.2063kg - 0.05206kg = 5.1548kg$$

3% $Sisal\ Fiber\ inclusion$

$$m_{sisal} = 0.03 * 5.2063kg = 0.15619kg$$

$$m_{Termite} + m_{white} = 5.2063kg - 0.15619kg = 5.0501kg$$

5% Sisal Fiber inclusion

$$m_{sisal} = 0.05 * 5.2063kg = 0.26032kg$$

$$m_{Termite} + m_{white} = 5.2063kg - 0.26032kg = 4.9459kg$$

Table 4-5: Experiment 4:- Type RWS mix proportion of single adobe brick reinforced with sisal fiber, 1%,3% and 5% Fiber inclusion by weight.

Composition	Mix design 1 R:W = 1:3	Mix design 2 R:W = 1:3	Mix design 3 R:W = 1:3
	1% Sisal Fiber	3% Sisal Fiber	3% Sisal Fiber
	Mass (kg)	Mass(kg)	Mass(kg)
Water	0.5740	0.5740	0.5740
Sisal inclusion	0.017163	0.051489	0.08581
Red Clay	0.42478	0.416203	0.40762
White Clay	1.27435	1.248608	1.22286
Total	2.2903	2.2903	2.2903

Table 4-6 : Experiment 5:- Type TRS mix proportion of single adobe brick reinforced with sisal fiber, 1%,3% and 5% Fiber inclusion by weight.

Composition	Mix design 1 T:R = 1:3	Mix design 2 T:R = 1:3	Mix design 3 T:R = 1:3
	1% Sisal Fiber	3% Sisal Fiber	5% Sisal Fiber
	Mass (kg)	Mass(kg)	Mass(kg)
Water	0.5860	0.5860	0.5860
Sisal inclusion	0.0176	0.0703	0.0879
Termite mound	0.4351	0.4219	0.4175
Red Clay	1.3053	1.2658	1.2526
Total	2.3439	2.344	2.344

Table 4-7 : Experiment 6:- Type TWS mix proportion of single adobe brick reinforced with sisal fiber, 1 % , 3 % and 5% Fiber inclusion by weight.

Composition	Mix design 1 T:W = 1:3	Mix design 2 T:W = 1:3	Mix design 3 T:W = 1:3
	1% Sisal Fiber	3% Sisal Fiber	5% Sisal Fiber
	Mass (kg)	Mass(kg)	Mass(kg)
Water	0.570	0.570	0.570
Sisal inclusion	0.0171	0.0513	0.0856
Termite mound	0.4233	0.4148	0.4063
White Clay	1.270	1.2445	1.2188
Total	2.280	2.280	2.280

Similar calculations are adopted for the remaining eight compositions, when sisal fiber is added to the matrix sample mix design is illustrated in a similar fashion.

Thus, from the mass of the composite which is obtained using equation three possible to determine the mass of constitutes of the adobe brick composite for each mix of the brick.

4.7 Production of Adobe brick Sample

For preparation of adobe brick the following major material were used, namely Termite mound, Clay, sisal fiber and water. The physical characterization of soils from termite mound and Clay discussed in 3.2.1, here the focus is only on the production of Adobe bricks. There were different procedures involved while producing the bricks starting from Collection, drying, crushing using appropriate crushing technique, sieving, well blending of the sample according to their combination which is stated in the table from Table 4-2 to Table 4-7 for each type of Adobe bricks with their corresponding mix proportions with and without the inclusion of sisal fiber. Three different Adobe bricks were produced by blending the soil obtained from termite mound with the clay used in the production of Standard bricks.

Step 1

The density of all ingredient used in the mixture must be determined first. This was done using laboratory experiments and density of sisal fiber taken directly from literature.

Step 2

By setting the volume of the composite to be the total sum of the volume of each part, the density and mass of the composite adobe bricks can be determined. For better production of units each soil samples were grinded to the size passing sieve of less than 2mm. By reducing the size of constituent of soil sample, the void that can be formed from mixing larger soil samples were avoided and it was easy to roughly mix the dry sample before the application pre-determined amount of water.

Step 3

Determine the batch weight of each soil sample from the weight of the composite. This is done by multiplying the total design batch weight with the percentage of the different soil types in the mix. The total design batch weight is generally dictated by the required number of bricks for the test at hand, for a unit production of adobe bricks the design weight is 2.314kg for adobe bricks composed with red and white soil.

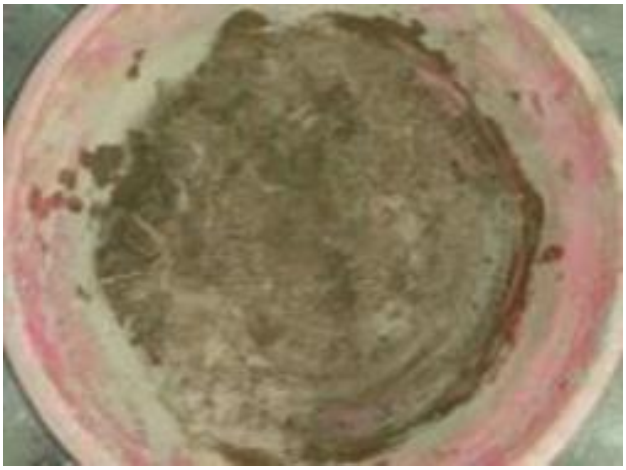
Step 4

The last step of the mix is to choose the optimum amount of water needed for the mix; this depends on the adopted method to produce the bricks, the desired final appearance of the adobe masonry units. The recommended amount of water to be used for producing single adobe units is 25% by weight of the composite and to fix the above figure rigorous trial batch was done.

Generally, as much water as possible should be added without causing the paste to be more plastic which imparts difficulties for placing the paste in the mould and the paste also unable to retain the shape when extracted from the mould or causing other production problems. Mixes that are too dry are difficult to properly take the desired shape and also produce adobe bricks of high porosity, low compressive strength. Final adjustments of the water content are therefore done by eye and trial batches. Water content for the production of adobe masonry units used for this study ranges between 25 and 30% of the mass of the green units, the starting amount of water content were decided from determination of optimum moisture content obtained from compaction test, and a trial tests were done to fix the range.

Production of Adobe brick Sample

Figure 4-3 : Step-1 Dry mixing of the soil and sisal fiber



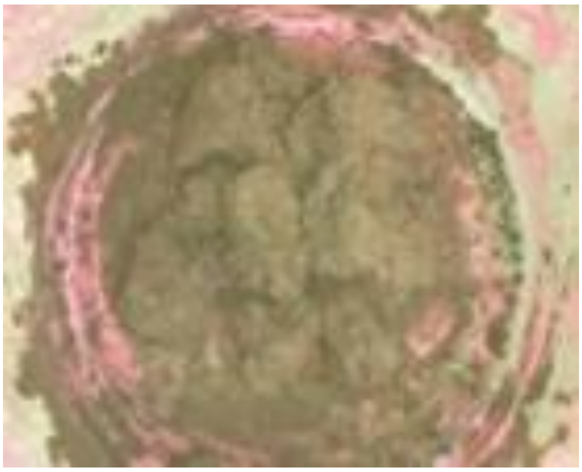


Figure 4-4 : Step-2 Wet mixing of all ingredients by adding water gradually.

Figure 4-5 : Step-3 Mix the whole ingredient until we get a plastic mix that

Figure 4-6 : Step-4 Using appropriate mould size produces a brick by applying hand compaction.


Figure 4-7 : Step-5 Smoothing bottom and top surface of the brick and gradually removing from the mould.


Figure 4-8 : Step-6 drying the bricks at room temperature to avoid early shrinkage.

4.8 Mechanical Characterization of Adobe

4.8.1 Uniaxial Compression Test

Uniaxial compression test were performed according to the British Standard BS EN 772-1[24]. In addition to this, the full Adobe brick were initially tested in the direction of loading but it was observed that testing adobe brick in this direction resulted in increased compressive strength and this is attributed to the confinement effect resulted from much lower aspect ratio. The machine compress the adobe brick without significant crack but spalling of the sides were observed. Therefore, it was decided to increase the aspect ratio or height to minimum width ratio to 2 after reviewing different tests performed on earth block. The height of the specimen was 120mm with square base having dimension of 60 mm as a side. The test sample was prepared from sawing the original adobe brick $(240mm\ x\ 120mm\ x\ 60mm)$ using a standard grinding machine, where samples having significant damage were eliminated from the test. This procedure is followed by rectification of the test sample to keep plane parallelism while testing the adobe brick in the compression machine, correlation between the testing procedures were explained in detail in the result part of this study. To further investigate the effect of drying condition on the compressive strength half of the samples were oven dried till constant mass is reached between two consecutive measurements after 24 hour intervals.

Figure 4-9 : Re sizing the original brick for test

4.8.2 Three Point Bending Test

Three point bending test were performed according to BS EN 772-1 on entire sisal fiber reinforced adobe bricks. The tests are conducted at deformation rate of 0.5mm/min to avoid dynamic effect during the test[25].

The test set up is shown on Figure 5-5, and it is conducted to determine the flexural strength of air dried sisal fiber reinforced adobe brick samples produced at different soil ratio. From the tset result it is noted that there are two region on force displacement curve, the first phase indicates elastic region until peak load and followed by the second phase of strain hardening. The existance of sisal fiber keeps the soil fiber matrix so that the adobe bricks can carry an increased strength.

CHAPTER 5 RESULT AND DISCUSSION

In this section of the study, test results of the experimental programs performed are presented and analyzed.

This chapter divides into three major topics, regarding the result obtained from different experiment conducted at AAiT Geo technical and material laboratory. The first part explain about the physical characterization of the parent material and the blended once, this categories includes granulometeric analysis tests, OMC and MDD determination, organic impurities and specific gravity tests. The second parts dedicated to the explanation of the mechanical characterizations, which includes uniaxial compressive strength, three point bending test of adobe units with and without fiber inclusion.

5.1 PHYSICAL CHARACTERIZATIONS RESULTS

5.1.1 Granulometeric Analysis

The procedure for granulometeric analysis explained in detail in Chapter 3 of this study, here only result obtained from the experiment is presented for each sample of soils extracted from different place and the classification also performed on the ingredient of the individual Adobe brick composite. The results are presented in the Table 5-1 as a range of values for each clay, silt and sand contribution each soil type. Furthermore, graphical representation and comparison of each soil type presented following the tabulated results.

Observation and Result For each soil sample, the percentage of sand, silt and clay content were determined from ASTM material classification system. The results for identification of other soil properties are presented in Table .

Table 5-1 : Geotechnical properties of the natural soil

Property	Termite Mound	Red Clay	White Clay
Percentage passing No.10 sieve. %	52.3	51.0	35.8
Percentage passing No.200 sieve. %	35.6	6.9	6.0
Plastic Limit	13	25	30
Liquid Limit %	41	36	48
Plasticity index	28	11	18
Specific gravity	2.52	2.52	2.64
MDD, g/cm^3	1.42	1.53	1.39
OMC,%	27.62	14.62	28.87
Organic Content	4.14	5.11	2.63

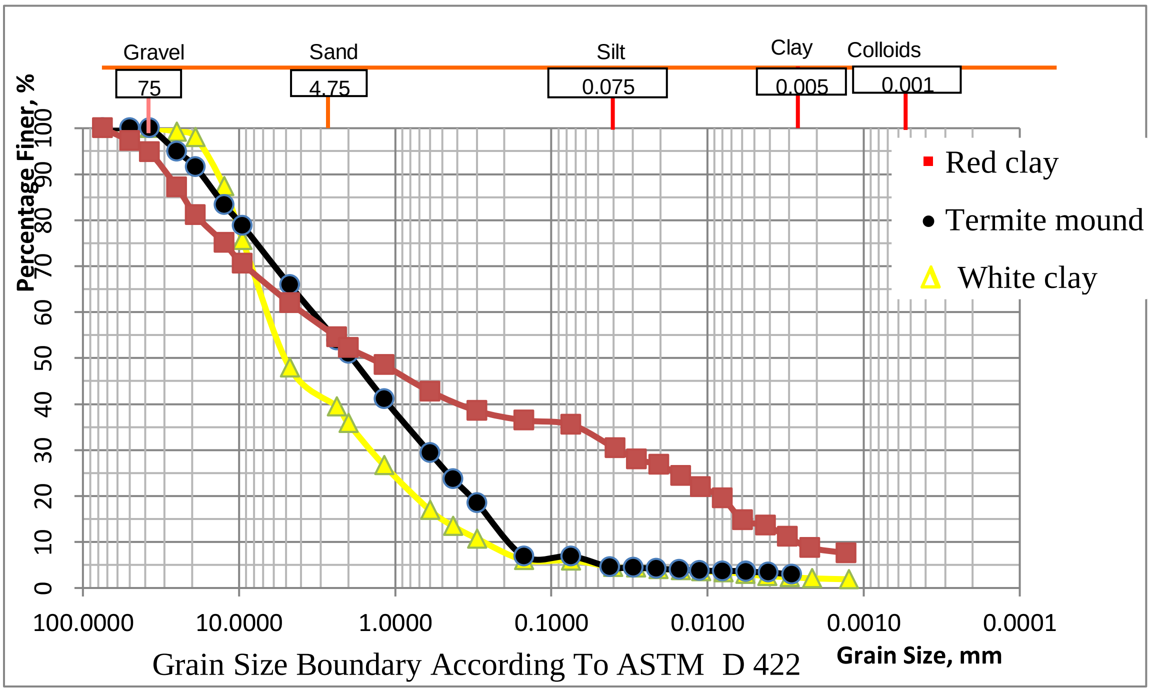


Figure 5-1: Grain Size distribution curve

For termite mound the grain size distribution is plotted by black solid line, the graph characteristics are 2.75% gravel, 42.77% sand, 24.14%silt, 30.38% clay, and for red solid line which stands for Red soil, 0% gravel, 45.43% sand, 48.01% silt and 7.01% clay, the solid line marked by yellow color represent white soil, 0% gravel, 60.55% sand,34.91% silt and 6.43% clay.

5.1.2 Maximum Dry Density and Optimum Moisture Content

The bulk density is an indicator of soil compaction. The bulk density of the individual soil samples has been determined on each sample. The bulk density varies from light to heavy which makes the average value 1.54

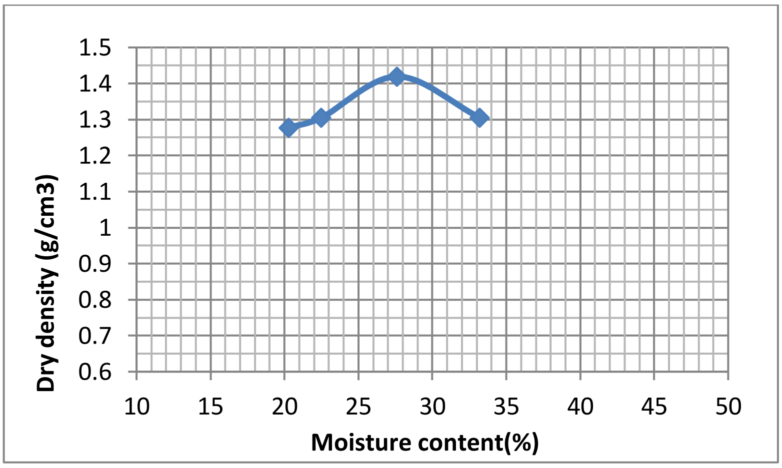


Figure 5-2 : MDD vs OMC graph of Termite mound Soil

5.1.3 Oxide Composition

Chemical analysis was carried out on the three adobe samples for SiO_2, Al_2O_3 , Fe_2O_3 , CaO , MgO , Na_2O, K_2O, MnO, P_2O_5 , TiO_2 , H_2O, LOI . The average results show that the alumina and iron contents are somewhat higher and the alkalines are low percentage which is acceptable. The result obtained from Geological Institute of Ethiopia was presented in table 3.1 of this paper.

5.2 MECHANICAL CHARACTERIZATION RESULTS

5.2.1 Uniaxial Compression Test

In this study, uniaxial compressive strength were determined using two different UTM machines. The first set of result were only able to capture the failure load and failure stress, whereas the second set of experiment capture all the properties related to mechanical parameters, such as force, displacement, stress and strain. Both of the tests were performed as per the standard of EN 772-1 which gives procedure and pre conditions for compressive strength measurement. In the first set of the experiment whose sample results are shown in the Table 5-2, by comparing the maximum failure stress. Among 45 samples on which uniaxial compressive strength are performed on sun dried adobe bricks, when termite mound mixed with red clay soil at pre-determined amount of water results in a compressive strength in the range of 2.21-3.64 MPa. Similarly, the effect drying process pertinent to mechanical response were investigated by oven dried half of the sample at 85^0 C, and the compressive strength for the above mentioned adobe brick is in the range of 2.9-5.45 MPa. It is worth mentioning that testing bricks after oven dried the sample increase the compressive strength. The remaining result from the first set of experiment can be found on the appendix part of this study.

In the second set of experiment, uniaxial compressive test were repeated by using UTM machine which is able to measure the deformational properties from the relative displacement of the steel plate, which were adjusted to descend at the rate of 0.5 mm/min, later this displacement were changed to 2mm/min for both cases the intension were to avoid impact induced by the testing machine.

For both tests conducted at different interval of time and testing equipment the observed failure pattern is started by a first crack appeared near the opposite edge of the front and lateral surface after attaining the peak load then crack spreads in at least two directions forming diagonal crack as can be seen from the following pictures.

Figure 5-3 : Result for uniaxial compressive strength test on adobe brick.

Table 5-2 : Type TR: Adobe Bricks from termite and red Soil

Type TR=1:3

	Description 1:3	Sample No	Dimensions (L,W and H)			Area mm2	Weight of Specimen(kg)	Failure Load (N)	Failure Stress (Mpa)
		Air dried sample at room temperature							
		A1	55	55	110	3025	0.6432	10200	3.37
		A2	55	55	110	3025	0.5538	10800	3.57
		A3	55	55	110	3025	0.5029	11000	3.64
		A4	55	55	110	3025	0.5909	6700	2.21
		A5	55	55	110	3025	0.5860	9900	3.27
					Average compressive strength				3.212
		Oven dried sample at 105 0c							
		A6	55	55	110	3025	0.5705	15000	5.45
		A7	55	55	110	3025	0.5080	8800	3.19
		A8	55	55	110	3025	0.5739	11700	4.25
		A9	55	55	110	3025	0.5643	8000	2.9
		A10	55	55	110	3025	0.4685	9100	3.3
					Average compressive strength				3.818

Figure 5-4 : Sample and Uniaxial testing Setup.

5.2.2 Three Point Bending Test.

Figure 5-5 : Sample and Three point bending test setup

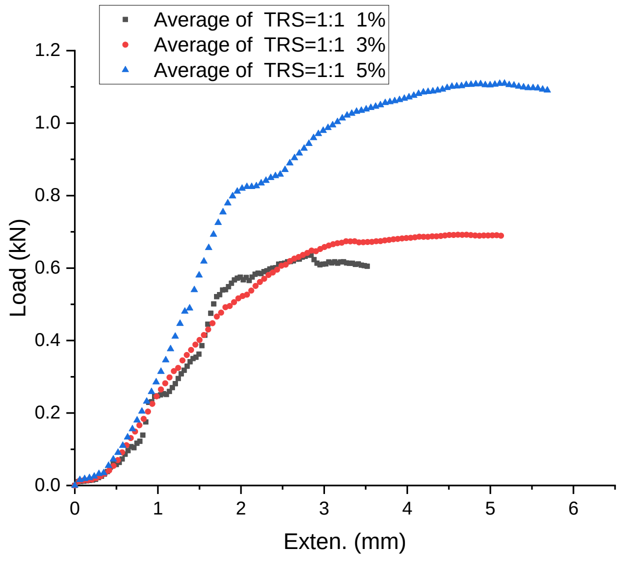


Figure 5-6 : Force – Displacement curves for air dried Termite: Red =1:1 with 1%,3% and 5% sisal fiber.

For each mix ratio and fiber inclusion a total 36 sample were tested for characterization of the material in tension, here the sample which are selected for this tests are those whose compressive strength are higher compared to the other specimen. Since testing samples whose compressive strength are lower for tension is not important with regards to the objective of the research.

For each test a failure mechanism were observed and the corresponding Force (F)-displacement(d) was plotted. They are shown in Figure 5.6, 5.7 and 5.8 for different brick types. In all test the failure pattern characterized by formation of small cracks at the bottom of the tensile region and two main cracks extending from the support to the center of the load as shown in the Figure 5-5 which is similar to failure mode of concrete materials. From the F-d diagram it is noted that increasing the fiber content doesn't significantly increase the compressive load instead increasing the fiber content can increase the deformation.

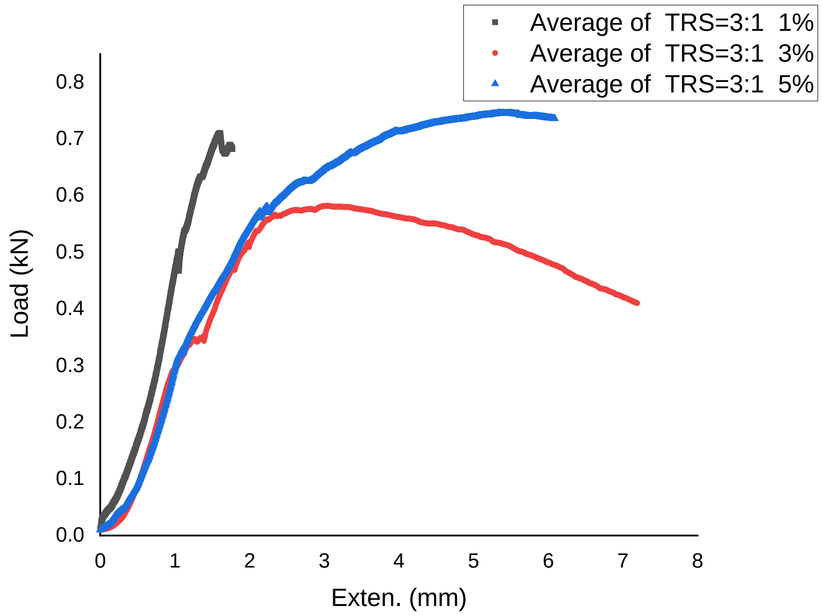


Figure 5-7 : Force – Displacement curves for air dried Termite: Red =3:1 with 1%,3% and 5% sisal fiber.

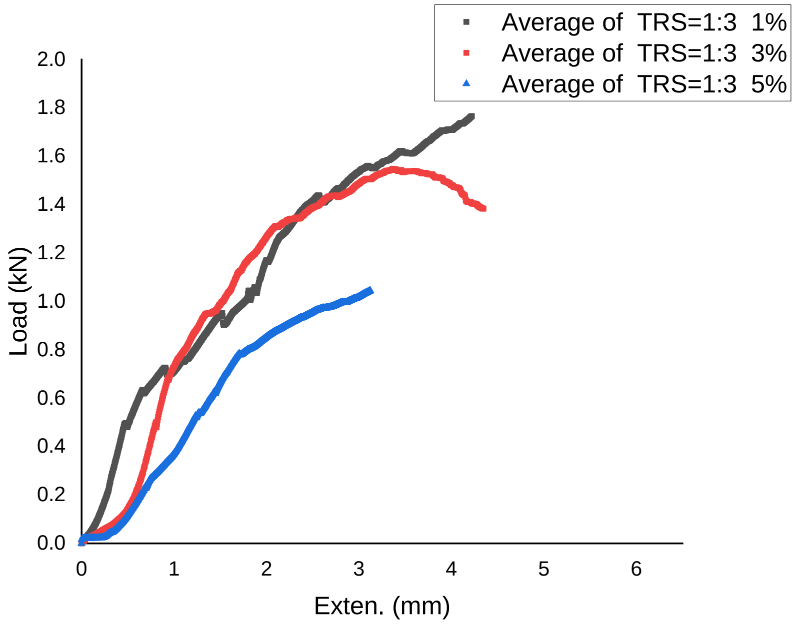


Figure 5-8 : Force – Displacement curves for air dried Termite: Red =1:3 with 1%,3% and 5% sisal fiber.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The demand to have a cheap building material for masonry wall from soil is starting point for this experimental investigation, as a result soil obtained from termite mounds were collected, mixed with clay soil and sisal fiber to enhance properties related to physical and mechanical characterization. In this study, experimental investigation performed on termite mound soils and soil with different mineralogical families. and finally sisal fiber also added to produce adobe bricks for characterization of the resulting adobe block performance under compression. As a result of the experimental investigation the following results are obtained

1. The mechanical properties of adobe highly depends on the mineralogical composition, and when termite mound mixed with red clay soil at pre-determined amount of water results in a compressive strength in the range of 2.21-3.64 MPa.
2. The upper bound of water content used to produce a single Adobe brick is a function of the percentage of clay content and sisal fiber, as the fiber content increase from 1% to 5% the water required varies from 25% to 30% by volume.
3. The inclusion of sisal fiber strongly affect both the strength and crack formation behavior of termite reinforced brick, from the tested specimen as the fiber content increases the compressive strength decreases.
4. The compressive strength of adobe bricks is also influenced by the dimension of the adopted sample size and the testing procedure used to test the sample.
5. Regardless of the composition of soil, the failure pattern for both adobe bricks with or without sisal fiber always characterized by the formation of micro cracks which are visible on the surface of adobe bricks.
6. This study is able to optimize the best mineralogical composition for better deformational property and strength of adobe bricks and shows the production mechanism of adobe bricks from pre-determined mix design.
7. The research also shows that termite mound soil can be used for the production of adobe bricks together with other locally available soils.

8. The sisal fiber affects both the deformation property and strength of adobe brick. In most cases, increasing the fiber content decrease strength and enhance deformational property.
9. The optimum amount of sisal fiber shall be in the range of 1%-5% by the mass of adobe brick.

6.2 Recommendations

Despite the results obtained on this study, many challenges are still there to fully understand the behavior of Adobe bricks with or without fiber. So, this research can be extended to include:

- Further investigation for mechanical characterization of adobe brick made of termite mound obtained different climatic and altitude conditions are required, for large scale experimental investigation.
- Earth building construction and design manual that can avoid repeated investigation on the area should be produced from large scale investigation.
- The effect of adopting different height to thickness ratio on the compressive strength of adobe bricks shall be investigated separately.
- A structural level assessment of the properties adobe masonry from individual properties of adobe bricks and mortar can be further investigated based on the result obtained from this experiment.
- The bond between adobe bricks and mortar, and the effect of using sisal fiber on the bond formation behavior between mortar and adobe bricks using masonry prism shall be investigated as the extension of this study.

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APPENDIX A

A. Mix Combination

Volume of the brick =$240mm\ x\ 120mm\ x\ 60mm$

$$= 1{,}872{,}000mm^3 = 1872\ cm^3 \ldots \ldots \ldots \quad (A.1)$$

Density of the Red Soil and White soil in gm/cm^3

Dry density of Red Soil = 1.38 gm/cm^3

Dry density of White Soil = 1.33 gm/cm^3

Density of Water is 1 g/cm^3 at 4^0 C.

(Density = Mass/Volume (or) Volume =Mass/ Density)

$$V_c = V_{red} + V_{white} + V_{water} + V_{air}$$

$$\frac{m_{composite}}{\rho_{composite}} = \frac{m_{red}}{\rho_{red}} + \frac{m_{white}}{\rho_{white}} + \frac{m_{water}}{\rho_{water}} \ldots \ldots \ldots \ldots (A.2)$$

Here, the red and white soil blended at a ratio of 1: 3 or in terms of percentage 18.75 % and 56.25% of Mass of composite for Red and White soil respectively. Water takes the remaining 25% by mass of the composite. Thus equation 2 further becomes,

$$\frac{m_c}{\rho_c} = \frac{0.1875m_c}{\rho_{red}} + \frac{0.5625m_c}{\rho_{white}} + \frac{0.25m_c}{\rho_{water}}$$

$$\frac{1}{\rho_c} = \frac{0.1875}{1.38} + \frac{0.5625}{1.33} + \frac{0.25}{1}$$

$$\rho_c = 1.2364\ gm/cm^3$$

Using the result of equation 1, and $m_c = \rho_c x v_c \ldots \ldots \ldots \ldots (A.3)$

$m_c =$ 1.2364 gm/cm^3 x 1872 cm^3 = $2314.5408gm = 2.314\ kg$

Atterberg Limit test Result and Hydrometer test Results

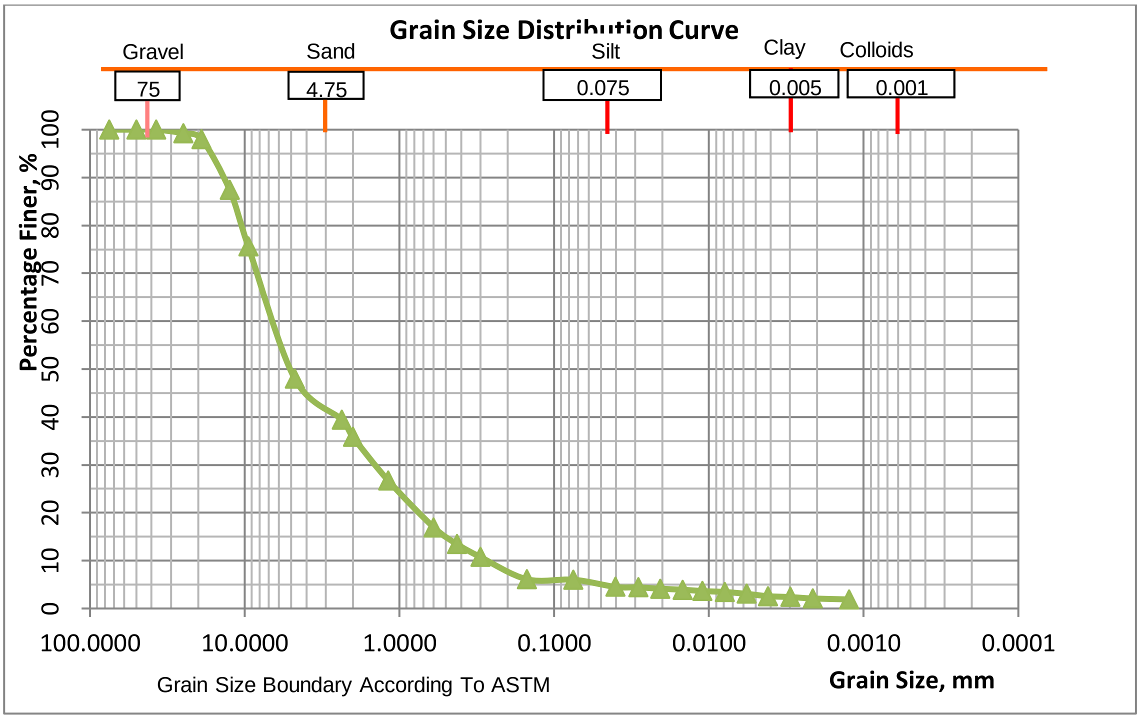

Fig A. 1 Grain size distribution for white soil

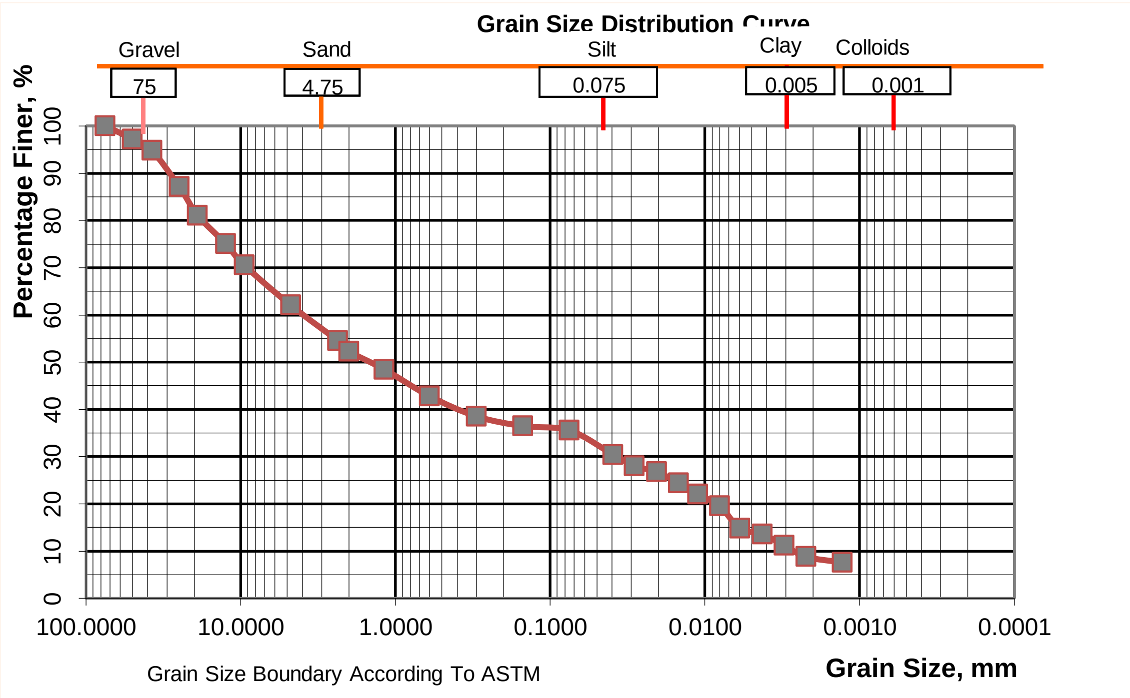

Fig A. 2 Grain size distribution for termite mound soil

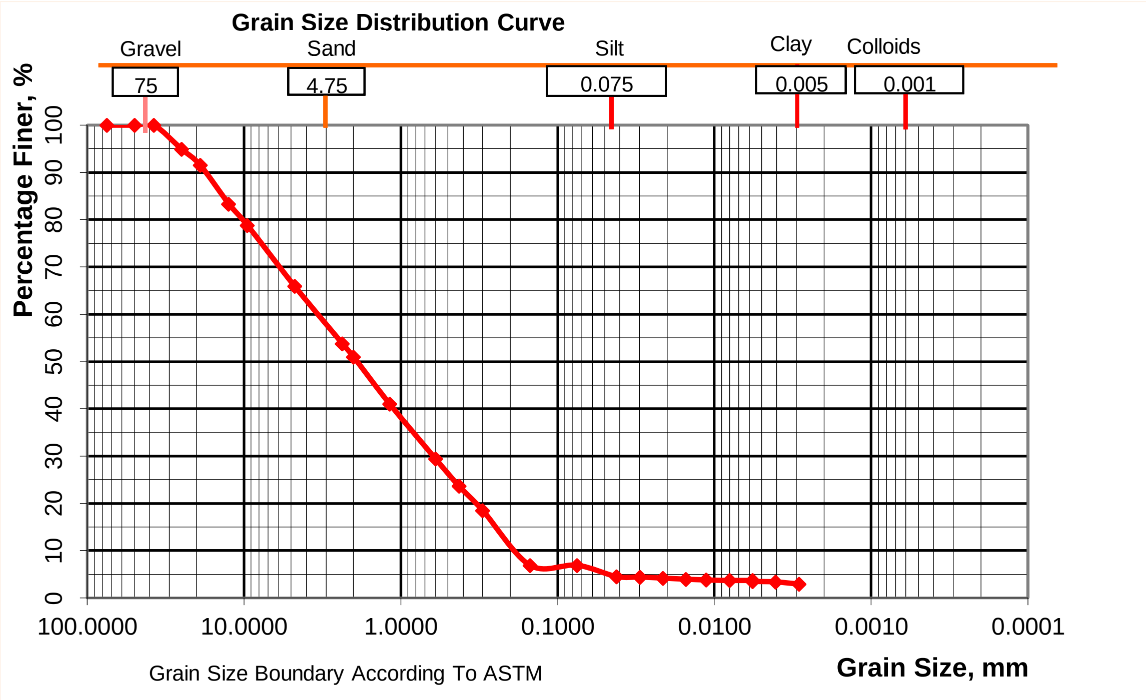

Fig A. 3 Grain size distribution for Red soil

Maximum dry density and Optimum moisture content result

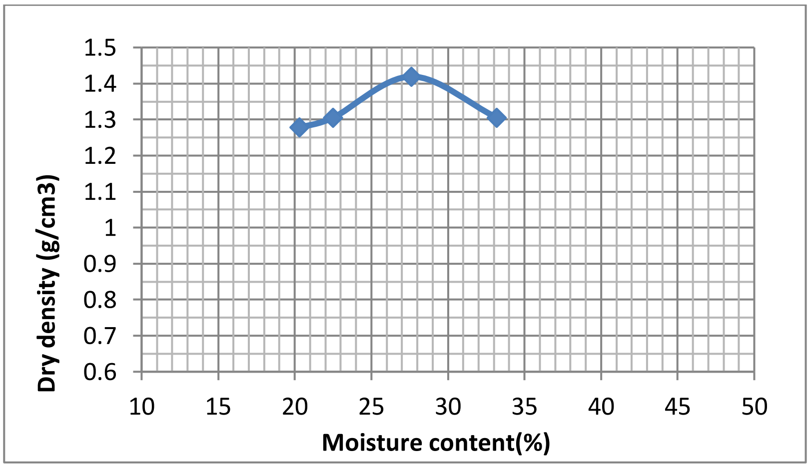

Fig A-4 MDD vs OMC graph of Termite mound Soil

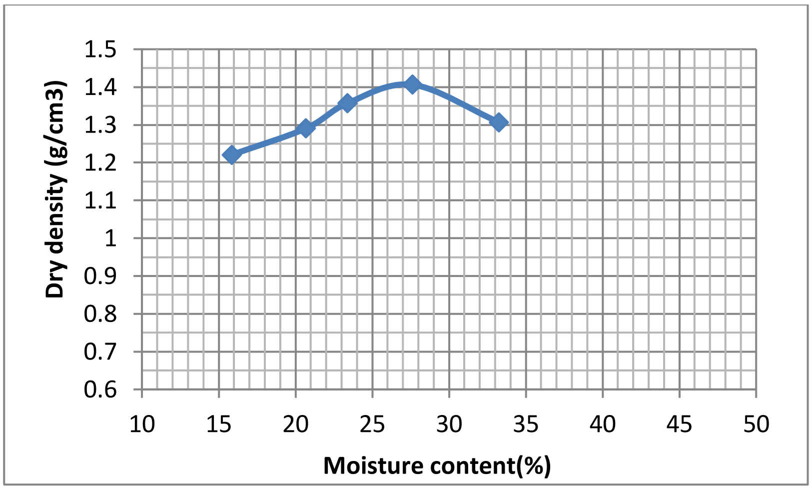

Fig A. 5 MDD vs. OMC graph of 3:1 Termite to Red soil ratio

Table A-1 MDD vs OMC table for Termite : Red = 1:3 ratio

Moisture content Vs dry density						
Determination No.		1	2	3	4	5
Mass of Mold, g		4777	4777	4777	4777	4777
Mass of mold + Compacted Soil, g		6168	6266	6420	6492	6459
Mass of Compacted soil, g		1391	1489	1643	1715	1682
Volume of Mold, cm3		944	944	944	944	944
Bulk density, g/cm3		1.47	1.58	1.74	1.82	1.78
Water Content, %		17.77	21.04	26.76	33.05	36.54
Dry density, g/cm3		1.25	1.30	1.37	1.37	1.30

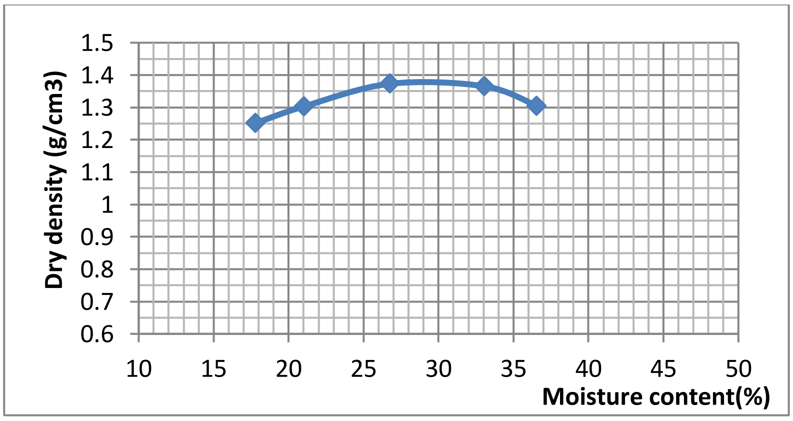

Fig A. 6 MDD vs. OMC graph of 1:3 Termite to Red soil ratio

Table A-2 Water Content table for Termite: Red = 1:3 ratio

Water Content						
Container No		157	75 l	752	J-0	59
Mass of container, g		15.6	20.3	15.6	14.4	15.2
Mass of container + wet soil, g		99.1	95.1	98.5	124.3	134.4
Mass of Container + Dry soil, g		86.5	82.1	81	97	102.5
Mass of Water, g		12.6	13	17.5	27.3	31.9
Mass of Dry soil, g		70.9	61.8	65.4	82.6	87.3
Water content, %		17.77	21.04	26.76	33.05	36.54
Dry Unit Weight, g/cm3		1.25	1.30	1.37	1.37	1.30

Table A-3 MDD vs OMC table for Termite : White = 1:3 ratio

Moisture content Vs dry density					
Determination No.		1	2	3	4
Mass of Mold, g		4777	4777	4777	4777
Mass of mold + Compacted Soil, g		6325	6460	6482	6409
Mass of Compacted soil, g		1548	1683	1705	1632
Volume of Mold, cm3		944	944	944	944
Bulk density, g/cm3		1.64	1.78	1.81	1.73
Water Content, %		22.51	27.61	30.41	35.87
Dry density, g/cm3		1.34	1.40	1.38	1.27

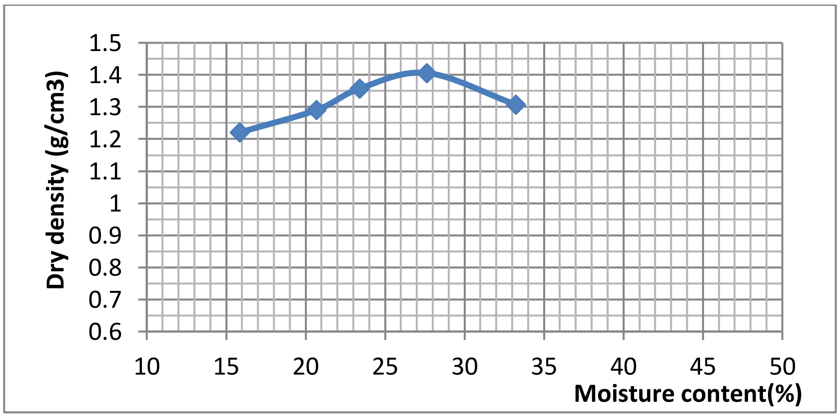

Fig A. 7 MDD vs. OMC graph of 1:3 Termite: White soil ratio

Table A-4 Water Content table for Termite: White = 1:3 ratio

Water Content					
Container No	M-2	100-5	27	R-515	5
Mass of container, g	15.2	15.8	15.5	15.7	15
Mass of container + wet soil, g	97.8	98.1	90.4	105.3	150.9
Mass of Container + Dry soil, g	86.5	84	76.2	85.9	117
Mass of Water, g	11.3	14.1	14.2	19.4	33.9
Mass of Dry soil, g	71.3	68.2	60.7	70.2	102
Water content, %	15.85	20.67	23.39	27.64	33.24
Dry Unit Weight, g/cm3	1.22	1.29	1.36	1.41	1.31

Table A-5 MDD vs OMC table for Termite : White = 3:1 ratio

Moisture content Vs dry density							
Determination No.		1	2	3	4	5	6
Mass of Mold, g		4777	4777	4777	4777	4777	4777
Mass of mold + Compacted Soil, g		5675	6275	6343	6385	6482	6466
Mass of Compacted soil, g		898	1498	1566	1608	1705	1689
Volume of Mold, cm3		944	944	944	944	944	944
Bulk density, g/cm3		0.95	1.59	1.66	1.70	1.81	1.79
Water Content, %		17.41	21.94	24.30	24.78	29.10	33.10
Dry density, g/cm3		0.81	1.30	1.33	1.37	1.40	1.34

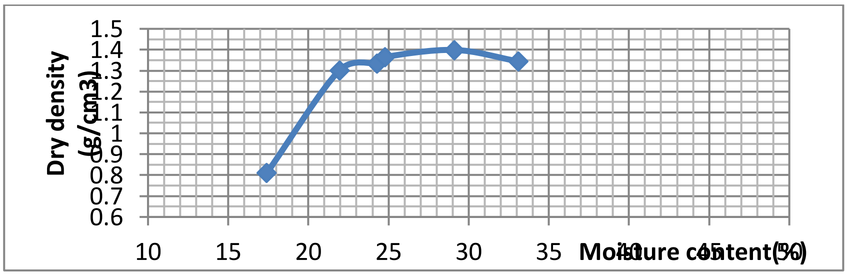

Fig A. 8 MDD vs. OMC graph of Termite: White = 3:1 soil ratio

Table A-6 Water Content table for Termite: White = 3:1 ratio

Water Content						
Container No	18	15/5	3	10	PM	753
Mass of container, g	15.9	15.5	15.6	14.3	15.5	15.9
Mass of container + wet soil, g	94.8	73.3	86.2	85.3	95.8	110
Mass of container + Dry soil, g	83.1	62.9	72.4	71.2	77.7	86.6
Mass of Water, g	11.7	10.4	13.8	14.1	18.1	23.4
Mass of Dry soil, g	67.2	47.4	56.8	56.9	62.2	70.7
Water content, %	17.41	21.94	24.30	24.78	29.10	33.10
Dry Unit Weight, g/cm3	0.81	1.30	1.33	1.37	1.40	1.34

Table A-7 MDD vs OMC table for Termite : Red= 3:1 ratio

Moisture content Vs. dry density					
Determination No.	1	2	3	4	5
Mass of Mold, g	4777	4777	4777	4777	4777
Mass of mold + Compacted Soil, g	6112	6247	6358	6471	6421
Mass of Compacted soil, g	1335	1470	1581	1694	1644
Volume of Mold, cm3	944	944	944	944	944
Bulk density, g/cm3	1.41	1.56	1.67	1.79	1.74
Water Content, %	15.85	20.67	23.39	27.64	33.24
Dry density, g/cm3	1.22	1.29	1.36	1.41	1.31

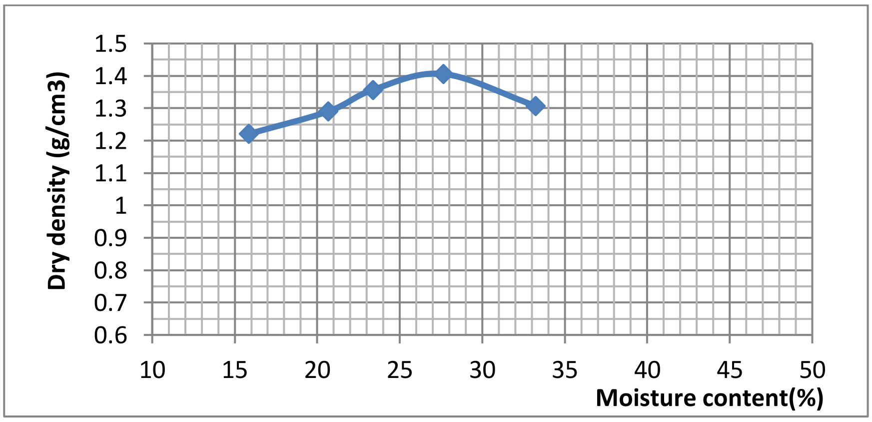

Fig A. 9 MDD vs. OMC graph of 3:1 Termite to Red soil ratio

Table A-8 Water Content table for Termite: Red = 3:1 ratio

Water Content					
Container No	M-2	100-5	27	R-515	5
Mass of container, g	15.2	15.8	15.5	15.7	15
Mass of container + wet soil, g	97.8	98.1	90.4	105.3	150.9
Mass of container + Dry soil, g	86.5	84	76.2	85.9	117
Mass of Water, g	11.3	14.1	14.2	19.4	33.9
Mass of Dry soil, g	71.3	68.2	60.7	70.2	102
Water content, %	15.85	20.67	23.39	27.64	33.24
Dry Unit Weight, g/cm3	1.22	1.29	1.36	1.41	1.31

Table A-9 MDD vs OMC table for Termite : White = 1:3 ratio

Moisture content Vs. dry density						
Determination No.		1	2	3	4	5
Mass of Mold, g		4774	4774	4774	4774	4774
Mass of mold + Compacted Soil, g		6193	6277	6408	6495	6462
Mass of Compacted soil, g		1419	1503	1634	1721	1688
Volume of Mold, cm3		944	944	944	944	944
Bulk density, g/cm3		1.50	1.59	1.73	1.82	1.79
Water Content, %		12.81	17.69	21.27	22.19	35.92
Dry density, g/cm3		1.33	1.35	1.43	1.49	1.32

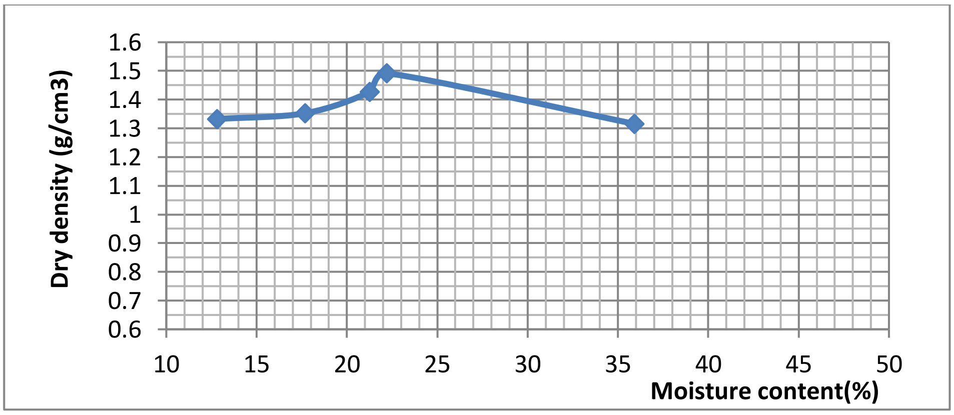

Fig A. 10 MDD vs. OMC graph of Termite to White = 1:3 soil ratio

Table A-10 Water Content table for Termite: White = 1:3 ratio

Water Content						
Container No		18	15-5	3	PM	10
Mass of container, g		16	15.6	15.7	15.5	14.4
Mass of container + wet soil, g		87.3	82.4	92.8	88.2	115.2
Mass of container + Dry soil, g		78.6	71.5	78.1	72.6	89.7
Mass of Water, g		8.7	10.9	14.7	15.6	25.5
Mass of Dry soil, g		67.9	61.6	69.1	70.3	71
Water content, %		12.81	17.69	21.27	22.19	35.92
Dry Unit Weight, g/cm3		1.33	1.35	1.43	1.49	1.32

B. Moisture content

Table B-1 Moisture content for termite mound

Moisture content for termite mound					
Can no.	R-515	59	75/L	752	
Wt. of wet soil + Can (gm)	88.70	87.70	89.40	89.90	
Wt.of dry soil + Can (gm)	74.20	72.30	75.00	74.00	
Wt. of Water (gm)	14.50	15.40	14.40	15.90	
Wt. of Can (gm)	15.60	15.00	15.70	10.50	
Wt. of dry soil (gm)	58.60	57.30	59.30	63.50	
Moisture Content(%)	24.74	26.88	24.28	25.04	
	Average (%)=				25.24

Table B-2 Moisture content for white soil

Moisture content for white soil					
Can no.	18	22	5	17	
Wt. of wet soil + Can (gm)	84.30	80.60	84.50	89.90	
Wt.of dry soil + Can (gm)	68.50	64.90	68.30	75.10	
Wt. of Water (gm)	15.80	15.70	16.20	14.80	
Wt. of Can (gm)	15.60	15.00	15.70	10.50	
Wt. of dry soil (gm)	52.90	49.90	52.60	64.60	
Moisture Content (%)	29.87	31.46	30.80	22.91	
	Average (%)=				28.76

Table B-3 Moisture content for Red soil

Moisture content for Red soil					
Can no.	R-515	59	75/L	752	
Wt. of wet soil + Can (gm)	88.70	87.70	89.40	89.90	

Wt.of dry soil + Can (gm)	74.20	72.30	75.00	74.00	
Wt. of Water (gm)	14.50	15.40	14.40	15.90	
Wt. of Can (gm)	15.60	15.00	15.70	10.50	
Wt. of dry soil (gm)	58.60	57.30	59.30	63.50	
Moisture Content (%)	24.74	26.88	24.28	25.04	
	Average (%)=				25.24

C. Soil Organic Impurities

Table C-1 Organic content for white soil

Organic content for white soil					
Can no.	1	2	3	4	
Wt. of dry soil + Can (gm)	129.2	107.20	117.3	115.10	
Wt.of burnt soil + Can (gm)	127.30	106.10	115.50	113.7	
Wt. of organic (gm)	1.90	1.10	1.80	1.4	
Wt. of Can (gm)	57.6	56.10	57.10	58.40	
Wt. of burnt soil (gm)	69.70	50.00	58.40	55.3	
Organic Content (%)	2.73	2.2	3.08	2.53	
	Average (%)=				2.63

Table C-2 Organic content for Termite soil

Organic content for Termite soil					
Can no.	5	6	7	8	
Wt. of dry soil + Can (gm)	136.10	141.40	64.00	91.90	
Wt.of burnt soil + Can (gm)	132.40	137.50	62.60	89.40	
Wt. of organic (gm)	3.7	3.90	1.40	2.50	
Wt. of Can (gm)	60.90	61.70	35.00	40.00	
Wt. of burnt soil (gm)	71.50	75.80	27.60	49.40	
Organic Content (%)	5.17	5.15	5.07	5.06	
	Average (%)=				5.11

Table C-3 Organic content for Red soil

Organic content for Red soil					
Can no.	9	10	11	12	
Wt. of dry soil + Can (gm)	104.10	105.70	95.60	97.40	
Wt.of burnt soil + Can (gm)	102.40	103.60	94.10	95.90	
Wt. of organic (gm)	1.70	2.10	1.50	1.50	
Wt. of Can (gm)	61.70	56.10	57.10	57.70	
Wt. of burnt soil (gm)	40.70	47.50	37.00	38.20	
Organic Content (%)	4.18	4.42	4.05	3.93	
	Average (%)=				4.14

D. Uniaxial Compression Test

Table D-1 Type A: Adobe Bricks Termite and Red Soil T:R=1:3

	Description 1:3	Sample No	Dimensions (L,W and H)			Area mm2	Weight of Specimen(kg)	Failure Load (N)	Failure Stress (Mpa)
Air dried sample at room temperature									
		A1	55	55	110	3025	0.6338	10200	3.37
		A2	55	55	110	3025	0.5900	10800	3.57
		A3	55	55	110	3025	0.5806	11000	3.64
		A4	55	55	110	3025	0.5748	6700	2.21
		A5	55	55	110	3025	0.6334	9900	3.27
					Average compressive strength				3.212
Oven dried sample at 105 0c									
		A6	55	55	110	3025	0.5705	15000	5.45
		A7	55	55	110	3025	0.5080	8800	3.19
		A8	55	55	110	3025	0.5739	11700	4.25
		A9	55	55	110	3025	0.5643	8000	2.9
		A10	55	55	110	3025	0.4685	9100	3.3
					Average compressive strength				3.818

Table D-2 Type A: Adobe Bricks Termite and Red Soil T:R=1:1

	Description 1:1	Sample No	Dimensions (L,W and H)			Area mm^2	Weight of Specimen(kg)	Failure Load (N)	Failure Stress (MPa)
Air dried sample at room temperature									
		A1				3025	0.5790	5300	1.76
		A2				3025	0.5853	5000	1.64
		A3				3025	0.5758	4400	1.44
		A4				3025	0.5181	4400	1.47
		A5				3025	0.5940	6300	2.07
									1.676
Oven dried sample at 105 0c									
		A6				3025	0.6035	11100	4.02
		A7				3025	0.5902	11900	4.34
		A8				3025	0.5219	11800	4.29
		A9				3025	0.5627	7900	2.89
		A10				3025	0.5616	5200	1.72
									3.452

Table D-3 Type A: Adobe Bricks Termite and Red Soil T:R= 3:1

	Description 3:1	Sample No	Dimensions (L,W and H)			Area mm^2	Weight of Specimen(kg)	Failure Load (N)	Failure Stress (MPa)
Air dried sample at room temperature									
		A1	55	55	110	3025	0.5239	3700	1.03
		A2	55	55	110	3025	0.5326	3600	0.99
		A3	55	55	110	3025	0.5894	2600	0.73
		A4	55	55	110	3025	0.5228	2900	0.81
		A5	55	55	110	3025	0.6424	5200	1.41
					Average compressive strength				0.994
Oven dried sample at 105 0c									
		A6	55	55	110	3025	0.5582	7000	2.53
		A7	55	55	110	3025	0.5353	4800	1.76
		A8	55	55	110	3025	0.5265	4000	1.46
		A9	55	55	110	3025	0.5414	5200	1.89
		A10	55	55	110	3025	0.5398	5300	1.93
					Average compressive strength				1.914

Table D-4 Type B: Adobe Bricks Termite and White Soil T:W=1:3

	Description 1:3	Sample No	Dimensions (L,W and H)			Area mm^2	Weight of Specimen(kg)	Failure Load (N)	Failure Stress (MPa)
Air dried sample at room temperature									
		A1	55	55	110	3025	0.6432	3000	0.83
		A2	55	55	110	3025	0.5538	2800	0.76
		A3	55	55	110	3025	0.5029	2000	0.55
		A4	55	55	110	3025	0.5909	3200	0.9
		A5	55	55	110	3025	0.5860	2300	0.62
					Average compressive strength				0.732
Oven dried sample at 105 0c									
		A6	55	55	110	3025	0.5705	5100	1.84
		A7	55	55	110	3025	0.5080	4400	1.61
		A8	55	55	110	3025	0.5739	3800	1.40
		A9	55	55	110	3025	0.5643	3400	1.25
		A10	55	55	110	3025	0.4685	5200	1.88
					Average compressive strength				1.596

Table D-5 Type B: Adobe Bricks Termite and White SoilT: W=1:1

	Description 1:1	Sample No	Dimensions (L,W and H)			Area mm2	Weight of Specimen(kg)	Failure Load (N)	Failure Stress (Mpa)
Air dried sample at room temperature									
		A1	55	55	110	3025	0.5664	2800	0.77
		A2	55	55	110	3025	0.5741	2800	0.78
		A3	55	55	110	3025	0.6234	4600	1.27
		A4	55	55	110	3025	0.5801	3100	0.83
		A5	55	55	110	3025	0.5315	2800	0.74
					Average compressive strength				0.878
Oven dried sample at 105 0c									
		A6	55	55	110	3025	0.5031	4300	1.56
		A7	55	55	110	3025	0.5366	5100	1.86
		A8	55	55	110	3025	0.4870	4300	1.55
		A9	55	55	110	3025	0.4601	2300	0.23
		A10	55	55	110	3025	0.4740	3700	1.21
					Average compressive strength				1.282

Table D-6 Type B: Adobe Bricks Termite and White Soil T:W=3:1

	Description 3:1	Sample No	Dimensions (L,W and H)			Area mm^2	Weight of Specimen(kg)	Failure Load (N)	Failure Stress (MPa)
Air dried sample at room temperature									
		A1	55	55	110	3025	0.6240	2000	0.55
		A2	55	55	110	3025	0.5454	2300	1.21
		A3	55	55	110	3025	0.6801	2400	0.66
		A4	55	55	110	3025	0.6220	1700	0.48
		A5	55	55	110	3025	0.6050	3300	0.92
					Average compressive strength				0.764
Oven dried sample at 105 0c									
		A6	55	55	110	3025	0.5589	2900	1.07
		A7	55	55	110	3025	0.5280	2200	0.76
		A8	55	55	110	3025	0.5624	4300	1.55
		A9	55	55	110	3025	0.5405	3500	1.24
		A10	55	55	110	3025	0.5296	3400	1.20
					Average compressive strength				1.412

Table D-7 Type C: Adobe Bricks Red and White Soil R: W=1:3

	Description 1:3	Sample No	Dimensions (L,W and H)			Area mm^2	Weight of Specimen(kg)	Failure Load (N)	Failure Stress (MPa)
Air dried sample at room temperature									
		A1	55	55	110	3025	0.6197	3800	1.25
		A2	55	55	110	3025	0.6039	3400	1.14
		A3	55	55	110	3025	0.6437	4800	1.6
		A4	55	55	110	3025	0.5557	4700	1.57
		A5	55	55	110	3025	0.6248	4200	1.39
				Average compressive strength					1.39
Oven dried sample at 105 0c									
		A6	55	55	110	3025	0.5818	12700	4.64
		A7	55	55	110	3025	0.6108	6100	2.24
		A8	55	55	110	3025	0.5062	7300	2.66
		A9	55	55	110	3025	0.5185	6000	2.19
		A10	55	55	110	3025	0.5596	12200	4.45
					Average compressive strength				3.2

Table D-8 Type C: Adobe Bricks Red and White Soil R: W=3:1

	Description 3:1	Sample No	Dimensions (L,W and H)			Area mm^2	Weight of Specimen(kg)	Failure Load (N)	Failure Stress (MPa)
Air dried sample at room temperature									
		A1	55	55	110	3025	0.6197	7600	2.51
		A2	55	55	110	3025	0.6039	5800	1.93
		A3	55	55	110	3025	0.6437	5400	1.78
		A4	55	55	110	3025	0.5557	8200	2.72
		A5	55	55	110	3025	0.6248	6800	2.24
					Average compressive strength				2.236
Oven dried sample at 105 0c									
		A6	55	55	110	3025	0.5893	7900	2.87
		A7	55	55	110	3025	0.5989	7800	2.83
		A8	55	55	110	3025	0.5777	8000	2.96
		A9	55	55	110	3025	0.5745	8100	2.92
		A10	55	55	110	3025	0.5865	10600	3.84
					Average compressive strength				3.084

E. Three point bending result

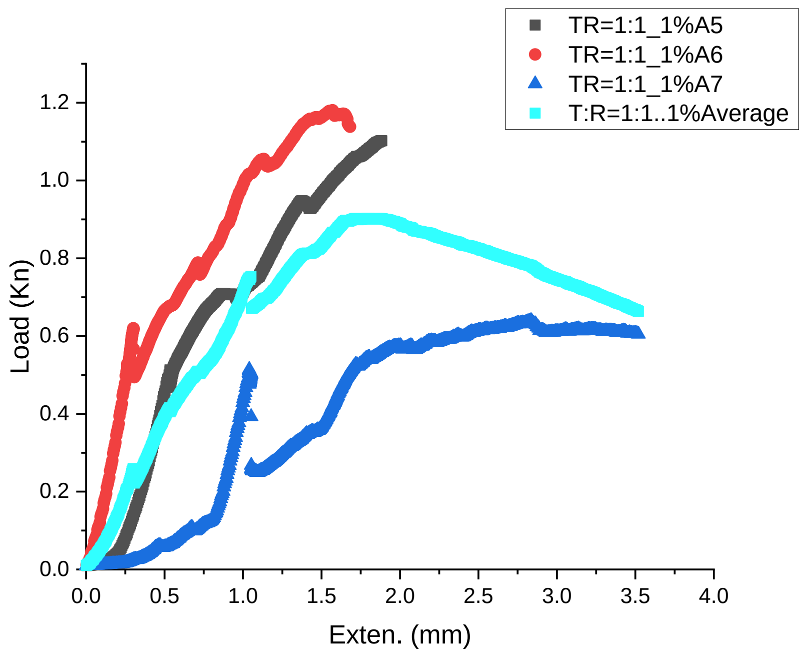

Figure E-1 T:R=1:1_1% Fiber Inclusion F_Displacement

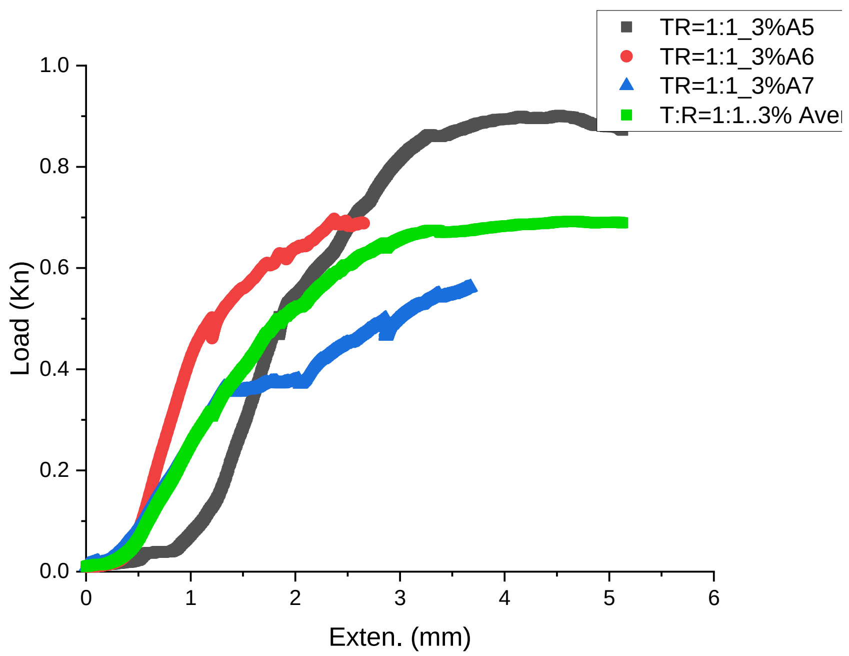

Figure E-2 T:R=1:1_3% Fiber Inclusion F_Displacement

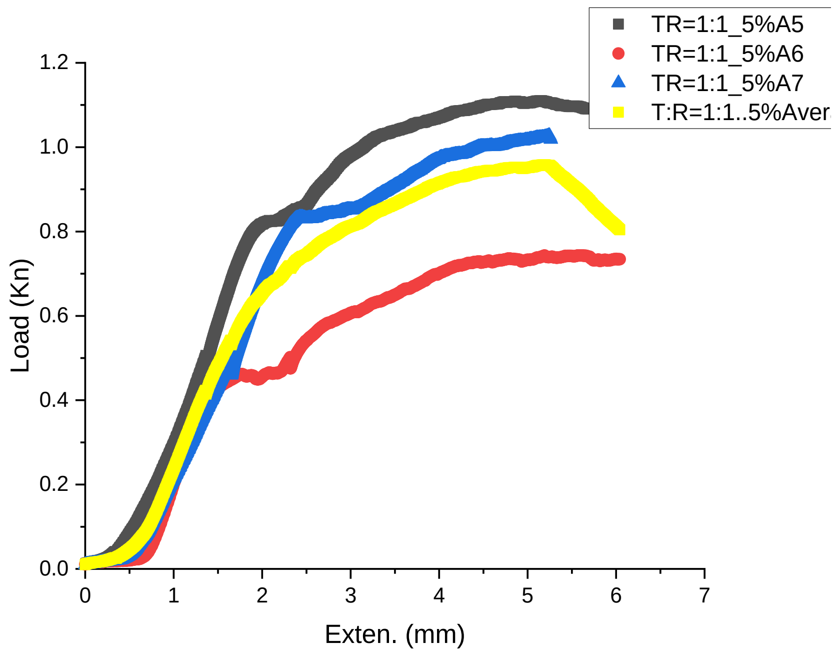

Figure E-3 T:R=1:1_5% Fiber Inclusion F_Displacement

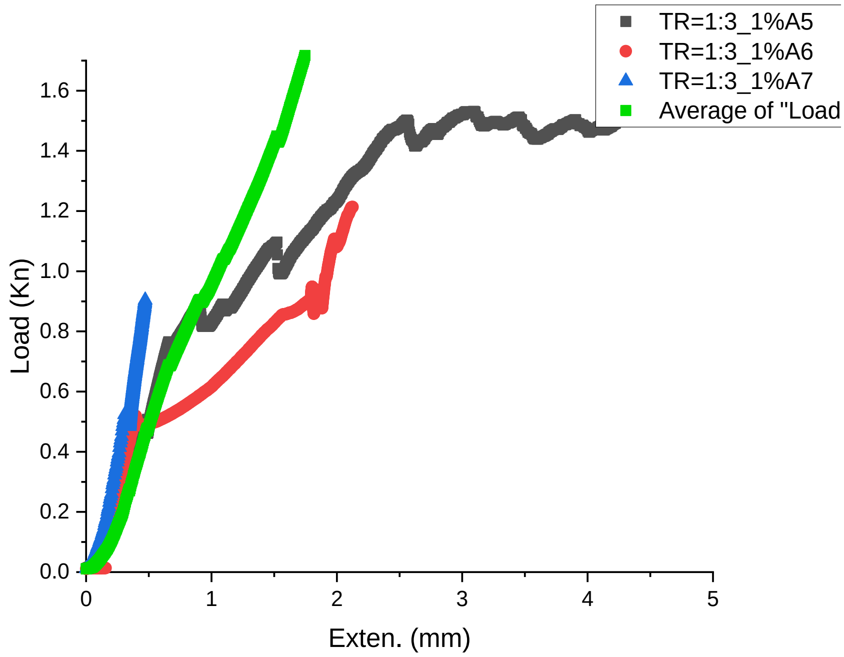

Figure E-4 T:R=1:3_1% Fiber Inclusion F_Displacement

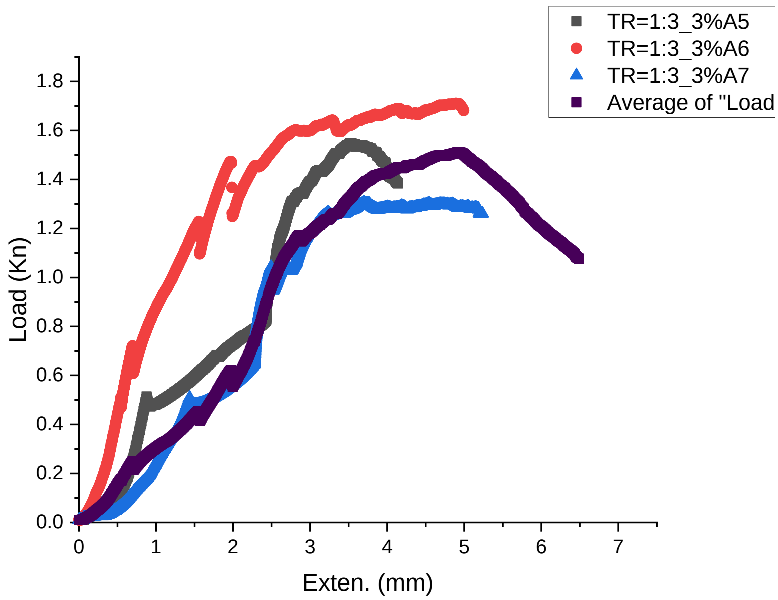

Figure E-5 TR=1:3_3% Fiber Inclusion F_Displacement

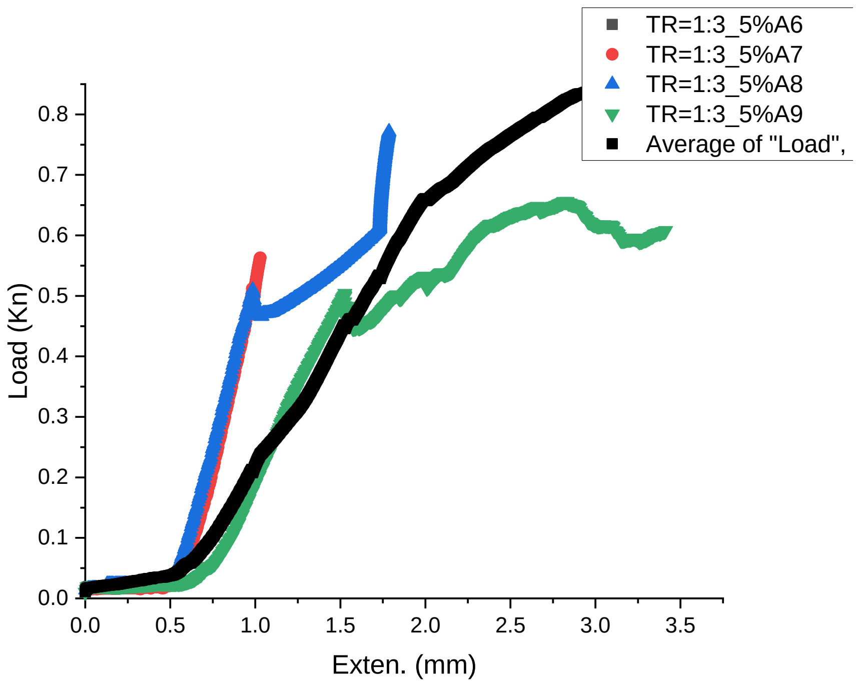

Figure E-6 T:R=1:3_5% Fiber Inclusion F_Displacement

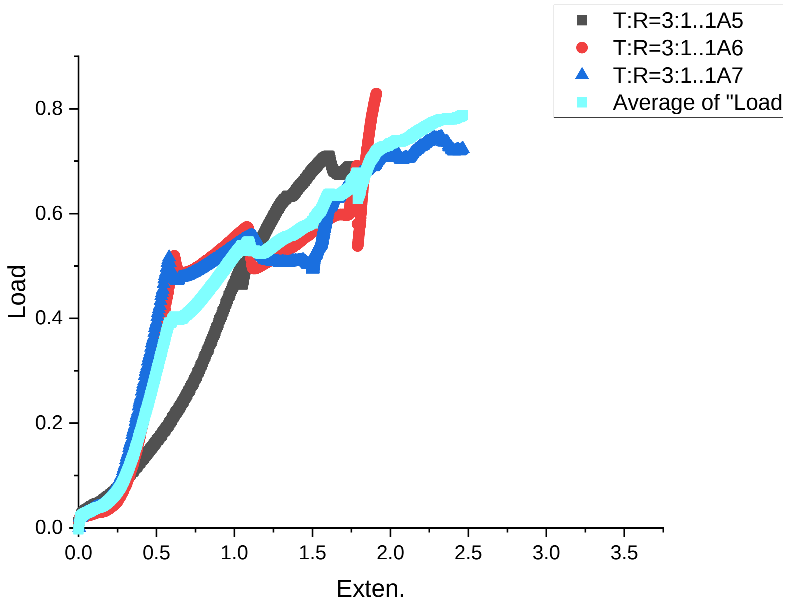

Figure E-7 TR=3:1_1% Fiber Inclusion F_Displacement

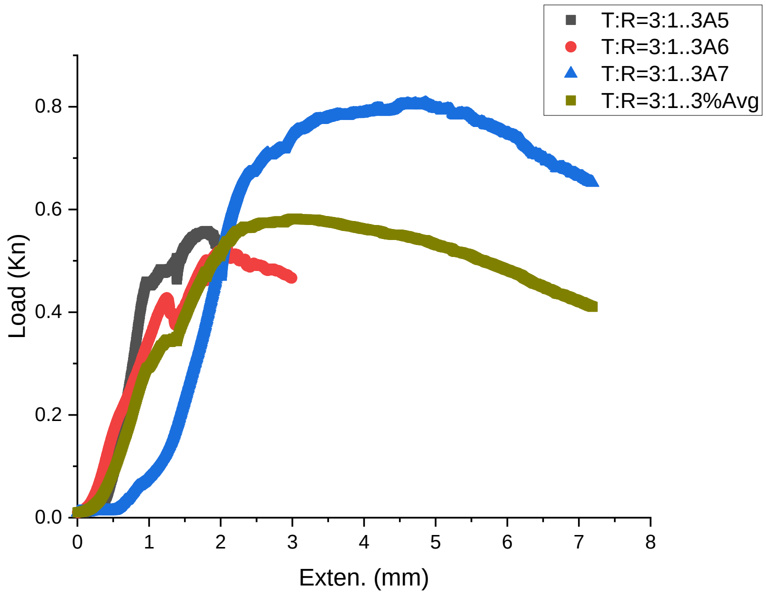

Figure E-8 TR=3:1_3% Fiber Inclusion F_Displacement

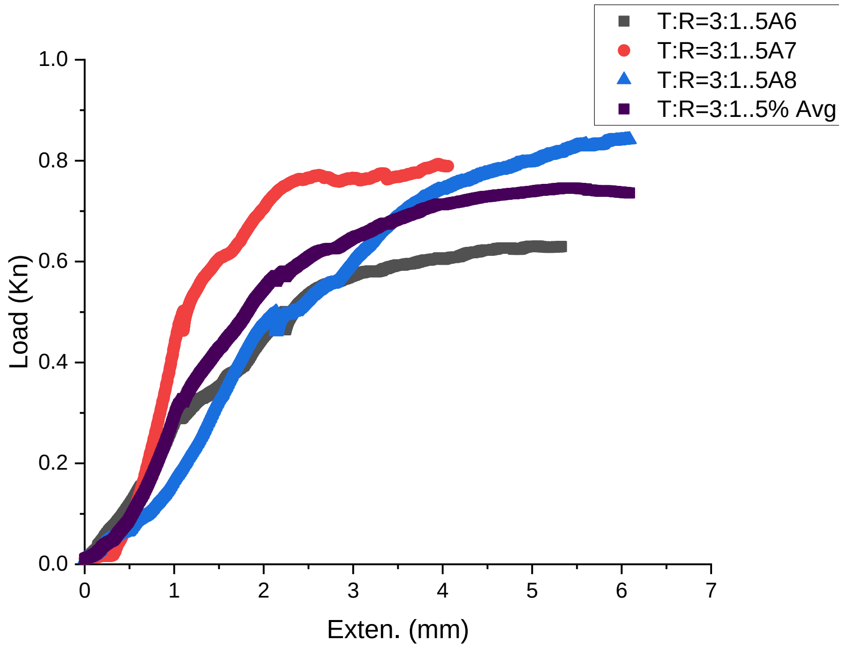

Figure E-9 TR=3:1_5% Fiber Inclusion F_Displacement