

INVESTIGATION OF NATURAL FIBER REINFORCED CEMENT STABILIZED TERMITE MOUND SOIL BLOCK



Adane Shanka Hardido

A Thesis Submitted to Department of Civil Engineering

School Of Civil Engineering and Architecture

**Presented In Partial Fulfillment of the Requirements of Masters of Science
in Civil Engineering (Specialization in Construction Engineering and
Management)**

Office of Graduate Studies

Adama Science and Technology University

June, 2023

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled **Investigation of Natural Fiber Reinforced Cement Stabilized Termite Mound Soil Block** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation. It is being submitted for the partial fulfillment for the award of the degree of Master of Science in **Construction Engineering and Management** at Adama Science and Technology University School of **Civil Engineering and Architecture**

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I/we hereby certify that I/we have read and evaluated this thesis entitled **Fiber Reinforced Cement Stabilized Termite Mound Soil Block** prepared under my guidance by **Adane Shanka Hardido** submitted in partial fulfillment of the requirements for the degree of Master's of Science in **Construction Engineering and Management**. Therefore, I/we recommend that the candidate has fulfilled the requirements and hence he/she can submit the thesis to the department.

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ABBREVIATION

AASHTO	American association of state of high way and transport office
Al ₂ O ₃	Aluminum Oxide
ASTM	American Society for Testing Materials
ASTRA	Application of Science and Technology to Rural Areas
ASTU	Adama Science and Technology University
BC	Before Christ
CO ₂	Carbon dioxide
CEB	Compressed Earth Blocks
CSB	Cement Stabilized Block
CSEB	Compressed Stabilized Earth Block
CSTMS	Cement Stabilized Termite Mound Soil
EBCS	Ethiopian Building Code of Standard
ETB	Ethiopian Birr
ESC	Ethiopian Standard Construction
FAO	Food and Agricultural Organization
FRCC	Fiber Reinforced Cement Composites
FRCSBs	Fiber Reinforced Cement Stabilized Blocks
FRCSTMSBs	Fiber Reinforced Cement Stabilized Termite Mound Soil Blocks
HCB	Hollow Concrete Block
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
OPC	Ordinary Portland cement
PPC	Portland Pozolanic Cement
SCSB	Sisal Cement Stabilized Block
Si ₂ O ₃	Silicon oxide
SO ₃	Sulfur trioxide
SMB	Stabilized Mud Block
SSB	Sisal Stabilized Block
TMSBs	Termite mound soil Blocks
TMS	Termite Mound Soil

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ABSTRACT

Conventional building materials such as sand, cement, aggregate and reinforcing bars can be expensive and harmful for the environment due to the large amounts of materials required for manufacturing as well as the energy consumption and carbon dioxide emissions from their production and transportation. The growing concern and interest in the environment and ecology have led to an increase in the use of earth as a construction material. Using soil as a construction material can be a more sustainable and affordable alternative as it is readily available and renewable. This has led to the development of stabilized soil blocks, however, using soil for building construction often leads to issues with strength and durability. To achieve the required strength, cement is often used as a stabilizing agent while fibers act as reinforcing agents, there is a need to find ways to reduce the amount of cement used in their wall construction without compromising on their dry strength and durability. To address these concerns, this thesis investigates the use of locally sourced Termite soil from Adama city area with the addition of cement and sisal fiber in order to produce cost effective load bearing wall making blocks. A total of 24 mix designs were created, with each mix containing four specimens casted into 10cm x 15cm x 25cm blocks. A range of tests including density, shrinkage, erosion, compressive strength, and water absorption capacity were conducted on the blocks, with the optimal mix design being identified was 10% cement and 1% sisal fiber. The results indicate that this mix design has a compressive strength of 10.325MPa and a water absorption capacity of 14.625%, both of which are more preferable than control and competitive with higher class Hollow Concrete Blocks used for wall load bearing purposes. Additionally, combined weight reduction is also observed for optimal mix design when compared to control and Hollow Concrete Block. Overall, this research demonstrates that termite mound soil blocks can be an economical and durable alternative to conventional wall building materials while also helping to reduce their negative impact on the environment.

Keywords: *Cement Stabilization; Termite Mound Soil; Sisal Fiber of Agave, Compressive strength, Erosion; Water Absorption; Shrinkage and Erosion.*

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

The use of soil as a building material has been observed in many regions of the world, with mud architecture first originating in Egypt and being developed alongside the Nile. Some of the earliest examples of this architecture were the adobes and sun-dried mud bricks used to construct the vault of Ramasseum in Egypt in 1300 BC. The world's largest adobe town can be found in Bam, situated in the Iranian deserts. In 1950, the Sri Lankan government used pressing machines to build a few structures; however, subsequent projects undertaken by the State Engineering Corporation utilizing compressed stabilized mud blocks proved unsuccessful. As a result, research into the parameters of soil and stabilization techniques was initiated in 1991 with regards to CSEB construction.

The demand for construction materials such as cladding and partitioning material is significantly increasing due to a rapid growth of construction activities for housing and other developmental projects. However, the manufacturing processes for these materials are heavily reliant on energy, and in turn produce carbon dioxide and other harmful pollutants, leading to environmental depletion and potential health risks. This high-energy production process also translates into higher costs for the end consumer, due to factors such as the cost of transportation and resource scarcity. As a result of these challenges, several ongoing construction projects are finding it difficult to obtain these materials at a lower cost. Consequently, there is an urgent need to search for alternative materials in order to fulfill construction demands while reducing negative environmental impacts and costs.

Throughout history, many different wall-making materials have been used to construct various types of masonry structures, including stone, mud brick, clay brick, and concrete blocks. In modern times, concrete blocks have become one of the most popular wall-making materials due to the development of hydraulic cements by English stonemason, Joseph Aspidin, in 1824, and the advancement of various concrete block making machines. Concrete blocks are widely used to construct foundations, piers, columns, and other structural members, as well as non-load-bearing walls, fire protection for steel, sidewalks, and more. (Spence & Kultermann, 2016)

The consumption of Portland cement worldwide is estimated to be around 4.37 billion tons per year, making it the most widely used construction material globally. However, the production of cement leads to harmful carbon dioxide emissions, with approximately 0.8 tons of CO₂ released into the atmosphere for every ton of cement produced. As a result, the cement industry is the second-largest producer of greenhouse gases, accounting for 5-8% of global CO₂ emissions. Manufacturing Portland cement also releases SO₃ and NO₂, which are known to cause environmental problems such as acid rain and the greenhouse effect. Therefore, reducing cement production while promoting sustainable development is a crucial problem in developing construction materials, as noted by James et al. in 2014.

Stabilization is a technique to enhance the strength of soil by improving its load-bearing capacity, permeability, and resistance, as well as resolving problems such as swelling and damping. Cement stabilization involves adding cement to soil to act as a binding agent, producing a weak form of concrete known as soil cement. The amount of cement to be added depends on the type of soil, with lime also added in small percentages. However, with very poor soils, cement stabilization may not be practical. Fiber reinforced cement-based materials have been extensively researched, with fiber reinforcement offering the advantage of additional energy absorbing capability and transforming brittle materials into pseudo ductile materials by serving as crack arrestors that create a stage of slow crack propagation and gradual failure (Otieno, 2016).

It's great to hear that researchers are exploring the use of natural fibers like sisal in cement matrices as reinforcement. Apart from being eco-friendly, these fibers require less energy for their production and can be processed with low industrialization. It is interesting to note that sisal fiber reinforcement can act as a crack arrestor and reduce crack propagation, making the construction products more structurally safe and durable. The use of natural vegetable fibers such as cellulose pulp, sisal, bamboo, fique, hemp, flax, jute, and ramie are especially important in regions where they are readily available. These composites have the potential to facilitate the construction of affordable buildings in developing regions of the world. It's excellent that this research has utilized locally available sisal fiber which is cheaper, renewable, and lacks health risks. It is crucial to continue finding alternative materials that meet our construction needs while reducing negative environmental impacts and costs.

It's fascinating to learn that the clay from termite mounds can be utilized for molding, and it even has improved plasticity due to the secretion from termites while building the mound. The fact that termite mound clay can maintain a permanent shape after molding and has low thermal conductivity is impressive. In this study, it's exciting to see that termite mound soil will be used as a pozzolanic material, a material that chemically reacts with calcium hydroxide in the presence of moisture to form compounds with cementitious properties. By reinforcing the termite mound soil with natural fibers, it's possible to create natural fiber reinforced cement stabilized termite mound soil blocks with pozzolanic properties. This research could prove to be an excellent alternative for developing eco-friendly construction materials that are both structurally sound and renewable. Soil block

1.2 Statement of problems

It's concerning to hear that the cost of construction materials is increasing in Ethiopia, especially considering the high demand and the increasing population density. This issue significantly affects the poorest sector of the community who cannot afford permanent building materials. Building materials make up a significant portion of the construction cost, and using techniques imported from the developed world is often capital and energy-intensive. It's vital to consider means of reducing the cost of constructing homes, especially for those who cannot afford it. The use of locally available traditional building materials can significantly (Zami & Lee, 2010) reduce the construction cost of housing. Efforts should be made towards developing eco-friendly alternative building materials that are cost-effective (Lal, 1996) and available locally. Using local resources could also help to reduce the overall use of cement in buildings (Van Velsen, 1981), which would be beneficial for both cost and environmental reasons. It's essential to find sustainable solutions to fulfill Ethiopia's growing demand for housing while reducing negative environmental impacts and costs.

The construction field is facing major concerns about the carbon emissions in the atmosphere. These emissions are associated with the production of cement which is typically used for construction of buildings across the world (Karim et al., 2014), constituting about 5-8% of global CO₂ emissions (Kim et al., 2016). It's clear that finding sustainable alternatives to traditional building materials will be key in reducing carbon emissions in the atmosphere. The use of natural fibers like banana, Enset vegetable, and sisal and other eco-friendly construction practices can certainly help in this regard. In

addition, exploring novel concepts like the use of termite mound soils for brick production could also have a significant impact in reducing cement consumption and decreasing gas emissions associated with cement production. It's exciting to see researchers in Ethiopia leading the way in these efforts.

Natural fiber reinforced cement stabilized soil block is being used in construction industry, but social acceptance has been a major problem due to various failure examples. Social acceptance is a key factor in the success of any new material or technique in the construction industry. It is essential to demonstrate through research and case studies that natural fiber reinforced cement stabilized soil are durable and can provide a comfortable living environment. This can help to increase the confidence of builders and clients in the material, and eventually promote its wider adoption in the construction sector. Additionally, by using local resources such as TMS, we can create technologies that are sustainable, eco-friendly and energy-saving, while also promoting local development and growth.

1.3 Objectives of the Study

1.3.1 General objective

The general objective of this research is investigating the suitability of sisal fiber reinforced cement stabilized termite mound soil block production.

1.3.2 Specific objectives

The specific objectives of this research are:

1. To characterize the local soils and fibers to determine their appropriateness for use in the production of stabilized blocks.
2. To study the physio-mechanical properties of TMS blocks with varying doses of cement and sisal fibers.
3. To conduct a Price-benefit analysis for sustainable wall construction materials, specifically natural fiber reinforced cement stabilized TMS blocks that are affordable and easy to produce.

1.4 Research Question

1. How to characterize the local soils and fibers to determine their appropriateness for use in the production of stabilized blocks?

2. To study the physio-mechanical properties of TMS blocks with varying doses of cement and sisal fibers?
3. How to conduct a Price-benefit analysis for sustainable wall construction materials, specifically natural fiber reinforced cement stabilized TMS blocks that are affordable and easy to produce?

1.5 Significance of the Study

The need for cost-effective wall construction methods for low-income housing in developing countries makes it essential to seek affordable solutions and easy maintenance techniques. This can be achieved through the use of stabilized soil block made from locally available materials. However, due to past failures associated with the use of soil blocks, it is necessary to conduct research and implement corrections to ascertain the strength, durability, and load-bearing capacity of these materials for better confidence in adopting stabilization technology. Strong and durable stabilized blocks can promote their usage and benefit low-income groups. Compared to traditional clay bricks, making stabilized blocks does not require high temperatures, reducing carbon dioxide emissions and being environmentally friendly. Research on the investigation of sisal fiber and cement on stabilized termite mound soil block is significant in terms of economy, energy efficiency, weight reduction, work opportunity, and providing affordable, eco-friendly building materials for stakeholders. The significance of this research also serves as a reminder for researchers to focus on locally available construction materials.

1.6 Scope and limitation of the Study

This research aims to conduct experiments on producing reinforced fiber cement blocks that are stabilized with termite mound soil. The scope of this study focuses on sisal fiber reinforced cement stabilized TMS blocks under static loading conditions. The study will determine how sisal fiber and cement contribute to the ultimate load carrying capacity of the blocks. Additionally, the project analyze how the amount of cement and sisal fiber impacts the compressive strength, water absorption behavior, linear shrinkage percentage, erosion prevention and block density. It will also compare the cost of using this type of block with previously used wall-making materials. However, this research is limited to only using samples of termite mound soil and sisal fiber each of them were collected from a single site due to time and budget constraint. Additionally, the study does not analyze the effect of different soil types or fibers for producing cement soil blocks. This research only

examines the effect of cement and sisal fiber on the load carrying capacity and durability characteristics of a single masonry unit. The termite mound soil used in this research was sourced from Oromia regional state, East Shoa Zone, Bolo Keble and natural fiber from SNNPR, Woleyta Zone Bilate area. While the cement used was PPC from Dangote Cement available in the local market.

1.7. Thesis Organization

There are five chapters in this thesis. A general introduction provided along with the problem statement, scope and limitation, research objective and significance in the first chapter. Previous related research is presented in Chapter 2. The methodology which contains data and sampling, the materials used, mix design and experimental program of the research is described in Chapter 3. The analysis of the experimental results for this set of tests and discussions related to the compressive strength and durability of mud block are presented in Chapter 4. Conclusions and recommendations are presented in chapter 5. The Appendixes give the results of the Individual tests, other relevant data and representative photos taken during the research work were presented.

1.8. Summary

In this chapter, the background and statement of the problem have been presented. Further, the study aims, associated objectives, scope of the study, significance of the study and the organization of the thesis to achieve these objectives have briefly been presented. In the next chapter, the literature review and the gaps in the prior research will be presented

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

Constructing a shelter is a fundamental aspect of human existence that dates back thousands of years. From ancient times, various cultures across the world have used earth and stone to build homes. Earth is abundant and readily available, which makes it a cost-effective, environmentally friendly, and recyclable building material. Because of its benefits, it has been used for construction since early civilizations, as noted by Hujbers in 1987.

Throughout history, soil has been a popular construction material because of its availability and suitability for building shelters. However, with modern concerns about environmental impact, it's important to find sustainable alternatives to conventional building materials. In Ethiopia, there is a research project underway that aims to develop low-cost construction blocks using sisal fiber reinforced cement stabilized termite mound soil by examining factors such as load capacity, durability and density. The results of this study have the potential to create affordable and eco-friendly solutions for construction in Ethiopia and beyond.

Soil is a popular construction material because of its availability, simplicity, thermal comfort, acoustic insulation, and aesthetics. However, it faced challenges such as the need for high strength for tall buildings and durability issues due to sensitivity to moisture. The rise of the concrete industry in the 20th century shifted people's focus away from soil blocks, as concrete could achieve strengths of up to 100MPa. Strength became the parameter for durability and quality, but there has been a recent trend towards the use of stabilized earth blocks due to environmental concerns.

According to EPA, the cement industry is the third largest source of environmental pollution, producing 500,000 tons of carbon monoxide per year, nitrogen oxide and sulfur dioxide, and 829 million tons of carbon dioxide (Hanle, et al.2004). And also In the last decades, the construction field is facing major concerns about the carbon emissions associated with production of cement which is typically used for construction of buildings across the world (Klopp & Petretta, 2017). Since these emissions are responsible for about 5-8% of global CO₂ emissions (Van Velsen, 1981) (Karim et al., 2014). Also Brick kilns

have been a serious treat for human health and environment, due to emission of carbon monoxide and sulfur oxides. These are the reasons why the researches are focusing on the stabilized earth blocks as it is a low cost sustainable material which requires less than 10% of the energy input for manufacturing compared to fired clay and concrete masonry units (Walker 1995).

There is a need to explore alternative building materials that will reduce the overall amount of CO₂ emissions. This has stimulated significant research efforts into alternative building materials (Karim et al., 2014) that can reduce the overall use of cement in buildings (Bediako, 2018). Within this context, earth-based materials are “green” materials that can reduce the carbon emissions (Mo et al., 2016) that are associated with the construction of buildings. Compared to conventional cement-based (Memon et al., 2018) building materials (Eires et al., 2014), earth-based materials are cheap (Mahamat et al., 2021), environmental-friendly (Soboyejo, 2003) and available (Ojo et al., 2020) globally. They can also have attractive combinations of mechanical properties (Megalingam et al., 2021) while consuming lower amounts of energy during their production [(Mustapha et al., 2016).

There is a need for affordable building materials in providing adequate housing for humankind in the world. The cost of conventional building materials has continued to increase. Therefore, as the majority of the population continues to fall below the poverty line, the cost of the conventional construction materials has become unfordable (United Nations, 2019). Thus, there is a need to search for local environmentally friendly materials as alternative and low-cost building materials, without compromising the quality in both rural and urban areas (Seghir, et al., 2019).

The construction materials account for between 40 and 60 % of the total construction cost, and this is attributed to the fact that basic conventional building materials like cement and aggregates are becoming increasingly expensive due to high cost incurred in their processes, production and transportation (Alake and Akaninyene, 2014; Omofunmi and Oladipo, 2018). This led us to the utilization of locally available materials like termite mound soil that can either reduce or replace the conventional materials. The characteristics of termite mound soil are suitable for construction material because they have binding properties as the mound is rich in silica and alumina (Omofunmi and Oladipo, 2018; Jouquet, et al., 2007; Jouquet, et al., 2020).

Housing is an asset that all family aspires to acquire and own in the world to feel secure. However, in many parts of the world, particularly in the developing countries, fulfilling housing requirement of the population remains challenging (Woetzel et al., 2014). Therefore, majority of the population of developing countries are either homeless or live-in slums or sub-standard houses.

However, according to estimates by UN Habitat, approximately 238 million people lived in slums or informal settlements in Sub-Saharan Africa (SSA) in 2018 (van Huis, 2017). These slums are generally considered to be sub-standard housing. They also contribute to low-life expectancy, poor health indices and low indices of well-being because housing is a major fundamental need for human being and constitutes the main factor for its survival and its development. Therefore, adequate housing contributes to physical development, moral health and social stabilization.

In Ethiopia, they do not encourage the conversion of indigenous resources into sustainable building materials, which leads to a heavy reliance on cement. Obtaining conventional construction materials in Ethiopia is also problematic as it depends on border movements which encounter shortages that disrupt the industry. Over the past few decades, Ethiopia has seen a massive increase in slums and a significant decrease in productivity. This has led to low-income citizens having a hard time affording adequate housing, making it almost impossible. Thus, one solution to the problem of housing in Ethiopia could be partially replacing cement with natural pozzolanas or exploring other locally available materials. This could solve the challenge of cost; however, the challenges related to the brittle failure can be addressed by addition of natural fibers as reinforcement.

In most cases, the structural applications of earth-based materials (Memon & Khan, 2018) require the use of cement as a stabilizer (Ndububa, 2018) or reinforcement with natural (Mustapha et al., 2016)/synthetic (Azeko et al., 2016) fibers. In any case, the underlying strengthening and toughening mechanisms associated with the stabilization of earth-based materials have not been studied using the mechanistic approaches that have been applied to the study of natural fiber-reinforced earth-based composites (Silva Mondragón et al., 2019).

2.2 Building Materials and Economic Development

The building materials and construction industry is one of the most important sectors of economic activity and represents an essential instrument of socio economic development.

It provides a wide range of services and capabilities for designing and constructing facilities necessary for economic development. The links between consumption, production and construction show that economic growth and social equality are dependent on construction. The activities of construction industry are not confined to the construction of dwelling houses, but extend to infrastructure, equipment and services as well as their repair and maintenance. Thus, construction is powerful stimulator of social growth and wellbeing. It is therefore not surprising that in the developed countries investment in the construction sector, including building materials is higher than in any other sector, (over half the total investment) (Documentation, 1983).

At present, the Ethiopian construction industry accounts for only 5.5% of GDP, compared to a sub-Saharan Africa average of 6%. However with sustained economic growth over the past four years, the sector has registered 8.2% growth; and public construction projects account for nearly 60% of the Government's capital budget. The building materials and the construction industry is one of the most important sectors of economic activity and represent an essential instrument of socio-economic development. It provides a wide range of services and capabilities for designing, approving and constructing facilities necessary for economic development (Documentation, 1983).

Considering the other factors needed for the smooth operation of the construction industry such as the goods produced by other industries, manpower and other inputs, it is easy to see why this sector is so sensitive to socio-economic conditions and why political leaders attach so much importance to controlling its development by formulating and adopting clearly defined policies and strategies. Strategic planning for building materials development should be based on an assessment of future needs. Firm policies on the use of non-conventional materials, backed by a demonstration of the government's commitment to use them in government sponsored projects would contribute greatly in enhancing their increased application in both public and private housing and building projects. There is also an urgent need for governments to ensure that are expected to make significant contributions to an improvement of the supply of essential building material receive priority in the allocation of funds.

2.3 Role of Traditional Housing Construction in Ethiopia

In Ethiopia like many countries in the third world, there is a big gap between the income of the majority of the population and the cost of the buildings. Based on Climatic conditions and altitude, Traditional house construction in Ethiopia are divided in to houses of low

lands-Kolla (<1400m); houses of highlands- Woina Dega (1400-2700m) and houses of highlands Dega (2700 above sea level).

In Ethiopia soil is used extensively in the traditional construction of mud walls (Chika) all 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” (*Eragrostis Abyssinica*) and water (Doc, 1983). 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. The mud walls suffer from extended shrinkage cracks, which weaken the walls. Mud walls can easily be eroded by rain. The practice was to cover mud walls 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.

2.4 Salient Features of Earth as a Building Material

2.4.1 Strength

Earth block buildings are structurally sound. New Mexico adobe code requires a minimum of 2MPa for traditional adobe blocks. The strength, durability and longevity of Earth Blocks stand in stark contrast to other building materials. A typical wood frame building has an average life span of 75 years while earthen structures will stand for centuries (Chau et al., 2015). The technology of the hydraulic press machine has enhanced the fundamentals of earthen construction, durability, simplicity and sustainability. These characteristics have remained constant throughout the ages. For thousands of years people around the world have relied on earthen construction for their shelter with minimal impact on the environment. Approximately about half of the world’s population currently resides in earthen dwellings. Earth block construction combines the purity and timelessness of a natural material with the opportunities and innovations of today, a timeless technology.

2.4.2 Cost and Energy Efficient

Probably the most impressive and important selling point of earth block building is the incredible energy savings the owner will be awarded throughout the life of the building.

The thermal mass quality alone defines the strongest attribute of earth block and can be spelled out in energy savings to the owner, which means the community, saves as well. Energy efficiency can also be realized in the construction process itself. Earth blocks are made on-site saving in transportation costs and fuel consumption and require little energy in the block making process.

2.4.3 Virtually Sound Proof

Earth Block is so dense a building material that occupants are relatively protected from the outside World (Adam, n.d.). Sound recording studios have been built with pressed block for that very quality. Earth block buildings create their own world on the inside, which most people find is an added bonus.

2.4.4 Non-Toxic

Block making itself is a non-toxic process; therefore, buildings themselves are clean. Often, man-made ingredients of modern construction set up an environment that is filled with toxic chemicals and gases. Earth block is a frequently chosen material for home construction for those people suffering from chemical sensitivity. It's a win-win for both occupant and the community when new buildings are constructed with earth-friendly materials.

2.4.5. Environmentally Friendly

When you consider the attributes listed above, the underlying theme is that building with Earth block is environmentally friendly. From the construction of the block itself to the finished product, this is a way to build that benefit everyone.

2.4.6 Durable

Durability is the measure of the ability of the block to endure or sustain its distinctive characteristics of strength, dimensional stability and resistance to weathering under conditions of use for the duration of the services lifetime of the structure (Bhomia, 2000). Earth blocks have to be durable and water proof to exclude any undesirable influences of the environment such as rain, winds, rising damp or other severe weather conditions of exposure. When you consider that the oldest structures standing throughout the world today are made of earth, the statement that earth block is durable speaks for itself. Earth block has a good resistance for fire and pest.

For the purpose of this thesis, fiber reinforced cement stabilized TMS block is defined as a durable material which is produced from a natural or modified soil containing sufficient

finer to provide cohesion on densification, sufficient to allow unsupported handling or stack curing.

2.4.7 Uses Available and Abundant Raw Materials

Three ingredients make up the right combination used for earth block: sand, clay and silt materials, which are combined with a small percentage of Portland cement. The only other ingredient needed for wall construction is water, to make the mud slurry that binds the blocks together.

2.4.8 Aesthetically Pleasing

Earth block buildings can be made to look like any kind of finished structure; however, most people who adopt for this type of construction find they love the look of the block itself and the adobe look of a finish plaster. Exteriors typically are given a weather-resistant skin that can be colored or left natural and interiors plastered with a variety of mixtures or left exposed.

2.5. Termite Mound Soil

Termite Mound Soil (TMS) is the soil obtained from the pile of earth (commonly called termite's hill) produced by mound-building termites. It is classified as earth-based materials, they are very abundant in Ethiopia but do not serve any economic value, so they are often demolished. In contrast, our basic understanding of termite hill soil composition, formation and bonding is still very limited. Termite hill soil or (termite mound soil, TMS) is obtained from termite hills that are produced by mound-building termites (Fapohunda & Daramola, 2019). Termites are the dominant species in the tropical ecosystem, where they constitute up to 95% of the total quantity of soil insect in the ecosystem. They are considered as “ecosystem engineers” because they bind the soil with their secretions (saliva) to produce complex and robust termite mounds. They also ingest and excrete organic matter and elements such as phosphorus, potassium, magnesium and nitrogen, which can be mixed with the soil for applications in agriculture (Gandia et al., 2019). Hence, termite mound soils contain relatively high contents of organic matter. Their relatively high pH values also increase their ability to mix with nearby soils. Furthermore, the guts of termites have been shown to contain compartments that present rising gradients of pH and different status of oxygen and hydrogen (Mujinya et al., 2013), which may contribute ultimately to the chemistry and structure of termite mound soils. In any case, the resulting termite mounds contain soils with clay contents that are 20% greater than those in nearby soils (Gandia et al., 2019).

Prior work by (Elinwa, 2006) has explored the potential to use termite mound soils as pozzolanic materials in mixtures of calcined ant mound clay and cement mortar. Their work explored the effects of ant mound clay on the hydration process (in cement), as well as the resulting compressive strength, and its repercussions for the flexural and splitting tensile strength. They concluded that their ant mound clay was a weak pozzolanic material. Previous work reported that termite mound clay is a better molding material than ordinary clay (Omofunmi & Oladipo, 2018). The improvements in the molding characteristics of the termite mound soil were attributed to the effects of saliva secretions (from termites) during the construction of termite mounds. (Gandia et al., 2019) have also shown that termite mounds have good resistance to erosion, abrasion and penetrations of liquids, compared to ordinary clay.

Other researchers have also suggested that the improved mechanical properties of TMS (compared to those of nearby soils) can be attributed to the effects of termite secretions (Omofunmi & Oladipo, 2018). Researchers have suggested that termites can also have a significant effect on nutrient cycling and the renewal of mineral soil (Sarcinelli et al., 2009). (Gandia et al., 2019) have also studied the effects of mixing synthetic termite saliva with adobe. The resulting materials exhibited a modest increase in the bulk densities of adobe with mixtures of saliva. Synthetic termite saliva products have emerged from prior studies on TMS (Corrêa et al., 2014); they play the role of stabilizer due to the formation of organo-mineral compounds (that are present in the soil) that bind clay particles together. The products obtained from termite saliva are also ecologically sustainable, hydrophobic, water soluble, resistant to oxidation, resistant to microorganisms, applicable as low viscosity and cost efficient (Kandasami et al., 2016). Subsequently, termite mound soil presents the characteristic of a sustainable and renewable alternative to conventional building materials except for the few problems that can be solved through stabilization among other techniques.

From the American Society for Testing and Materials (ASTM), stabilization is a technique to increase the soil strength by enhancing its load-bearing capacity, improving its permeability and resistance and solving swelling and damping problems (Douglas & Britain), 1990). Boga et al. carried out studies on the spatial distribution and density of termites in an artificial botanic forest. They found out that over 26 termites' mounds were inactive out of 165 mounds (Jean-Pierre et al., 2015). Based on these results, it can be

deducted that the quantity of inactive termite mounds may be higher in the natural environment.

According to (Alemu Mosisa Legese, Tesfaye Kenate, and Fekadu Fufa Feyessa, 2021) The chemical compositions of the Termite Mound Soils (TMSs) samples were studied Both in Jawaj termite mound soils (JTMSs) and Sene termite mound soils (STMSs) had silica, $\text{SiO}_2 > 60\%$. The alumina, Al_2O_3 , contents for each of the TMSs from the two localities was $> 17\%$. The sum of the percentage of SiO_2 and Al_2O_3 content are 80.59 and 79.86% for JTMSs and STMSs, respectively. According to the study conducted by (Toure et al. 2017) on the mechanical and thermal characterization of bricks, a combined percentage of SiO_2 and Al_2O_3 should be greater than 70% to be a good binder for the brick production. The combined percentage of SiO_2 and Al_2O_3 composition also meets the requirements of ASTM C-618 (ASTM C 618, 2010). Thus, TMSs can be considered as suitable raw materials for brick production.

2.5.1. Binding Mechanism of Termite Mound Soil

The strength and durability of materials are determined by the binding mechanism. Consequently, to enhance the stability and toughness of construction materials, it is crucial to evaluate and comprehend the binders. Cement and lime are the most commonly used binders in earth-based materials. However, in addition to these conventional binders, there exist non-traditional stabilizers such as chemical stabilizers and by-product stabilizers (Onyelowe et al., 2019). The binders used differ in terms of their ability to create new compounds and their hydrophobicity. TMS has excellent binding properties and potential pozzolanic characteristics. Moreover, TMS is known as an "ecosystem engineer" because it binds soil with its secretions (saliva) to construct complex and robust termite mounds.

2.5.2 Theories of Pozzolanic Reaction Mechanism

Based on research, there are two main theories that explain the mechanism of the lime-pozzolan reaction, which is an essential factor in the pozzolanic reaction. The older theory is known as Base Exchange, which involves cation exchange or the process of replacing one ion with another in the crystal lattice. However, this theory has been discredited due to several reasons such as the absence of pozzolanic activity in normal zeolites, electro dialysis which did not affect pozzolanic reaction and the fact that the amount of lime reacted was more than what can be accounted for by exchange reactions.

The newer theory is that pozzolan-lime reaction is a surface reaction between dissolved lime and low solubility solids which results in the formation of a solid product. Lime-pozzolan mixes show an increase in the soluble silica and alumina, indicating their reaction with lime. Quartz and lime also react at elevated temperatures, and burnt bauxite acts as an excellent pozzolan, which further supports that silica and alumina are likely to be the reactive components of pozzolans. Ferric oxide and sulfate compounds may react with lime to form compounds that increase cementation, but these secondary reactions are not considered as significant as the primary surface reaction. (Leonard, 1958)

2.5.3 Pozzolanas

Pozzolana is a cementitious material categorized as natural or artificial and contains silica in a reactive form. According to ASTM 618-88a, it is described as a siliceous or siliceous and aluminous material that has little or no cementitious value on its own but will react chemically with calcium hydroxide when present in a finely divided form and moisture. It will form compounds with cementitious properties at ordinary temperatures. The finely divided state is essential for the silica to mix with calcium hydroxide produced by hydrating Portland cement with water. Thus, stable calcium silicates with cementitious properties can form. The silica should be in an amorphous, crystalline, or glassy state because crystalline silica has low reactivity. Pozzolan materials can be natural or artificial, and natural pozzolanas' examples are volcanic ash, pumicite, opaline shales and cherts, calcined diatomaceous earth, and burnt clay. They are classified as class N by ASTM C 618-08a. However, some natural pozzolanas may pose problems due to their physical properties. For example, diatomaceous earth requires high water content because of its angular and porous form. Natural pozzolanas can increase their activity through calcination at 550 to 1100°C, depending on the material. Furthermore, ASTM C 311-07 establishes the measurement of TMS's strength activity index for assessing pozzolanic activity with cement by determining the strength of TMS with a specified replacement of cement by pozzolana.

2.5.4 Pozzolan Characteristic of Termite Mound Soil

Pozzolan reactions are additional reactions that are related to calcium-based binders. A pozzolan is a material that contains silica in a reactive form, and it has little or no cementitious value, but when it is divided into fine form and in the presence of moisture, it will chemically react with calcium hydroxide at ordinary temperatures to create compounds with cementitious properties. The chemical composition of Termite Mound

Soils (TMSs) was analyzed in a study conducted by Alemu Mosisa Legese, Tesfaye Kenate, and Fekadu Fufa Feyessa in 2021. It found that TMSs from Jawaj and Sene have silica content greater than 60%, and alumina content greater than 17%. For both JTMSs and STMSs, the sum of the percentage of SiO₂ and Al₂O₃ content is above 70%. These characteristics make TMS an excellent material for producing blocks that require good binding agents. According to (Toure et al.'s 2017) study of block mechanical and thermal characterization, a combination of SiO₂ and Al₂O₃ percentages should be greater than 70% to be considered a good binder for block production. The SiO₂ and Al₂O₃ composition also meets ASTM C-618 requirements. As a result of its good pozzolanic characteristics, TMS proves to be a promising alternative for sustainable construction materials in areas where conventional building materials are scarce.

2.6. Fiber Reinforcement

2.6.1 Theories of Fiber Reinforcement

The mixture rule for strength can be modified to predict the strength of natural fiber reinforced cements in aligned continuous fibrous composites. This modification occurs under the assumption that the fibers are broken at failure but are also pulled out of the cement matrix. According to ACK theory, the matrix in fiber-reinforced cement and gypsum plaster is brittle and fails at the strain point of the fibers. Therefore, the tensile strength of natural fiber reinforced cements relies solely on the fiber contribution (Yongni, 1995).

2.6.2. Structure of Fibers

The structure composed of reinforcing fibers or wires may be characterized by the following parameters: material of fibers; shape of the fiber; distribution of fibers in the matrix. The number of the above listed parameters indicates how many different types of reinforcing fibers structures may be used in composites. The reinforcement in the form of fibers or wires is by its nature subject to randomness in comparison with classical reinforcement by bars or pre-stressing cables which are very precisely positioned in the reinforced elements (Brandt, 1995).

2.6.3 Synthetic Fibers

Synthetic fibers are manufactured from a variety of materials including natural organic fibers, synthetic organic polymers, and inorganic substances. Some common examples of synthetic fibers include rayon and acetate, which are made from natural organic polymers. Other synthetic fibers such as acyclic, aramid, nylon, olefin, and polyester are based on

synthetic polymers. Inorganic substances like glass, metallic fibers, and ceramics can also be used to manufacture synthetic fibers (Vinton, n.d.). Overall, there are a diverse range of materials that can be used to create synthetic fibers with different properties and applications.

2.6.4 Natural Fibers

Natural fibers are defined as materials that are derived from plants, animals or minerals and can be woven or spun into textiles, strings or other materials. Plant-based natural fibers include cotton, flax, hemp, jute, ramie and sisal. Animal-based natural fibers include wool, silk and cashmere, while mineral-based natural fibers include asbestos. These fibers are generally renewable, biodegradable, and have low embodied energy compared to synthetic materials, which makes them popular for use in sustainable textiles and other eco-friendly products.

Vegetable fibers are derived from the different sources of plants: bast fibers extracted from the bark of certain plants; leaf fibers (hard fibers) used for cordage; seed-hair fibers (cotton); and palm fibers (brush fibers) from various section of the plant. The principal chemical composition of vegetable fibers is cellulose bound by a natural gummy substance closely associated with lignin. While all vegetable fibers have cellulose as a major chemical component.

The concept of applying vegetable fibers for commercial and domestic uses dates back to the ancient Egypt (4000BC)-ropes, cords, and fabrics were made from reeds and grasses; boats, sails and mats were made from palm leaf fibers and papyrus stalks from the pith section. These days, sisal is mainly used for sacking, balling for rugs, webbing and twine. For the manufacture of a wide variety of products in different fields of applications in fine arts, flooring materials, food science, forensic aspects, furniture and fracture (fatigue) mechanics. The detail discussions of fiber types, their properties, methods of productions and applications are available in literatures G. Minke, (2000).

Fibers have been used as reinforcement since ancient times. Historically, horsehair was used in mortar and straw in mud bricks. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers like jute and sisal. Vegetable fibers are derived from the different sources of plants: bast fibers extracted from the bark of certain plants; leaf fibers (hard fibers) used for cordage; seed-hair fibers (cotton); and palm fibers (brush fibers) from various section of the plant. The principal chemical composition of vegetable fibers is

cellulose mostly bound by a natural gummy substance closely associated with lignin. While all vegetable fibers have cellulose as a major chemical component, other components like hemicelluloses, pectin's, extractives and lignin vary significantly providing the characteristics of specific fibers as shown in Table 2.1 below H. F. Mark et al., (2000) & H. F. Mark et al., (1986).

Table.2.1:- Chemical Composition of Common Vegetable Fibers (G. Minke, (2000))

Fiber	Cellulose	Hemice cellulose	Pectin	Lignin	Extractives
cotton	94	2	2		2
Kapok	43.2	32.4	6.6	15.1	
Flax	71.2	18.5	2	2.2	6
Hemp	74.3	17.9	0.9	3.7	3.1
Ramine	76.2	14.5	2.1	0..7	6.4
Jute	71.5	13.3	0.2	13.1	1.8
Abaca	70	21.8	0.5	5.7	1.8
Sisal	73.2	13.3	0.9	11	1.6

Natural fibers have gained a lot of interest in earth-based matrix reinforcement. In addition to their biodegradability, renewability and eco-friendly features, natural fibers possess good tensile properties. Straw, sisal, coir, bagasse, jute, hemp are the natural fibers commonly used as reinforcements in earth-based composites.

2.6.5 Sisal Fiber

Sisal fiber is the most important group of hard fibers. Sisal is essentially a plant of the tropics and subtropics and production benefits from temperatures above 25°C and Plenty of sunshine. Sisal fiber is obtained from the leaves of the plant *Agave Sisalana* and is produced in the regions such as Mexico, Brazil, Tanzania, Kenya, Ethiopia, Madagascar and China. Sisal is used for padding, mats and stair carpet, also for paper and building panels; sisal is also used to make ropes, sacks and bags of various types as well as marine cordage.

The product from sisal has tread or fiber like nature. It can group as fibrous material. This material is high in tensile strength and very light in weight it occupies large space with small mass and 100% biodegradable and environment friendly. It is one of the low-priced natural fibers. This comes second or just after the cotton in terms of the production and utilization. Sisal fibers are primarily made of various specific plant materials such as

cellulose, hemicellulose, lignin, and pectin. The fineness of the fibers allows them to reinforce the mortar fraction, delaying crack formation and propagation. For this reason, it is mostly used in agricultural products packaging and production of wires and Giraffe. It is one of the most adaptive natural fibers that has been used in raw materials for construction and agricultural sectors Habitat, (1991).



Figure 2.1:- Sisal plant *M Eswar Kumar Yadav (2019)*

In this research sisal fiber is used as reinforcement in TMS with cement for wall construction, therefore competing uses and availability becomes a key issue for justification of its use in the country.

2.6.7 World Production of Sisal Fiber

In terms of production, sisal occupies 6th place among fiber plants, representing 2% of the world's production of plant fibers, and it accounts for about 70% of the world's hard fibers. World sisal production reached its peak of over 600,000 ton per year in the 1960s, but has declined gradually since then due to the introduction of synthetic fibers and stagnating prices. Brazil has nearly regained the level of its peak production; production has decreased.

In most other countries, Kenya has become the second largest producer; according to FAO estimates the average annual world sisal fiber production (line fiber and tow) in 2004–2008 was about 350,000t. Among this Ethiopia is the 11th producer which has been shear 0.2% of world sisal production according to Food and Agricultural Organizations of United Nations (2020, January).

Table 2.2:- World Sisal Fiber Production According to FAO in 2011 E.C

Country	Rank	Sisal production quantity (ton)
Brazil	1	283,797
Kenya	2	27,560
Tanzania	3	24,828
Mexico	4	20,113
Madagascar	5	18,937
China	6	14,683
Haiti	7	9,229
Venezuela	8	6,177
Morocco	9	1,500
South Africa	10	1,347
Ethiopia	11	623

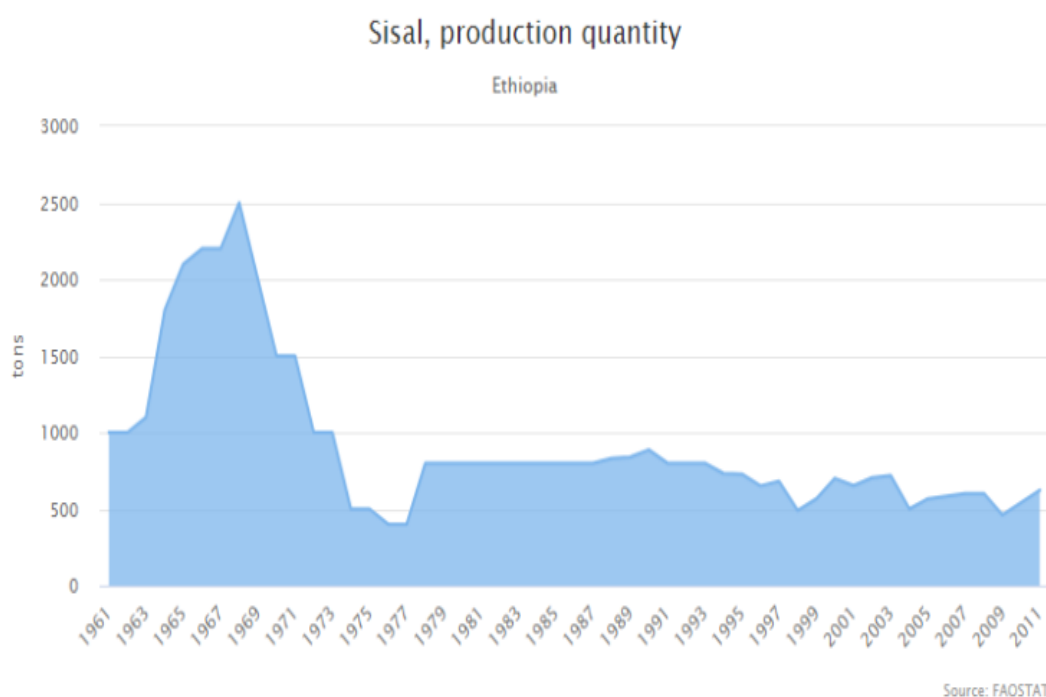


Figure 2.2:- Sisal Fiber Production in Ethiopia According to FAO Study

2.6.8 Natural Fiber Reinforcement Composites

In recent years, a great deal of interest has been created worldwide on the potential applications of natural fiber reinforced cement based composites. Investigations have been carried out in many countries on various mechanical properties, physical performance and durability of cement based matrices reinforced with naturally occurring fibers including sisal, jute, bamboo and wood. These fibers have always been considered promising as reinforcement of cement based matrices because of their availability, low cost and low consumption of energy. Fibers such as sisal, jute and coconut have been used as reinforcement of cementitious matrices in the form of short filament fibers. Short filament geometry composites presented a tension softening behavior with low tensile strength, resulting in products which are more suitable for non-structural applications (Suryawanshi, 2013).

2.7. Cement Stabilization

Cement is the most widely used construction material throughout the world with an estimated consumption of about 4.37 billion tons of Portland cement per annum worldwide. Cement production is however harmful to the environment due to carbon dioxide emission. Approximately 0.8 tons of CO₂ is estimated to be released into the atmosphere per ton of cement produced. With the cement industry accounting for 5-8% of global CO₂ emission, the cement industry is the second largest producer of this greenhouse gas. SO₃ and NO₂ released as a result of Portland cement manufacture are also known to cause serious environmental problem such as greenhouse effect and acid rain. Reducing cement production while maintaining sustainable development has thus been an important issue in the development of construction materials (James et al., 2014).

Stabilization is a technique to increase the soil strength by enhancing its load-bearing capacity, improving its permeability and resistance and solving swelling and damping problems. Cement stabilization is the addition of cement to a soil, which acts as a binding agent and produces a weak form of concrete called soil cement. The quantity of cement to be added depends upon the type of soil. Cement can be used with most types of soil, providing the clay fraction is reasonably small and other specified impurities are not present. A small percentage of lime is usually added. With very poor soils, cement stabilization may be uneconomical or impracticable.

2.8.1. Cement Based Composites

The Fiber Reinforced Cement Composites (FRCC) have been widely used since the middle of the 20th century and currently recognized as one of the most efficient and high performing materials for construction of slab and wall systems, manhole covers, roads, pavements and industrial floors, pipe works and tunnel lining, jacketing around columns.

This is because FRCC provide combined properties of interest to civil engineering applications which include strength, toughness, energy absorption, durability, corrosion resistance, water tightness, appearance and constructability. The role of the fibers in construction materials is not only to overcome the traditional weakness of inorganic cements, namely poor tensile strength and brittleness but also to improve the resistance to impact, blast, explosion and other forms of dynamic loads when large amounts of energy are suddenly imparted to the structure (Sakthivel et al., 2012). This research attempts to address the issues of tensile weakness in TMS with sisal fiber to reduce crack propagation.

The major advantage of fiber reinforcement is to impart additional energy absorbing capability and to transform a brittle material into pseudo ductile material. Fibers in cement or concrete serve as crack arrestor which can create a stage of slow crack propagation and gradual failure (Reynaldo, 2011). Knowledge of fiber properties is important for design purposes; fiber tensile strength is usually higher than the matrix strength and becomes influential in post-cracking (Romildo et al., 1999).

2.10 Stabilized Earth Blocks

Soil stabilization technique was started back in 1930's in the fields of highway and airfield construction (Fitzmaurice 1958). The builders were not slow in picking up this idea and soon started using this technique for building walls. The two main purpose of stabilizing the soil are to improve the strength bearing capacity and waterproofing, which is a requirement for durability (Rogers, et.al. 1996). The soil blocks used in construction are stabilized using mechanical and/or chemical methods. The soil is compacted mechanically to modify the arrangements of the soil particles; and the inclusion of other materials, which chemically react with the soil (usually pozzolanic reaction occur), to alter its properties.

The use of sustainable building materials, particularly in Ethiopia, has gained attention over the years. One of the alternatives that have been explored is natural fiber reinforced cement stabilized TMS (Traditional Masonry System) blocks. In their study, Rahman et al. (2019) discussed the potential of these blocks as sustainable building materials. Guillaud

(1996) also highlighted this topic in his report on building with compressed stabilized earth blocks. However, it is important to acknowledge that limitations exist and appropriate techniques must be used to ensure strong and durable structures. Soil stabilization techniques, for instance, are recommended by Bindu.B.Nair and Deepa.P (2015). Finally, Ross Spiegel and Dru Meadows (2006) provided a comprehensive guide for selecting and specifying green building materials.

Even though the compressed soil blocks were being produced using the compression technique from the 18th century, it was not too popular until Raul Ramirez invented CINVA-RAM press in 1952 (Deboucha and Hashim 2010). As a consequence, Sri Lanka, New Zealand, Australian, French, German and Indian governments promoted their usage. Several countries came up with standards and regulations for construction using compressed stabilized earth blocks. Australia was the first country to come up with regulations for earth constructions which were published in 1952 by the Commonwealth Scientific and Industrial Research Organization (CSIRO) and later replaced by the Australian Earth Building Handbook in 2002 (Pacheco-Torgal and Said Jalali 2012).

The United States has no regulations for earth construction. However, New Mexico State includes adobe and rammed earth construction regulations in the appendix of Housing and Construction Building Codes General in 1991, under the title New Mexico Earthen Building Materials Code, further revised in 2009. New Zealand has three standards addressing the earth construction as an integral part in the building codes. NZS 4297, NZS 4298 and NZS 4299, published in 1998, provide details about Engineering design of earth buildings requiring specific design and performance, materials and workmanship required in earth construction and earth buildings not requiring any specific design, respectively.

Indian Standard Institution also published a standard (IS 15:1725 “Specifications for soil based blocks used in general building construction”) in 1982. Even though these standards and handbooks do not provide complete details about the understanding of the soil and performance related to the soil type used, it has at least given a start for those people who are interested in constructing residential buildings using soil for the wellness of their family and future generations. The soil is compacted mechanically to modify the arrangements of the soil particles; and the inclusion of other materials, which chemically react with the soil (usually pozzolanic reaction occur), to alter its properties. The use of sustainable building materials, particularly in Ethiopia, has gained attention over the years

2.11 Role of Stabilized Earth Blocks in the Developing Countries

Adequate housing is one of the basic needs to lead a peaceful and dignified life and also represents the economic and social development of the country. However, in developing countries it is challenging to provide economical housing for working class people. The hurdle for these housing problems are high cost of land, construction materials and labor (Kabiraj and Mandal 2012). Even though governments are coming up with financial and housing schemes to help people get house ownerships, it is not helping in any ways due to the constant hike in construction cost. According to United Nations Center for Human Settlements (UNCHS) by 2030, about 40 percent of the world population will require proper housing. Unfortunately, because of limited resources in many developing countries, it is necessary to work towards finding a way to reduce the construction costs and move towards the development of low-income housing (Adam and Agib 2009).

Furthermore, in response to the need for global environmental changes and the importance of ensuring environmental, social and economic sustainability, it is critical to explore a sustainable building material. This can be achieved by improving the traditional construction techniques in which locally available cheap materials is used. Moreover, the locally available material must be renewable in nature. The usage of these materials for producing construction materials will contribute towards the development of the country by generating local employment, reducing the import and improving the standards of the rural and urban people (Adam and Agib 2009). Earthen construction is the one of the most popular construction technique used since ages. Local soil is readily available and a renewable material which suits aptly for the problems discussed above (Kabiraj and Mandal 2012). As per the statistics from UNCHS, 40% of the world population currently lives in earthen dwellings. One such technology which is a form of earthen construction is the use of compressed stabilized earth blocks (CSEB). A remarkable reduction in the building construction can be achieved by using this technique. Tadege (2007) reported that the CSEB wall construction cost is 55.2% cheaper than hollow cement bricks which prove that economical construction can be achieved by this technique.

The construction industry and building materials are important sectors which represent the socio-economic development. Development of a nation is also characterized by the ability of government and communities to keep pace with the movement of people from villages to cities and make sure the number of households living in adequate housing increases (Makay 2009). This requirement has increased the tendency of usage of CSEB for

construction of low cost housing. This technique will be beneficial for the countries in developing the economy and in moving towards the sustainable future city.

The carbon dioxide emissions for the experimental unfired bricks were determined to be 42.9kg CO₂/ton with a total energy usage of 667.1MJ/ton. In comparison, common fired bricks have a total energy usage (input) estimated at 4186.8 MJ/t with equivalent output emissions of 202kg CO₂/ton (Oti and Kinuthia 2012). CSEB can be a source of income from carbon trading too, as there will be reduction in the carbon emission. Setting up of CSEB production units in rural or urban areas will generate employment opportunities for local people. Economic system of the society can be improved by using the CSEB for cultural facilities, social housing, administrative buildings, and medical facilities, which also helps in improving the standard of living of the society (Tadege 2007).

Mayotte, a French territory, is a development model who has been using CSEB for more than 20 years for building social housing. Since the people had no financial resources, CSEB was chosen as the building material. Until 2000, almost around 12,500 houses were built with the production of CSEB rounding up to 30,465,000. More houses are being built till today (Auroville Earth Institute). The use of CSEB helped them in setting up an industry which leads to the economy development along with the social development. Today it has become an international reference for development from CSEB production and usage strategy.

2.12 Previous Studies on Stabilized Soil Block

(Cardinale et al., 2018) conducted an experiment on adobe bricks with natural and bio-based filler. This work was focused on some natural fiber composites made from different mixtures containing clay soil with different percentages of jute, straw and basalt fibers. In this study the materials used for the specimens made as adobe bricks were clay, sand, water and fillers such as basalt, jute and straw. Clay was used as binder. The straw fillers used for his study have been obtained from plants of durum wheat characterized by medium height and late production. In this work two different specimens' geometries were prepared; the first one is 160mm x 40mm x 40 mm clay bricks, used for mechanical test, and the second one is 300mm x 300mm x 20mm specimens used to investigate the thermal properties of resulting materials. In a first part of this work the influence of clay mass was studied; for this purpose, 160mm x 40mm x 40mm specimens with mixture components were prepared. According to this study an amount of 20% of clay shows the best compromise between mechanical strength and shrinkage.

The use of straw filler in the clay/sand mixture causes a decrease in the maximum flexural and compressive strength. On the contrary mechanical performance of adobe bricks containing basalt and jute fibers increase with the filler amount, exhibiting a binder behavior with clay/sand mixture. This is probably due to the ability of these types of fibers to restrain the extension of cracks, reduce the extent of stress concentration at the tip of cracks, and delay the growth rate of cracks. The study generalizes that, the presence of the fiber involves a decrease in the final density of the product and a better behavior from the thermal point of view. The obtained results show an improved mechanical strength and a better thermal conductivity of the clay composite material.

Raj et al., (2017) Investigate that the optimum proportion of coconut fiber and cement suitable for rammed earth wall construction. Coconut fibers and cement were incorporated into the soil mixture for strength and durability to wall. Stabilization of soil was done by adding Ordinary Portland Cement (2.5, 5.0, 7.5 and 10.0 percent by Weight of soil), whereas coconut fiber in length about 15 mm was added (0.2, 0.4, 0.6, 0.8 and 1.0 per cent by weight of soil) as reinforcement. Thirty types of mixes were created by adding different proportions of cement and fiber to locally available soils and Compacting the mix at constant compaction energy in three layers with Proctor rammer. Samples were tested for compressive strength and tensile strength, and failure patterns were analyzed. They conclude that the use of cement and fiber increases ultimate strengths significantly up to an optimum limit of 0.8 per cent fiber content provides a secondary benefit of keeping material bound together after failure and increases residual strength. Benefits of fiber reinforcement include both improved ductility in comparison with raw blocks and inhibition of crack propagation after its initial formation.

After analyzing the results, they recommended using 0.8 percent fiber and 5-10 percent cement by weight of soil to achieve considerable strength. A detailed study was conducted to analyses the behavior of the mix on density, unconfined compressive strength and split tensile strength. The main difference observed between cement stabilized rammed earth blocks with and without fiber reinforcement was the failure pattern. According to their work both type of blocks exhibited brittle failure, but the blocks having fiber reinforcement were attached firmly even after failure. In the split tensile test, they reported that the samples without fibers cracked quicker than the samples with fibers as reinforcement. Quick and abrupt failure was observed for raw blocks. The two halves were held together by fibers even after failure. Finally, they concluded that using fiber as

reinforcement in rammed earth walls serves as a protection and safety measure during earthquake and sudden failure of walls and structures.

Mostafa & Uddin, (2015) this researcher focused on the use of banana fiber and its effect on the compressive and flexural strength in compressed earth block. The results presented in this study provide important insights into the influence of fiber length on the flexural and compressive strengths of compressed earth block. According to their finding the compressed earth block matrices, soil constituents, fibers content, level of chemical stabilization, compaction effort, and curing conditions all contribute to high mechanical properties. All these variables were kept constant throughout their study to enable observation of the influence of the banana fibers on the flexural strength, compressive strength, and post-initial crack behavior of fiber-reinforced compressed earth block.

On average, specimens reinforced with 50 mm fibers performed better, in both flexural and compressive strength, compared to the unreinforced specimens and specimens reinforced with different variations of 25 mm fibers. The highest flexural and compressive strength values were recorded at reinforcement with 50 mm fibers and 0.35% fiber content by weight. The results made plain that the treated 50 mm fibers were the better performing fiber in this study. Compared to the unreinforced specimens, specimens reinforced with 50 mm fibers at 0.35% by weight, were 94% and 77% higher, in terms of flexural and compressive strength, respectively.

(Getachew, 2017) Investigates that the efficiency of Locally Produced Clay Brick Quality and Suitability for Load Bearing Element in Jimma Area, Ethiopia. The objective of the study was to Assess factors affecting locally Manufactured clay Brick's qualities and being alternative construction material for different building elements compared with the standard, conduct laboratory test on locally Produced Clay Brick and Identify how much their strength is weak when compared with the standard. Two different sample were collected from Burayu and Boye. In this study, the existing physical properties of local clay brick was tested in laboratory and test results were collected and the extent is known. They perform different test on locally produced brick like the compressive strength test, inflorescence and water absorption test.

The Compressive test, result shows average compressive strength of local brick is 5.0Mpa, which is 50% of Burayu Brick. Water absorption is 33 % that exceeds the standard (20%) nearly by 65%. According to the result obtained they justify that compressive strength

result is very competitive to that of higher class of Hollow Concrete Block of 5.5Mpa as wall load bearing according to Ethiopian standard. But the Combined Physical Clay Brick test results indicate that traditional local brick in Jimma are not qualified compared to Ethiopian, Indian, British and American standards. The study concludes that major quality problem is water absorption due to firing temperature and less compaction effort and hence firing and mold method.

(Esayas et al., 2018) In Ethiopia Investigates that the Development of Wall Construction Material Stabilized with Enset Vegetable Fibers for Rural Housing Units. The objective of this research was to develop non-structural earthen wall construction material stabilized with Enset vegetable fibers for rural dwelling units specifically Ethiopia SNNPR state Tarcha Town Sore neighborhoods. The material used were (Enset vegetable fiber and clay soil) collected from the study area. Laboratory tests (grain size distribution, Atterbergs' limit and specific gravity) were conducted and confirms that the soil is suitable for earthen block production as per as stabilization with Enset vegetable fiber for durability and other parameters.

It was taken from 50cm depth in order to prevent organic matter from top soil. The organic composition was checked and confirms that this composite material is good construction material. Single fiber pulls out test were done and indicates that a very thin fiber diameter of 0.07mm can resist the dead load of 10.39N and 0.21mm can resist dead load of 20N and have average stress of 0.2341N/mm². According to these researches the compressive and flexural strength of earthen block reinforced with Enset vegetable fiber enabled different strength for increasing fiber amount from 0%-5%. His study indicates that increased amount of fiber in the block decreased both wet and dry density of the block and adding excess amount of fiber to the block can opposite the standards; and lowering the connection of soils inside joints; the optimum amount of the fiber obtained were 1.5% for density achievement and water absorption capacity.

(Yadav et al., 2019) Studied the Influence of Sisal Fibers on the Properties of Rammed Earth. This thesis presents the result of an experimental study to evaluate the compressive strength and bond strength properties of untreated, treated bamboo splits and steel reinforced cement stabilized rammed earth blocks to overcome the deficiencies of blocks, sisal fiber was added to improve the performance of CSRE blocks. In this experimental study, red soil is mixed by adding four different percentages (5%, 10%, 15%, and 20%) of OPC and sisal fiber with 0.2%, 0.4%, 0.6%, 0.8%, and 1.0% by weight of respectively the

bamboo splits were treated by soaking them in chemical solution. After 28 days curing period, the cubes were tested for compressive strength, pull-out test is done for a series of CSRE blocks in which Bamboo splits and steel bars are embedded to find out its bond strength. According to their research the compressive Strength is more for 0.4% sisal fibered and 20% cement which is 12.546 N/mm². The Pullout tests obtained were greater Strength and deflection for this optimum value of cement and fiber.

(Danso, Martinson, Ali, & Williams, 2015) Conducted research on physical, mechanical properties of soil building blocks. The study perform laboratory experiments including workability, water absorption, density, tensile strengths shrinkage, compressive strength and wearing and erosion tests on stabilized soil block. The study uses two soil types and three fiber types (coconut, bagasses and oil palm) were used. The percentage of fiber for this study were 0%-1% by weight. It was found that the physical mechanical properties of the soil block were improved. The researcher recommends that 0.5% of fiber and high clay soil will improve the physical as well as the mechanical properties of soil block. (Humphrey, n.d) conclude that using fiber in soil block reduce the density and shrinkage of soil block this means that the fibers have great contribution on the reduction of weights in structure the compressive and tensile strength were improved there was 57% increase in strength compared with un reinforced sample. The rate of erosion was also improved by 20%.

(Toure et al., 2017) on the mechanical and thermal characterization of bricks, a combined percentage of SiO₂ and Al₂O₃ should be greater than 70% to be a good binder for the brick production. The combined percentage of SiO₂ and Al₂O₃ composition also meets the requirements of ASTM C-618 (ASTM, 2012) & ASTM C 618, 2010). Thus, termite mound soils can be considered as suitable raw materials for brick production. In general, the research findings concluded that TMSs can be used as a raw material for brick/blocks production, as the termite mound soils are mainly available in nature.

Mahamat et al., (2021) the stabilized termite mound soil displayed the highest mechanical properties of 13.91 MPa, 10.25 MPa and 3.52 kPa·m^{1/2} for compressive strength, flexural strength and fracture toughness, respectively. Besides displaying good mechanical properties and being locally available at no cost, renewable and an eco-friendly material, the termite mound soil will contribute to lowering the cost of housing in Sub-Saharan Africa.

Tsega et al., (2017) the chemical compositions of the Termite Mound Soils (TMSs) samples were studied both in Jawaj termite mound soils (JTMSs) and Sene termite mound soils (STMSs) had silica, SiO₂ greater than 60%. The aluminas, Al₂O₃, contents for each of the TMSs from the two localities were greater than 17%. The sum of the percentage of SiO₂ and Al₂O₃ content are 80.59 and 79.86% for Jawaj termite mound soils and Sene termite mound soils, respectively.

Based on the analysis of both samples of TMS, it can be concluded that they meet the chemical composition requirements for construction purposes. Therefore, it can be inferred that TMS is a suitable construction material, especially when used in conjunction with stabilizers for wall construction.

2.13. Summary

Overall, the importance of fiber reinforcement and cement stabilization on soil blocks has been well-established in extensive literature review. Research has shown that the use of stabilizers(Esayas et al., 2018) can modify soil properties(Cardinale et al., 2018) and increase ultimate strengths, as well as keep materials bound together after failure and improve residual strength(Akbulut et al., 2007). This has led researchers to conduct studies on the physical and mechanical properties(Danso, Martinson, Ali, & Williams, 2015; Tsega et al., 2017) of stabilized soil block for wall construction(Esayas et al., 2018; Raj et al., 2017), including workability, water absorption, density, tensile strength, shrinkage, compressive strength and wearing and erosion tests(Abd Halip et al., 2019).

In addition, the research highlights the importance of reducing cement consumption in the construction industry(Karim et al., 2014) by using soil as an alternative building material(Gowda, 2016; Tadege, 2007). The use of different types of soils (clay, sand, and silt), fibers (coconut, banana, sisal, etc.) (Raj et al., 2017)and cements (OPC, PPC, etc.) have been explored to achieve this goal(Klopp & Petretta, 2017). However, there may be further opportunities for research in this area, such as exploring new materials or techniques for fiber reinforcement and cement stabilization on soil blocks, or investigating the potential for soil-based construction methods beyond wall construction. Termite mound soil(Kandasami et al., 2016; Olaniyi & Umoh, 2014; Omofunmi & Oladipo, 2018) is one of best earth materials to use as alternative wall building materials(Esayas et al., 2018). The development of natural fiber reinforced cement stabilized soil blocks is a novel concept(Bordoloi et al., 2017; Documentation, 1983; Silva Mondragón et al., 2019). Tsega et al., (2017) the chemical compositions of the Termite Mound Soils (TMSs) samples were

analyzed. Based on the analysis of both samples of TMS, it can be concluded that they meet the chemical composition requirements for construction purposes. Therefore, it can be inferred that TMS is a suitable construction material, especially when used in conjunction with stabilizers for wall construction

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Therefore this study focuses on the development of natural fiber reinforced cement stabilized termite mound soil blocks. It's believed that reinforcing block, gives strength to the blocks and reducing the consumption of cement in the blocks and reduces the effective cost of sustainable building materials. In addition, it may also lead to a decrease in overall gas emissions associated with cement production for conventional wall making materials. This method could contribute towards a more eco-friendly and sustainable construction industry.

2.14. Gap Identification

Previous researchers have conducted various studies on soil block(Bhomia, 2000; Bordoloi et al., 2017; Danso, Martinson, Ali, & Williams, 2015; Ghavami et al., 1999), which is a soil-based technology. They used stabilizers such as cement and fiber (Danso, Martinson, Ali, & Williams, 2015; Gowda, 2016; Savastano Jr et al., 2009) to address the problems of durability and load carrying capacity associated with this technology. Some researchers improved the natural soil gradation by adjusting the amount of fines(Sabry, 2022), while others added sand(Gandia et al., 2019) to improve the gradation and then combined it with cement or fiber to enhance block quality. However, several issues were observed, including problems with load carrying capacity and durability, which led to a lack of confidence in using soil blocks as walling material.

This thesis aims to overcome these challenges by using termite mound soil combined with cement and sisal fiber to improve the quality of soil blocks. By doing so, the method which is stabilizing cement and fiber, with termite mound soil could reduce the problems associated with soil block, thereby enhancing its acceptance as a durable and effective walling material.

CHAPTER THREE

3. RESEARCH METHODOLOGY AND MATERIALS

3.1. Introduction

The literature review in the previous chapter discussed various past studies and research gaps in relation to high-range water-reducing and accelerating admixtures and their effects on block properties with different cement and sisal contents. Based on the identified research gaps, Chapter one outlines the research objectives set for this study. This chapter clarifies the methodology adopted to accomplish the study's objectives. This chapter reviews the materials and methods used in this study. The first section designates the overall research design, materials used, test parameters, and specimen preparation, and then finally the experimental work to accomplish the research objectives.

3.2. Research Approach and Design

As Walliman (2005) notes, a well-organized research design is an essential prerequisite for effective data collection and analysis. Additionally to these, Fellows and Liu (1997) highlight that successful research often entails synthesizing and analyzing existing theories and ideas, as well as past findings from other research studies. In doing so, the aim is typically to answer specific research questions or gain new insights in the given area of inquiry.

It appears that my research approach and design is experimental in nature, utilizing both qualitative and quantitative data analysis methods. The research begins with a literature review followed by an assessment of the case in Ethiopia and other world. Conceptual and contextual frameworks of the problem were reviewed to develop fundamental concepts for the research. Methods of data collection was determined based on the approach to the solution of the problem, and various methods such as experiments, observations, and archival records were examined and used as appropriate.

The materials used in this study were carefully described with respect to their source and physical properties. In order to conduct the investigation, relevant data was collected on the materials used, including their strength, loading, and cross-sections. One of the key advantages of this research is its potential applicability beyond Ethiopia, as both termite soil (a common building material in many parts of the world) and sisal fibers are readily available in other countries as well.

3.3. Research Methodology Framework

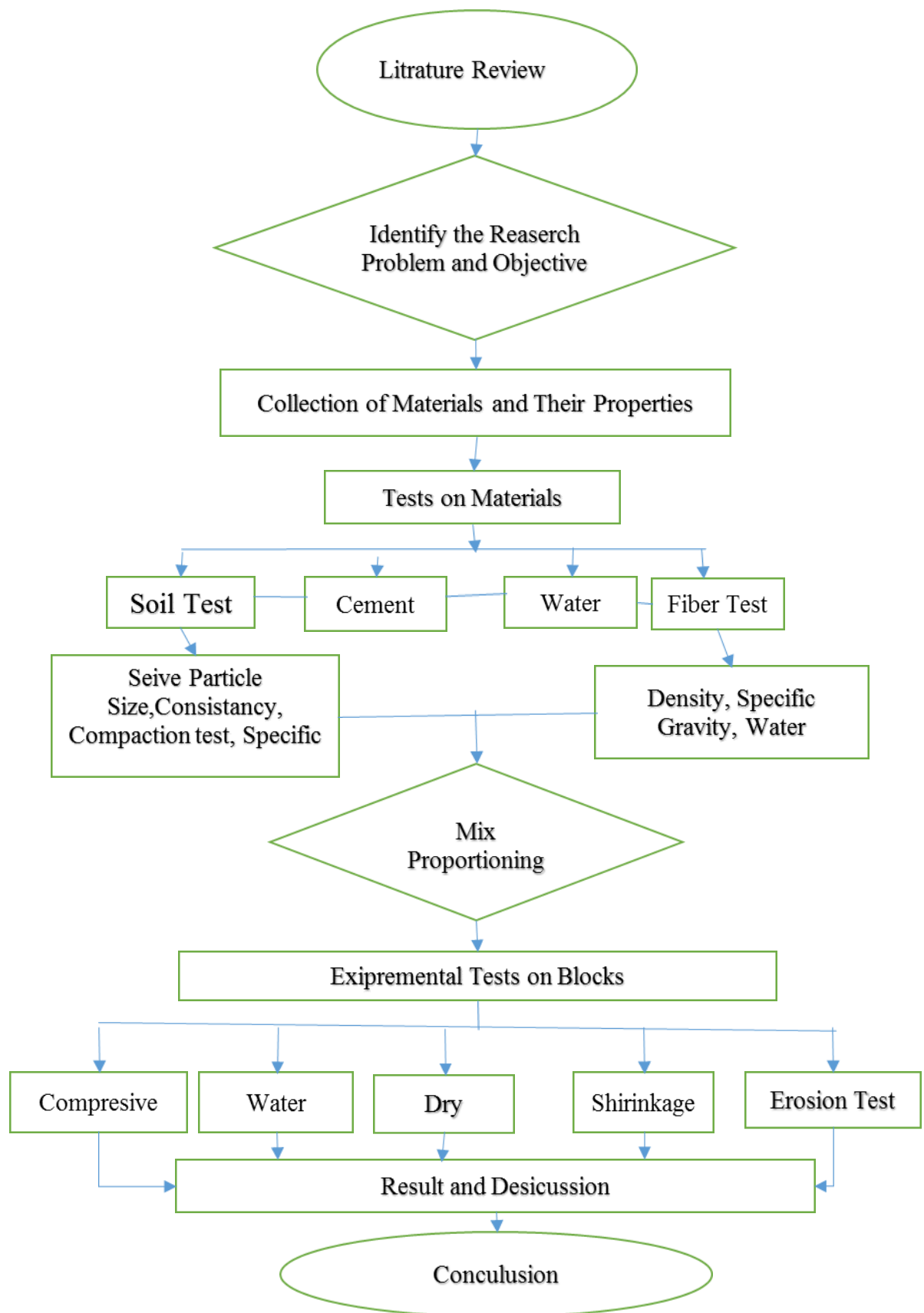


Figure 3.1 Work Methodology Flow Chart

3.4. Material Compositions

It appears that the materials utilized for the research include natural fibers (sisal fiber of agave), TMS, cement, and water.

3.4.1. Termite mound Soil

Termite Mound Soil (TMS) is a type of soil that is obtained from termite hills produced by mound-building termites. It is classified as an earth-based material and is abundant in Ethiopia, but it does not hold any economic value and is often demolished. Our understanding of TMS composition, formation, and bonding is limited. Termites are dominant species in the tropical ecosystem, constituting up to 95% of the total quantity of soil insects. They are referred to as "ecosystem engineers" due to their ability to bind soil using secretions (saliva), resulting in the production of complex and robust termite mounds. In this study, soil samples were collected from three depths in Adama: TMS was obtained by clearing the site to a depth of 50cm; another sample was collected by excavating clay soil from a depth of 50cm to prevent organic matter from the topsoil, and also the third clay soil sample was collected from 50cm depth from the topsoil. It was illustrated in figure 3.2.

The quality of blocks produced depends on the quality of selected soil samples and the type of stabilizer used. Various tests were conducted to identify the properties of each soil and to assess their suitability for earth-based construction, especially for stabilized-blocks. Three soil samples were selected for testing TMS from Bolo kebele, clay soil from Hangatu kebele, and a third sample was collected from ASTU campus around the stadium. Tests included specific gravity, Atterberg's limit, compaction, and grain size analysis tests.



Figure 3.2 a) Termite mound soil . Figure 3.2b&c) clay soil.

3.4.2. Cements

The same type of cement was used for all the trial mixes and the amount added per mix was kept constant. The types of cement for the lab work were bought from the local market of Adama. Pozzolanic Portland cement (PPC) with a grade of 32.5R and manufactured by Dangote Cement Factory and no test was conduct on the cement. Its grade was illustrated in figure 3.3



Figure 3.3 Cement grade

3.4.3. Fibers

The type of fiber used for this study is natural fiber known as sisal fiber obtained from sisal plant. Tests carried out to the sisal fibers were density, water absorption and specific gravity. Figure 3.4 show what the fiber looks like.



Figure 3.4 Sisal Fiber

3.4.4. Water

Throughout the investigation tap water, which is supplied by the Adama water supply system of the city, is used. No test was conducted on the water.

3.5. Methods for Soil Particle Test Characterization

3.5.1. Particle size analysis of soil particles

The particle size distribution analysis provided information on the ability of soil to pack tightly to form a dense structure and the quantities of fines present (a combination of silt and fine fraction). Dry sieve analysis, as per the ASTM D422 standard, is a commonly used method to determine the particle size distribution of soil samples. In this method, a sample of dry soil is passed through a series of sieves of different sizes, with the largest sieve at the top and the smallest at the bottom. The amount of soil left in each sieve is weighed, and the percentage of soil in each size range is calculated.

To perform a dry sieve analysis, a representative sample of the soil is first dried in an oven and then weighed. The sample is then placed on the top sieve, which is then placed on a shaker that vibrates for a specified period. The soil left on each sieve is weighed and recorded. Finally, a graph is plotted with the percentage of soil passing through each sieve size against the sieve size to obtain the particle size distribution of the soil sample. Figure 3.5 illustrates sieve size analysis equipment.



Figure 3.5 Sieve Analysis for soil Particle size distribution

3.5.2. Consistency Limits

The term consistency is used to denote the degree of firmness of a soil, such as soft, firm, stiff or hard. The water contents at which the soil passes from one state to the next are known as consistency limits, also known as Waterberg limits as it was demonstrated by

Waterberg, a Swedish scientist. The limiting water contents when a soil mass passes from liquid to plastic, plastic to semi-solid and semi-solid to solid states of consistency are respectively termed as liquid limit, plastic limit and shrinkage limit. The values of liquid limit and plastic limit are used for classifying the fine-grained cohesive soils. The values of these limits are also used in determining the flow index, toughness index, and plasticity index which are useful in giving an idea about the plastic limit and cohesiveness of cohesive soils. The numerical difference between the liquid limit and plastic limit is known as plasticity index, the plastic range of the soil. The plasticity index provided an idea of the cohesion of fines in the soil sample.

The liquid limit and plastic limit of the soils was determined by following the procedure of ASTM D 4318-05. Dry preparation method was followed for this research work. The soils were first dried at room temperature and then pulverized in a mortar. The crushed soils were then sieved over #40 (425 μ m) sieves. The soil passing #40 sieve was used in this test. Figure 3.6 illustrates weighing and oven drying soil samples for both plastic and liquid limit determination purpose.



Figure 3.6 Consistency limit test procedure sample picture

3.5.3. Compaction Characteristics of Soil

Compaction is a process of making soil particles more compact by reducing air voids and increasing dry density, usually measured quantitatively. The maximum dry density is achieved at optimum moisture content. Compacted soil has increased density and shear strength capacity but reduced voids ratio, porosity, permeability, and settlement. In order to prepare the blocks, laboratory compaction soil test was performed to determine the moisture content needed to attain the maximum dry density. ASTM D 698 - 00a was used

for the test. The results from grain size analysis and Waterberg limits were used to classify the soil using Unified Soil Classification System and AASHTO procedures. All soil tests are performed based on ASTM and AASHTO standards.



Figure 3.7 Compaction test procedure

3.5.4. Specific Gravity of Soil Particles

The specific gravity (G_s) of a soil particle is the ratio of the mass of unit dry soil particles to the mass density of an equal volume of distilled wafer at 20°C. It is determined by density bottle or Pycnometer. It gives the details about how much lighter or heavier the material is than water. The test is carried out on the soil particles passing #4 (4.75mm) sieve according to ASTM specifications (ASTM D 854-92). In this research work the specific gravity value of the soils was used to determine the zero air void curve in soil compaction tests and for determining the grain size distribution curve in hydrometer analysis. The specific gravity of the soil was found to be 2.69 for all the soil used in this work. Figure 3.8 illustrates weighting and measuring specific gravity of soil samples.



Figure 3.8 Compaction test procedure

3.6. Methods for Fiber Test Characterization

The fibers were washed and separated until individual fibers are clearly identifiable, then sun-dried Araya Abera Betelie^{1*} and Redda,(October 2019). ASTM D7865-13(2017) and FAO guidelines followed, Due to the irregularities observed in the cross-section areas of a bundle of sisal fibers, the Archimedes principle was used to determine the apparent density of the sisal fibers. The lengths of the sisal fibers were 50 mm and cut from full-length fibers to meet the workability and strength test. These lengths were based on work done by Mostafa, (2015).

3.7. Methods of Mix Proportions Used for Block Production

The investigation aims to assess the potential of local materials like cement, fiber, and soil, in order to provide detailed technical and economic information on the production of these blocks. Different types of cement from manufacturers, sisal fiber from natural vegetable, and a termite mound soil sample from a selected site were collected and prepared. The mix proportions were based on literature recommendations, and a series of mixes were done to check the compressive strength, water absorption test, density and shrinkage of the block samples over 28 days.

Different series of mixes were also prepared using locally available termite soil. The four types of TMS blocks studied included un-stabilized TMS blocks, sisal-stabilized TMS blocks, cement-stabilized TMS blocks, and sisal-cement stabilized TMS blocks. The type and amount of stabilizers used had a significant impact on the compressive strength and water absorption capacity of the stabilized TMS blocks. The study focused on studying the type, amount, and effect of these stabilizers in order to better understand their influence on the blocks.

The study involved testing various combinations of termite soil, sisal fiber, and cement for the production of sisal fiber reinforced cement stabilized TMS blocks. The termite soil used in the study was constant throughout the production of all the block specimens. The ratios of sisal and cement were varied by weight, with cement content ranging from 0% to 15% and fiber content ranging from 0% to 1.25%. The total dry mixture mass was calculated based on the maximum dry density of the termite soil. Water content was determined based on the optimum moisture content of the soil, water absorption of the sisal fiber, and the water-cement ratio, with additional 5% water added for workability.

Table 3.4:-Mix Design

Mix No.	Cement (%)	Fiber (%)	Soil(kg)	Fiber(kg)	Cement(kg)	Water(kg)
Mix1	0	0	28.044	0	0	8.414
Mix2		0.25	27.974	0.071	0	8.533
Mix3		0.5	27.904	0.141	0	8.65
Mix4		0.75	27.834	0.211	0	8.767
Mix5		1	27.764	0.281	0	8.885
Mix6		1.25	27.694	0.351	0	9.002
Mix7	5	0	26.642	0	1.403	7.997
Mix8		0.25	26.572	0.071	1.403	8.116
Mix9		0.5	26.502	0.141	1.403	8.234
Mix10		0.75	26.432	0.211	1.403	8.351
Mix11		1	26.362	0.281	1.403	8.468
Mix12		1.25	26.292	0.351	1.403	8.585
Mix13	10	0	25.24	0	2.805	7.581
Mix14		0.25	25.17	0.071	2.805	7.7
Mix15		0.5	25.1	0.141	2.805	7.817
Mix16		0.75	25.03	0.211	2.805	7.935
Mix17		1	24.96	0.281	2.805	8.052
Mix18		1.25	24.89	0.351	2.805	8.169
Mix19	15	0	23.838	0	4.207	7.165
Mix20		0.25	23.768	0.071	4.207	7.284
Mix21		0.5	23.698	0.141	4.207	7.401
Mix22		0.75	23.628	0.211	4.207	7.518
Mix23		1	23.557	0.281	4.207	7.635
Mix24		1.25	23.487	0.351	4.207	7.752
Total			618.382	4.22	46.283	186.259

3.8. Specimen Preparation

The preparation of samples was a critical stage in the experiment, and close attention was paid to the termite soil, sisal fiber, cement mix, moisture content, compression, curing, and sizing. The testing regimes demanded high levels of accuracy, consistency, and reliability. Dry soils were manually sifted to remove pieces and then mixed with cement and fibers. Water was added to achieve the desired consistency, with additional water added for fiber absorption, workability, and cement paste. The samples were produced in various configurations, including plain and reinforced TMSBs, using a manual compaction machine with mold dimensions of 10cm x 15cm x 25cm. After proper mixing, the wet mixture was cast in the compacting machine and cured for 28 days. Careful handling was required during removal of the mold and placement of the samples, followed by wet cloth curing for the prescribed period.

Table 3.3:-Test Specimens for Compressive Strength and Water Absorption Test for a Given TMS Sample

Mix No.	Cement (%)	Fiber (%)	No. Specimens	Mix No.	Cement (%)	Fiber (%)	No. Specimens
Mix1	0	0	4	Mix13	10	0	4
Mix2		0.25	4	Mix14		0.25	4
Mix3		0.5	4	Mix15		0.5	4
Mix4		0.75	4	Mix16		0.75	4
Mix5		1	4	Mix17		1	4
Mix6		1.25	4	Mix18		1.25	4
Mix7	5	0	4	Mix19	15	0	4
Mix8		0.25	4	Mix20		0.25	4
Mix9		0.5	4	Mix21		0.5	4
Mix10		0.75	4	Mix22		0.75	4
Mix11		1	4	Mix23		1	4
Mix12		1.25	4	Mix24		1.25	4
Total			48	Total			48
				Whole total			96

3.9. Curing Process

To achieve maximum strength, TMS blocks need a period of damp curing, where they are kept moist. What is important is that the moisture of the termite soil mix is retained within the body of the block for a few days. If the block is left exposed to hot dry weather conditions, the surface material will lose its moisture and the clay particles tend to shrink Ahmed, (2015). This will cause surface cracks on the block faces. To get good quality block continuous supervision is required.

The normal block, sisal stabilized blocks, 5%, 10% and 15% cement stabilized TMS blocks were sprayed lightly with water daily at morning and afternoon starting from next day of casting for a minimum of seven days to allow for complete hydration of cement before being tested in the laboratory and then the blocks were tested 28 days after production slam.

3.10. Tests on Blocks

To investigate the effects of reinforcement, stabilization, and molding pressure on the strength and performance of blocks, various tests and experiments were conducted. These included dry compressive strength tests, water absorption tests, workability tests, and shrinkage checking tests. While these tests are now standard performance tests for stabilized soils, they were originally developed for concrete blocks and fired bricks.

3.10.1. Compressive strength test

Masonry blocks are often tested for compressive strength, as it is a widely accepted way of measuring material quality and predicting durability. This type of testing involves measuring the force required to crush a block and is relatively easy to conduct in a laboratory setting. The ASTM C67 standard test is often used, and after 28 days of curing time, the block is placed under a static load and the maximum compressive stress is recorded. 96 TMS blocks were tested using this method, with four blocks tested for each of the 24 mix designs. Other factors such as mortar strength, bonding pattern, and water absorption can also influence the quality of masonry units.

The relative ease of undertaking laboratory compressive strength testing has also contributed to its universality as an expression of material quality Jean- Claude Morel, (2007). The compression test is carried out on specimens rectangular in shape of the size 10cm*15cm*25cm by using compressive testing machine figure 3.9. After 28 days the specimens are tested under static load in a compression testing machine. The loads at the block failed were recorded and maximum compressive stresses were calculated.



Figure 3.9 Compressive Strength Test Sample Picture

3.10.2. Water Absorption Test

The water absorption test is basic in nature and useful in assessing the durability of block. The test will be determined following the procedure in ASTM C67 standard test. After 28 days of casting, TMS blocks were weighted this was dry weight this sample was immersed into the water tank for period of 24 hours. Then after 24 hours of immersing this sample were put out from the tank and wiped with dry cloth then reweighted and the water absorption capacities of the block were determined.



Figure 3.10 Water Absorption Test Sample Picture.

3.10.3. Shrinkage Checking Test

First, a moist sample of termite soil block was measured, and also measuring dry sample of termite soil block. Then the difference between the original block sample and dry block sample, is shrinkage limit. Shrinkage due to drying is significant in clays, but less so silt and sands. If the drying process is prolonged after the plastic limit has been reached, the soil will continue to decrease in volume, which is also relevant to converse condition of expansion due to wetting. But due to the presence of cement and fiber shrinkage will reduce.

3.10.4. Erosion Test

In this test, a jet of water is directed at the surface of the soil block at a specified angle and pressure for a specific time duration. The amount of material eroded from the surface of the soil block is measured by weighing the block before and after the test.

3.11. Data Analysis

The data were collected from laboratory result and analyzed based on a descriptive and quantitative approach. During the experiment, one group exposed to the usual condition the control and the others are the experimental group .the processes involved examining the truth of the statically hypothesis relating to the stated research problem using a comparative experiment. The experiment was conducted before and after the introduction of treatment. The design can be represented graphical description and MS excel program technic were used for data collection and analysis of recorded data; it helped to consider systematically illustrating recording information and manipulating it easily.

3.12. Summary

This chapter focuses on the materials and procedures followed in carrying out experimental research. The procedures used were developed with the intent of ensuring the validity and reliability of the study results. A comprehensive explanation of the research materials is provided in the chapter's preface. These included a variety of equipment, tools, and materials needed for collecting and analyzing data. Along with the steps taken to assure data accuracy and quality, the sources of the data were clearly described. The results will be thoroughly presented and discussed in the subsequent chapter

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Introduction

In this section, tests were carried out to determine the physical properties (such as dry density, water absorption, and Shrinkage. checking) and mechanical properties (such as compressive strength) of termite soil blocks that contain sisal fiber and cement. The study also involved comparing the cost of using these modified blocks to conventional HCB wall making materials. Furthermore, the degree to which sisal fiber and cement can effectively determine the property of soil blocks, and the results of these tests were presented, analyzed, and discussed in detail.

4.2 Soil Test Result

4.2.1 Particle Size Analysis of Soil Particles

The study tested the particle size of three soil samples, and the results were presented in Figure 4.1. In this method, a sample of dry soil is passed through a series of sieves of different sizes, with the largest sieve at the top and the smallest at the bottom. The amount of soil left in each sieve is weighed, and the percentage of soil in each size range is calculated. Further details on the soil samples can be found in Appendix A2. The analysis indicated that a significant proportion of the soil in the sample was retained on the smaller sieves (0.075 mm and below), which suggests that it consists mostly of fine particles such as clay. The highest percentage of the soil retained (42.024%) was on the 0.15 mm sieve, while only a small percentage (3.703%) passed through it. For soil particles greater than or equal to 0.075 mm in size, 100% retention was recorded, with no soil particles passing through. These results suggest that these particular soil samples have a high content of fine particles and could potentially be suitable for stabilization purpose.

The chart illustrates the results of a soil gradation test conducted on three different soil samples: soil 1, soil 2, and soil 3. The test measures the percentage of soil particles within different size ranges that are able to pass through a series of sieves. Based on the results, it was observed that soil 1 had a higher amount of fine particles (clay and silt) than the other two soils, which led to a higher percentage of passing through the sieves. As a result of this, soil 1 was selected for the study on its suitability for use as a block construction material with stabilizers.

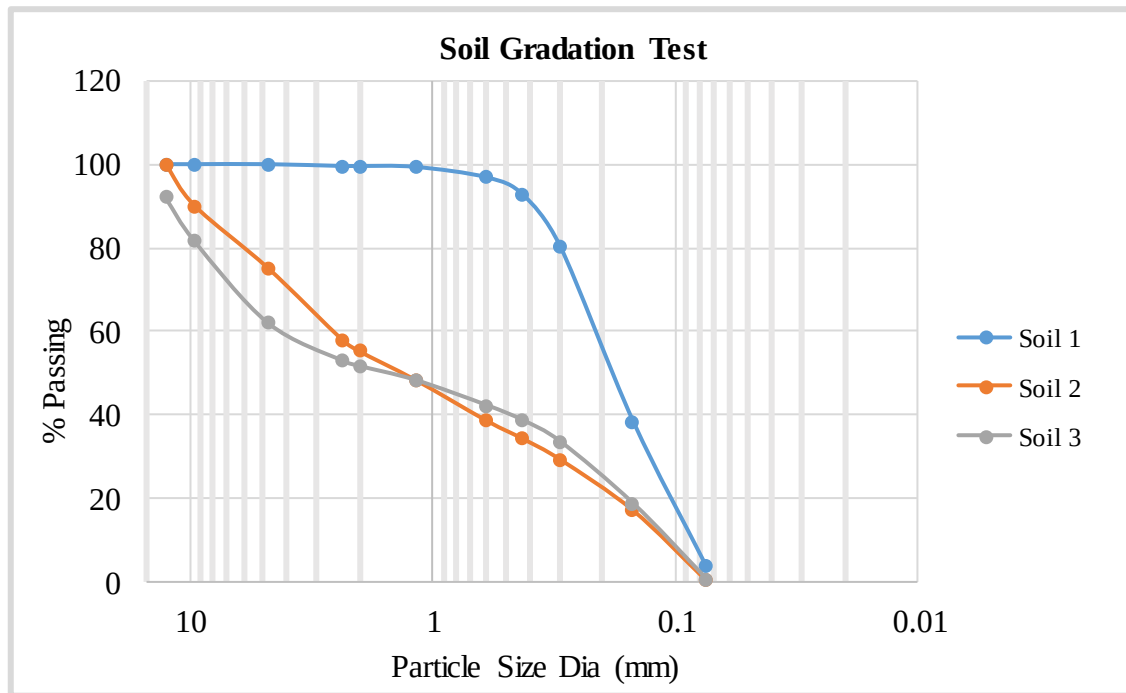


Figure 4.1:-Soil Gradation Test Result

4.2.2 Consistency Limits

The consistency limits of a soil can be determined using the Atterberg Limits test. This test measures the water content of a soil at different stages of plasticity to determine its consistency limits, which are defined as the moisture content at which the soil changes from one state of consistency to another. The tables and more information was attached on Appendix A4.1 and A4.2. Plastic limit table provides information on the plastic limit of three soil samples (Soil1, Soil2, Soil3) using the Atterberg Limits test.

For Soil1, the plastic limit is 22.653%, which means that the soil's water content must reach 22.653% before it changes from a plastic state to a semisolid state. For Soil2, the plastic limit is 32.825%, which is higher than that of Soil1, indicating that it requires more water to reach its plastic limit. For Soil3, the plastic limit is 24.88%, which falls between the plastic limits of Soil1 and Soil2.

Also Liquid limit of Soil 1 has an average liquid limit of 64.51%, which means that it requires a relatively high amount of water to change from a plastic state to a liquid state to reduce this amount replacement of cement would be recommended. Soil 2 has a lower liquid limit with an average value of 45.71%, indicating that it requires less water to reach a liquid state than Soil 1. Soil 3 has an even lower liquid limit with an average value of 43.86%, which is somewhat close to Soil 2 but still lower and it has been illustrated in figure 4.2. From these two variables the plasticity index was found, which is a useful

metric for selecting a suitable type of soil. The test result obtained from the plasticity index test has been compiled and organized into a clear table format, which can be found as Table 4.1. the result showed that soil 1 has high plastic index than the other two sample soil.

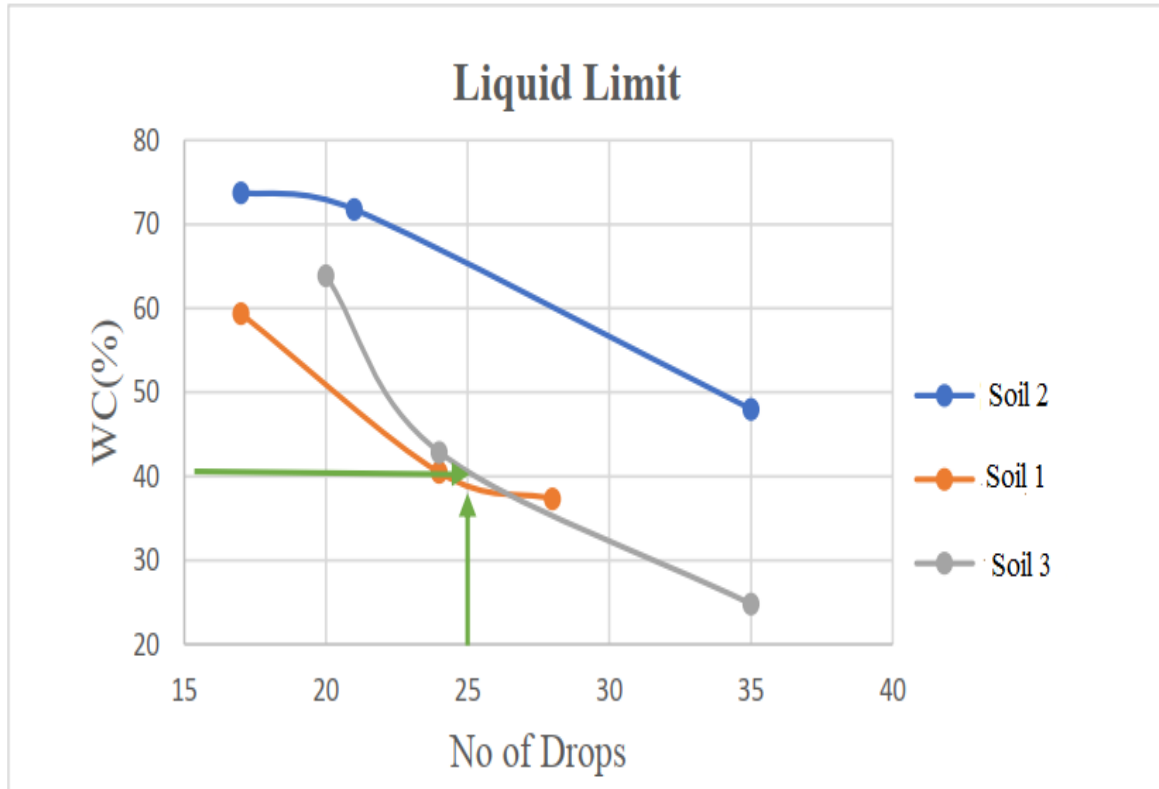


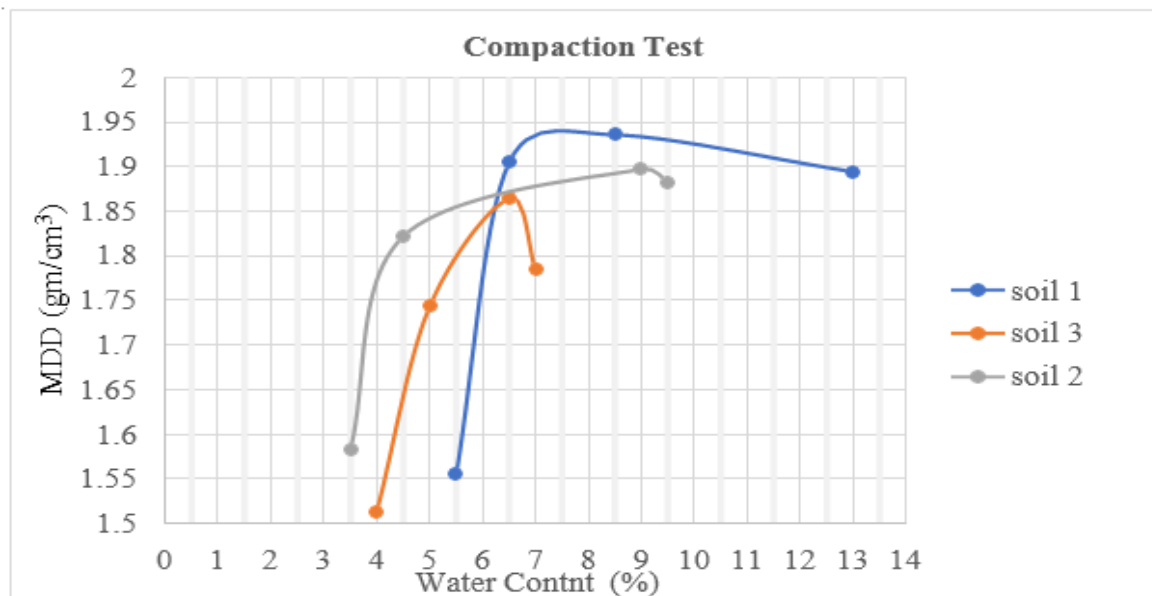
Figure 4.2:- Liquid Limit Test Result

4.2.3 Compaction Characteristics of Soil

One of the most commonly used tests to determine soil compaction is the standard proctor test. In this test, a soil specimen is compacted inside a mold that has a diameter of either 4 or 6 inches (101.6 or 152.5mm). This was done by dropping a hammer weighing 24.4 N from a height of 305 mm, which results in a compaction effort of 600 KN-m/m³. The mold used has a volume of 944 cm³ and a weight of 4795gm. The standard proctor test result has been illustrated in Appendix A3. It presents the results of compaction tests performed on three different soil samples. The data in the table can be used to compare the compaction characteristics of different soil samples and determine their suitability for the study. For sample Soil 1 has higher maximum dry density values which is illustrated in table 4.1 compared to Soil 2 and Soil 3, making it a potentially better candidate for the study.

Table 4.1:-Physical Property of Soil

Soil Type	Proctor Test		Atterberg limits		
	Maximum Dry Density (MDD)	Optimum Moisture Content (OMC)	Liquid Limit Wl(%)	Plastic Limit Wp (%)	Plastic Index Ip
Soil1	1.935	24.5	45.7	32.83	12.87
Soil2	1.897	25	64.5	22.65	41.85
Soil3	1.864	25	43.89	24.88	19.01

**Figure 4.3:-Standard Proctor Test Result**

According to USCS the result indicates that soil1 has low plastic limit, due to that plastic index become less than the other two soil. A soil with a low plasticity index (PI) is generally preferred for earth-based construction applications that require good shrinkage resistance. This is because soils with a lower PI generally exhibit less volume change in response to changes in moisture content. Soils with a high PI, on the other hand, tend to exhibit greater volume changes due to changes in moisture content, which can lead to cracking and other issues that negatively impact the durability and longevity of the structure and the compaction test result shows soil1 which is termite mound soil can give higher dry density than the other two soil samples which is 1.935gm/cm³. When comparing three soil samples, it was found that soil 1 has a high level of fines, a favorable

plastic index, and maximum dry density. Therefore soil 1 have been used throughout the study.

4.2.4 Specific Gravity of Soil Particles

According to ASTM D854- 92 Specific gravity of soil is the ratio of the weight in air of a given volume of material at stated temperature to the weight in air of an equal volume of distilled water at the stated temperature. The table data was illustrated in Appendix A1, which it presents the results of specific gravity tests conducted on three different soil samples. Specific gravity is an important indicator of soil properties and can be used to determine soil composition, pore size distribution, and other factors that affect soil behavior. The specific gravity of the soil 1 was found to be 2.69 in this work.

4.2.4 Comparison of Soil Characterization with Standards

Table 4.2 show comparison of soil properties with standards.

Table 4.2: Comparison of soil characterization with Standards

No	Soil Properties Types	Study Test Result	Standards Used	ASTM Recommendations	Decided Results
1	Particle Sieve size of soil	fine soil at sieve size 0.075mm retain	ASTM D422	soil with high percentage of pass at sieve size 4.75mm-0.075mm	Soil 1
2	Liquid Limit(LL)	45.70%	ASTM D4316	Less than 50%	Soil 1
3	Plastic Limit(PL)	32.835	ASTM D4316	Less than 35%	Soil 1
4	Plastic Index(PI)	12.875	ASTM D4316	Difference of LL & PL with low PI	Soil 1
5	Maximum Dry Density(MDD)	1.935gm/cm ³	ASTM D698	Soil with high dry density	Soil 1
6	Optimum Moisture Contents(OMC)	25%	ASTM D698/D2216	2% to 50%	Soil 1
7	Specific Gravity(Gs)	2.69	ASTM D854-92	Greater than 2	Soil 1

4.3 Fiber Test Result

Sisal fibers have a unique combination of properties that make them well-suited for soil stabilization applications, particularly when mixed with cement in specific ratios for

optimal strength. Sisal fiber has a high tensile strength compared to other natural fibers, which makes it suitable for reinforcement purposes. Length of the fiber affects how it interacts with the soil matrix and how well it can reinforce the block. Sisal fibers are hydrophilic, meaning they absorb moisture readily. This property can affect the durability of the fiber and its ability to resist biodegradation. Sisal fibers have a specific gravity of around 1.45, which is higher than many other natural fibers and can improve their ability to reinforce the soil block.

ASTM D7865-13(2017) Standard Test Method for Determination of Density, Specific Gravity and Apparent Porosity of Bulk Materials. The exact values may depend on the specific standards or guidelines being followed, as well as the specific type and quality of the fiber being tested. However, some typical values for these properties in sisal fibers are illustrated in table 4.3.

Table 4.3: Physical Property of Sisal Fiber for ASTM D7865-13(2017) and FAO

Properties	ASTM D7865-13(2017)	FAO
Specific Gravity	1.35 - 1.45	1.125 – 1.469
Density (g/cm³)	1.25 - 1.45	1 – 1.27
Water Absorption (%)	not exceed 17	19.5

According to the guide FAO, natural fibers can be effective as secondary reinforcers in soils with cohesive properties, provided that the fibers are properly mixed and dispersed in the soil matrix. The fiber length and content should be chosen based on the desired level of reinforcement, and can range from 0.5% to 2% by weight for most applications. The guide also recommends that the fiber content be adjusted to compensate for variations in soil type, texture, and moisture content. The study result has been show that the physical properties of sisal fibers were under the limit of both ASTM D7865-13(2017) and FAO. The numerical value of the physical properties of fiber was illustrate in table 4.4. Due to its requirement for physical properties, sisal fiber was selected as good stabilizer materials for the study

Table 4.4: Comparison of Physical Property of Sisal Fiber Results with Standards.

Sisal Fiber Property	Study Result	ASTM D7865-13(2017)	Remarks to Study
Specific Gravity	1.43	1.35 - 1.45	Between range
Density (g/cm ³)	1.4365	1.25 - 1.45	Between range
Water Absorption (%)	15	not exceed 17	Below range

4.4. Block Test Result

4.4.1. Compressive Strength Test Result

Compressive strength test result for various mixes is presented in Table 4-5 and Figure 4.4. The graphs indicate that an increase in the amount of cement and fiber used in stabilization leads to an increase in compressive strength only up to a certain optimal value, beyond which it starts to decrease. This decrease is irrespective of the type of soil used in production and the increase in compressive strength is attributed to the formation of a cement gel between the soil particles, which binds them together and creates a strong bond. Also the test results for termite soil with sisal fiber and cement exhibited that the stabilized materials improved the compressive strength compared to a control block that was not stabilized. As the percentage of sisal fiber increases up to 1%, there is also an increase in compressive strength. The combination of termite soil with 10% cement and 1% sisal fiber showed the maximum compressive strength of 10.326 Mpa.

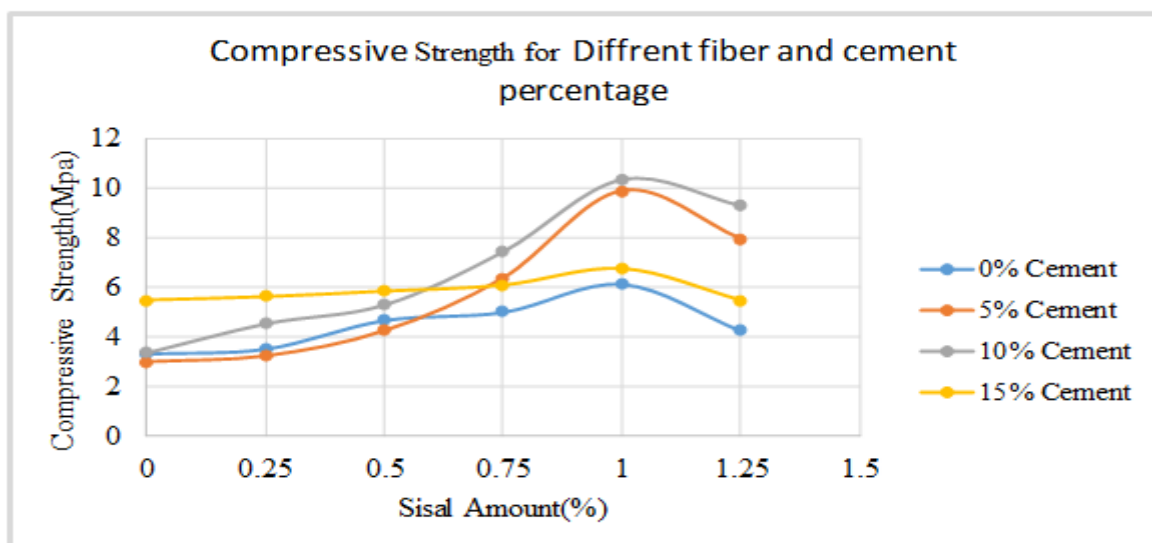


Figure 4.4:- Compressive Strength Test Result

Table 4.5:-Average Density, Weight and Compressive Strength Test Result

Mix Type	Dry Block Weight (gm)	Density (gm/cm3)	Compressive Strength(MPa)
1	5712.575	1.586	3.33
2	5622.5	1.563	3.525
3	5521.8825	1.534	4.68
4	5416.625	1.519	5.01
5	5299.75	1.473	6.14
6	5129.625	1.425	4.2525
7	5872.175	1.632	2.9925
8	5777.75	1.605	3.2275
9	5754.625	1.599	4.245
10	5547	1.541	6.3675
11	5456.3	1.516	9.875
12	5248.375	1.458	7.9275
13	5935.25	1.649	3.365
14	5897.05	1.639	4.54
15	5867.6	1.63	5.295
16	5638.7	1.567	7.4375
17	5486.75	1.552	10.32525
18	5482.75	1.523	9.2725
19	6351	1.765	5.4775
20	6254.925	1.738	5.6175
21	6082.525	1.69	5.8475
22	5971.575	1.659	6.0925
23	5806.65	1.613	6.78
24	5775.69	1.605	5.47

4.4.1.1. Effect of Sisal Fiber on the Compressive Strength of TMS Blocks

The Compressive test results of termite soil blocks with randomly distributed natural Sisal fibers yield higher compressive strength results compared to the unreinforced blocks, as

shown in Figure 4.5 below. At 1% sisal fiber content, the compressive strength is higher by 44.096% as compared to row termite soil block. The increase in strength could be linked to increase fraction between fiber and soil matrix.

Furthermore, the association of fibers and the soil matrix prevents the speed of crack in the blocks, as fiber forms Bridge across cracks and therefore contribute to the improved strength. Where the compressive strength reduced 1.25% of sisal fiber by 19.283% compared to the row termite soil block. This trend is consistent with previous studies of (Akbulut et al., 2007; Bouhicha et al., 2005; Ismail & Yaacob, 2011; Millogo et al., 2014) which used other fibers in soil blocks, where an optimum strength has been followed by a subsequent decline at the higher fiber inclusion. After critical point ,the increase fiber content caused strength reduction when fiber begin to knot and overlap each other(Ismail & Yaacob, 2011) resulting the reduced cohesion with the soil and break-up of the soil matrix(Millogo et al., 2014) causing the soil fiber composite to weaken.

The use of sisal fiber in soil blocks has been found to improve their mechanical performance and durability. Sisal fibers are known for their high tensile strength, which can help to reinforce the block and prevent cracking. The addition of sisal fibers to soil blocks can also improve their resistance to water erosion and increase their thermal insulation properties. Sisal fibers are a promising material for soil stabilization purposes, and can be used to improve the mechanical properties of soil-based construction materials. Therefore adding 1% sisal fiber shows the maximum percentages of increase in compressive strength compared to other percentage of sisal fiber.

4.4.1.2. Effects of Cement Amount on the Compressive Strength of TMS Blocks

Cement can improve the compressive strength of TMS in building construction applications. According to (Karim et al., 2014), adding up to 8% of cement can increase the compressive strength by up to 50%. However, adding too much cement can make the soil more brittle and less durable. The results from this study As shown in the figure 4.5 the compressive strength of termite block is higher by 1.04% and 39.2% for cement amount 10% and 15% respectively as compared from the row termite soil block but the compressive strength is lower by 10.21% at 5% of cement as compared to un stabilized block because of the soil cement mixture are fire to compact each other.

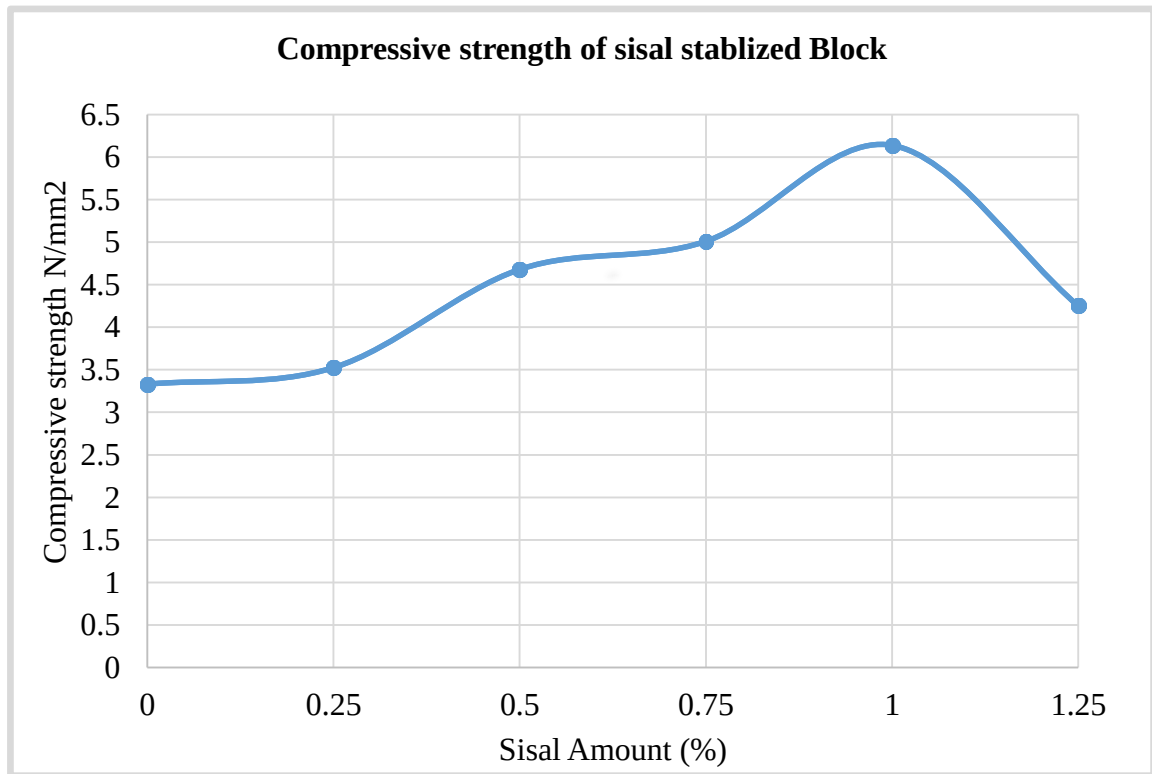


Figure 4.5:- Effect of Sisal Fiber on the Compressive Strength

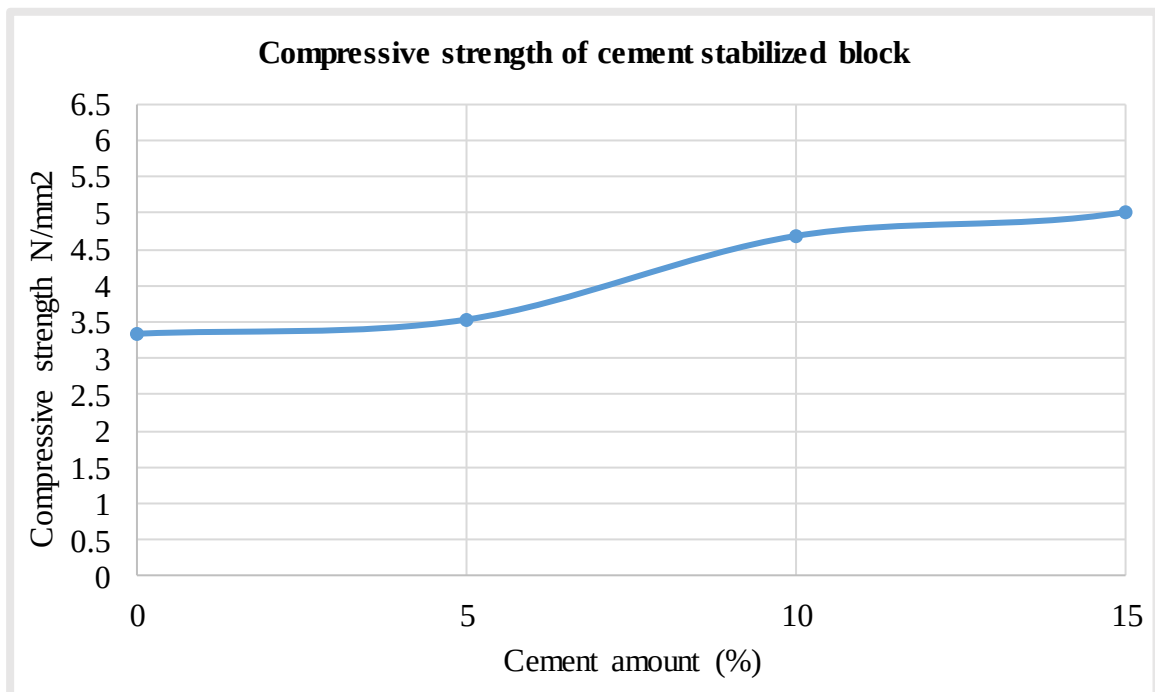


Figure 4.6:- Effects of cement amount on the compressive strength of TMS block

4.4.1.3. Comparison of Sisal - Cement Stabilized TMSBs on Compressive Strength

Table 4.6 presents a comparison of sisal reinforced blocks, cement stabilized blocks, and cement-sisal reinforced blocks.

Table 4.6:- Percentage Difference for Each Mix Design.

Mix Type	Compressive Strength	% Increase	Mix Type	Compressive Strength	% Increase
Mix1	3.33		Mix13	3.365	1.052
Mix2	3.525	5.856	Mix14	4.54	36.337
Mix3	4.68	40.541	Mix15	5.295	59.01
Mix4	5.01	50.451	Mix16	7.4375	123.349
Mix5	6.14	84.385	Mix17	10.32525	210.068
Mix6	4.2525	27.703	Mix18	9.2725	178.454
Mix7	2.9925	-10.136	Mix19	5.4775	64.49
Mix8	3.2275	-3.079	Mix20	5.6175	68.694
Mix9	4.245	27.478	Mix21	5.8475	75.601
Mix10	6.3675	91.217	Mix22	6.0925	82.958
Mix11	9.875	196.547	Mix23	6.78	103.604
Mix12	7.9275	138.064	Mix24	6.88	101.32

Results from the tests indicate that the optimal sisal reinforced block had 1% sisal content and showed an 84.385% increase in compressive strength compared to an unstabilized termite soil block (mix1). Conversely, the compressive strength of cement stabilized blocks (mix7) declined by 10.136% with 5% cement content but increased by 64.49% with 15% cement content (mix19).

When sisal and cement were combined, the highest compressive strength was achieved with 1% sisal content and 10% cement content, which corresponds to mix 17 (210.068% increment), surpassing the control mix (mix1).

4.4.2. Water Absorption Test Result for TMS Blocks

Water absorption test is a test conducted over 24 hours to determine the quantity of water absorbed by a block. The water absorption measures the unit's total capacity to absorb moisture. Tests were conducted on plain-termite soil blocks, sisal stabilized termite soil blocks, and 5% cement and fiber stabilized termite soil blocks. However, the water absorption was found to be very high for fiber amounts of 0.25%, 0.5%, and 0.75%, and the tests were not performed. For 5% cement stabilized blocks with 1% and 1.25% sisal

fiber amounts, the tests were performed but a part of the sample failed. However, the 10% cement with 1.25% sisal stabilized block showed higher water absorption with an average of 14.687%. The test results showed that increasing sisal fibers with a given amount of cement will increase water absorption compared to plain blocks.

The high water absorption of fiber-reinforced blocks may be due to the water absorbed by sisal fibers. This results is consistent the result of (Ismael & Jacob, 2011) which also recorded increase in water absorption of laterite blocks with increase in sisal fiber content. The increase may be attributed to the amount of water absorbed by the cellulose of the fibers, which is due to the void volume and the amount of cellulose materials present in block (Jeefferie et al., 2011). The absorbent nature of fiber creates pathway through soil blocks, thereby allowing more water to be absorbed by blocks (Danso, Martinson, Ali, & Mant, 2015; Ghavami et al., 1999). However, the presence of cement reduces the water absorption capacity. The data obtained shows that all processed TMSBs had a water absorption capacity in the range of 0%-15%. However, blocks made with 10% and 15% cement with different fiber percentages met the minimum requirements for use in building construction within this range.

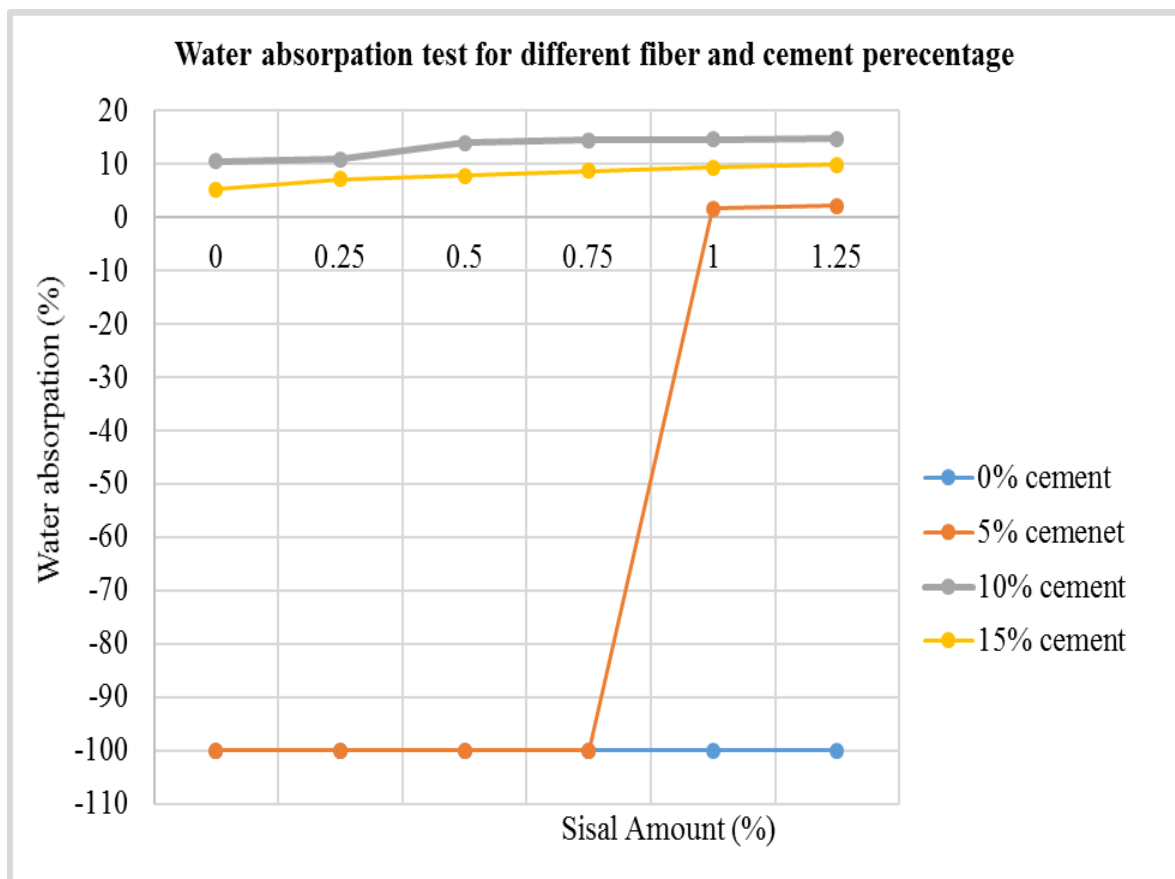


Figure 4.7:-Water Absorption Test

Table 4.6:-Density, Weight and Water Absorption Test Result

Mix Type	Dry Block Weight(gm)	Immersed Block Weight(gm)	Water Absorption (%)
1	5554.625	0	-100
2	5473	0	-100
3	5352.875	0	-100
4	5201.875	0	-100
5	5079.825	0	-100
6	4969.5	0	-100
7	5702.75	0	-100
8	5616.125	0	-100
9	5475.5	0	-100
10	5460.125	0	-100
11	5301.5	5389.25	1.656
12	5198.75	5312.25	2.184
13	5739.1	6338.75	10.449
14	5619.625	6234.5	10.942
15	5664.125	6455.625	13.974
16	5619.625	6434.125	14.494
17	5483.875	6285.875	14.625
18	5482.75	6288	14.687
19	6214.25	6539.25	5.23
20	6140.0025	6580.625	7.177
21	6063	6535.875	7.8
22	6048.5	6572.75	8.668
23	6035.875	6601.125	9.365
24	6060.5	6659.75	9.888

4.4.2.1. Effects of Cement on Water Absorption of Blocks

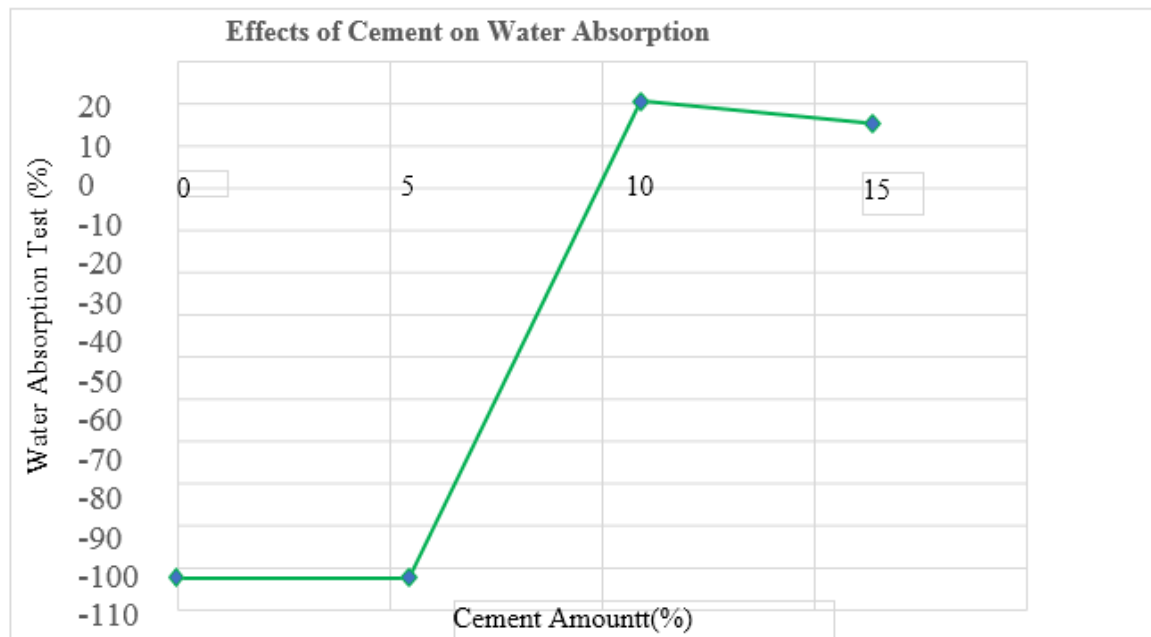


Figure 4.8:- Effects of Cement on Water Absorption

The effect of cement on Water absorption of the blocks shows that the presence of cement reduces the water absorption capacity of TMSBs compared to the unreinforced blocks, as shown in Figure 4.5. The negative values shows that the block is failed to perform the test which means that the water absorption is infinite. As cement increase from 5% to 10% and 10% to 15% of cement the water absorption effect is reduced by 10% and 49.8% respectively.

4.4.2.2. Effects of Sisal Fiber on Water Absorption of Blocks

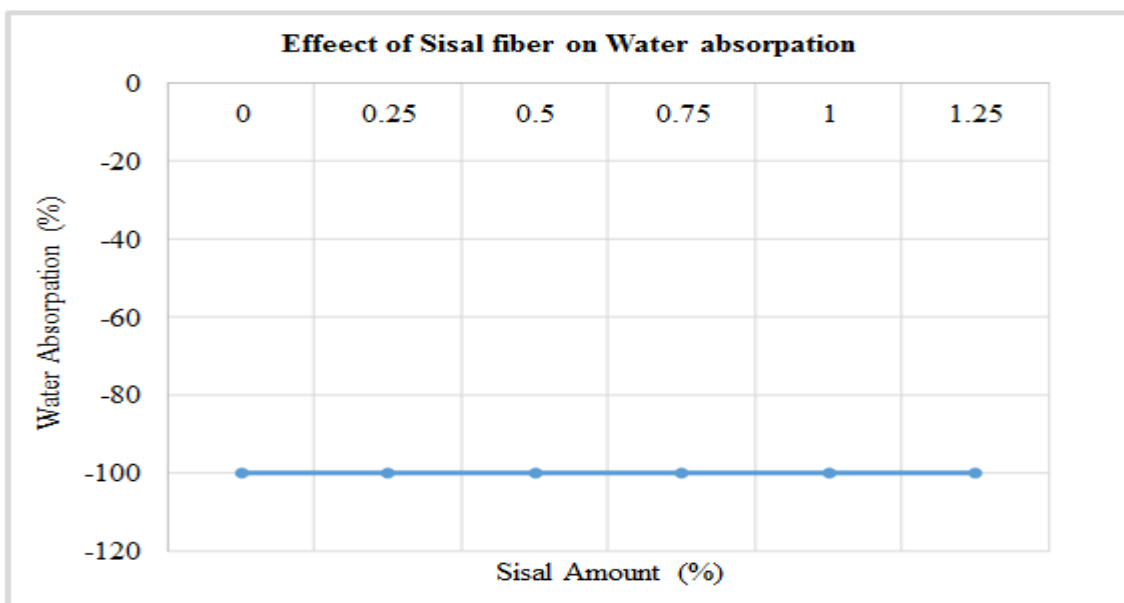


Figure 4.9:- Effects of Fiber on Water Absorption

As we see from the figure 4.9 the water absorption of sisal fiber stabilized termite soil blocks is very high which is infinite and the blocks failed to perform the test. The presence of fiber without cement has no effect for water absorption.

4.4.3. Dry density test result for TMS Blocks

The dimensions and mass of the dried blocks, after 28 days of curing, were recorded before subjecting the blocks for compression test. The recorded data was used to calculate the actual dry density of the blocks to verify if the blocks had the maximum dry density which was supposed to be achieved. The density data of blocks are represented in table 4.4 and illustrated in figure 4.5. It was found that there was decrease in dry density with increase in fiber content. The reduction in the density was observed due to the low density of the fibers, and with increase in the low density fiber percentage usage in the blocks contributed to the reduction in the density of these blocks. There reduction in density was between 7-9.67% for the selected soil. The trends were seen in previous study (Chee, 2011; Demir, 2006) of reinforced soil blocks with other natural fibers, the drop density was expected as fibers have low density 810-500kg/m³ compared to compressed soil density of about 1780kg/m³, and therefore increase fiber contents displaced soil content, which is heavier, so decreased density of blocks.

The dry density encountered by the blocks with increase in fiber content was close to the maximum dry density that the soil could achieve at that particular fiber content except for 1.25% fibers in the blocks which showed lower density than the maximum dry density determined from the proctor test. This was due to the relaxation of the blocks in vertical direction due to high content of the fibers which was absorbing moisture during the curing was carried out which leads to increase in swell pressure of the fiber causing the blocks to relax. The reduced mass of the blocks due to usage of 1.25% of fibers and increased dimension of the blocks contributed to the reduction in the density. It can also be noticed that 5% cement blocks with 1.25% fibers with all the three soils had lower density than the 10% and 15% cement. Low cement content was not sufficient to hold the soil against the swell character of the fiber which was resulting in expansion of the blocks. However, 10% and 15% cement contributed towards a better binding property thus reducing the impact of the fibers on the density of the blocks which helped in achieving a density closer to maximum dry density. This result explains why same dry density was not achieved for the soil blocks at all the fiber content.

The cement content also had effected the dry density of the blocks. From the above plots the density of the blocks with different cement was compared and was found that blocks

with 5% cement had lower dry density than the one with 10% and 15% cement. Variation in the density of the blocks was noticed between 5% and 10% cement content usage. The cement used for stabilization have proved to increase the density with increase in the usage percent in various studies carried out. The hydration process of cement, leading to formation of silicate binding gel contribute to the density of the blocks.

Fiber usage of more than 1% had an impact on the density of the blocks which brings about a drastic reduction in the density. The density effects the compressive strength, water absorption and porosity of the blocks. It is important to achieve better density close to the maximum dry density of the soil being used. Based on the test results it is recommended not to use more than 1% sisal fibers which will lead to the reduction in the dry density which in turn will have a major impact on the strength and long term life of the blocks.

4.4.4. Strength Comparison of TMS Blocks with Mud Blocks and HCB

The table 4.4 shows that various mix designs can meet the minimum compressive strength requirement for hollow concrete blocks. ESC D3 301 classifies hollow concrete blocks into three categories: Class A and B can be used for load-bearing purposes, such as external walls, cavity walls, stone masonry, internal walls, partitions and panels in steel and reinforced steel buildings. Class C is suitable for non-load-bearing purposes, such as walls and partitions, non-load-bearing internal panels in steel framed and reinforced concrete buildings.

Table 4.7:- The minimum compressive strength for HCB According to ESC D3 301, (n.d) is indicated below at age of 28 days

Class	Average of Six Units		Individual Units	
	MPa	Kg/cm ²	MPa	Kg/cm ²
A	4.2	4.2	3.8	3.8
B	3.5	3.5	3.2	3.2
C	2	2	1.8	1.8

Table 4.8:-TMS block class classification

Types of Mix	TMS Block Class Range
3,4,5,6,9,10,11,12,14-24	A
2	B
1,7,8&13	C

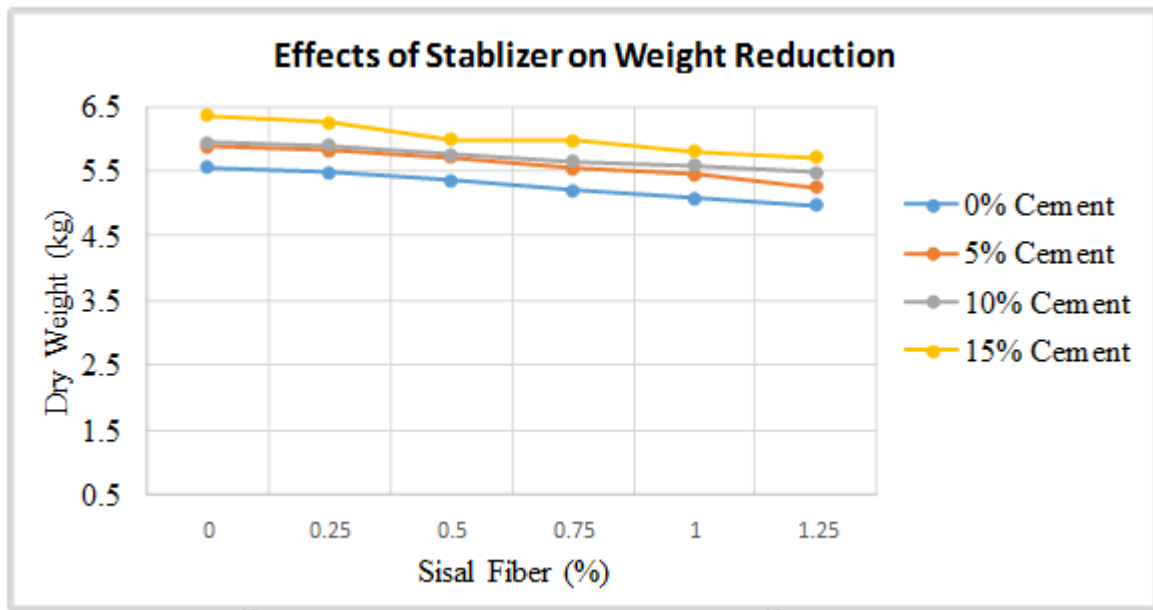
For the optimum mix design mix 17 the compressive strength is higher by 80.63% for control and 59.326%, 66.105% and 80.63% as compared to class A, class B and class C HCB respectively.

4.4.5. Effect of Stabilizers on the Weight Reduction for a TMS Blocks

From table 4.10 above the positive value shows percent of reduction in weight and the negative values shows percent of increment in weight compared from the control mix (mix1). The result shows that the maximum weight reduction of block observed were 10.138% for mix 6. And the maximum weight increment was mix 19 which is 11.259 %. For the optimum mix design which is mix 17 the amount of weight reduction observed were 2.15%. The result shows that increasing cement will increase the weight of the block and increasing fiber will decrease the weight of the block. For the combined effect the weight reduction is observed compared with its own mix design control of each mix design group (mix1, mix7, mix13 and mix19).

Table 4.9:-Effects of Stabilizer on Weight Reduction

Mix Type	Weight (gm.)	%Reduction	Mix Type	Weight (gm.)	%Reduction
Mix1	5708.325		Mix13	5935.25	-3.976
Mix2	5623.75	1.482	Mix14	5897.05	-3.307
Mix3	5520.875	3.284	Mix15	5758.7	-0.883
Mix4	5416.625	5.111	Mix16	5638.7	1.22
Mix5	5299.75	7.158	Mix17	5585.625	2.15
Mix6	5129.625	10.138	Mix18	5482.75	3.952
Mix7	5872.175	-2.871	Mix19	6351	-11.259
Mix8	5816.225	-1.891	Mix20	6254.925	-9.576
Mix9	5704.625	0.065	Mix21	6082.525	-6.556
Mix10	5547	2.827	Mix22	5971.575	-4.612
Mix11	5456.3	4.416	Mix23	5806.65	-1.723
Mix12	5248.375	8.058	Mix24	5774.75	-1.164



4.4.6. Weight Comparison of Termite Soil Block with Mud and HCB

Based on ASTM CEB/90 and EBCS1 (1995), Hollow Concrete Blocks (HCB) typically have a unit weight ranging from 14-20kg/m³ and an average of 16 for soil block and 17 kg/m³ for HCB were used for comparison in this study.

Table 4.10 shows that the maximum weight reduction observed was 19.3% for sisal-stabilized termite mound soil blocks with 1.25% sisal, 16.608% for TMS blocks stabilized with 0.5% cement and 1.25% sisal, 11.623% for TMS blocks stabilized with 10% and 1.25% sisal, and 9.567% for the optimal mix design.

Table 4.10:-Weight comparison of termite soil block with Mud Blocks and HCB

Mix Type	¥TMSBs (kg/m ³)	¥Mud (kg/m ³) ASTEM CEB/90	¥HCB (kg/m ³)	% Difference with HCB	% Difference Control
Mix1	1585.646	1600	1700	-7.212	-0.90
Mix2	1562.153	1600	1700	-8.825	-2.43
Mix3	1533.577	1600	1700	-10.852	-4.33
Mix4	1504.619	1600	1700	-12.986	-6.33
Mix5	1472.153	1600	1700	-15.478	-8.97
Mix6	1424.896	1600	1700	-19.307	-12.288
Mix7	1631.16	1600	1700	-4.221	1.910
Mix8	1615.619	1600	1700	-5.223	0.966

Mix9	1584.619	1600	1700	-7.282	-0.970
Mix10	1540.834	1600	1700	-10.33	-3.839
Mix11	1515.639	1600	1700	-12.164	-5.566
Mix12	1457.882	1600	1700	-16.608	-9.748
Mix13	1648.681	1600	1700	-3.113	2.952
Mix14	1638.07	1600	1700	-3.781	2.324
Mix15	1599.639	1600	1700	-6.274	-0.022
Mix16	1566.306	1600	1700	-8.536	-2.151
Mix17	1551.563	1600	1700	-9.567	-3.121
Mix18	1522.987	1600	1700	-11.623	-5.056
Mix19	1764.167	1600	1700	3.638	9.305
Mix20	1737.48	1600	1700	2.158	7.912
Mix21	1689.591	1600	1700	-0.617	5.302
Mix22	1658.771	1600	1700	-2.486	3.543
Mix23	1612.959	1600	1700	-5.397	0.803
Mix24	1604.098	1600	1700	-5.979	0.255

4.4.7. Linear Shrinkage Test Result

Shrinkage due to drying is significant in clays, but less so silt and sands. If the drying process is prolonged after the plastic limit has been reached, the soil will continue to decrease in volume, which is also relevant to converse condition of expansion due to wetting. But due to the presence of cement and fiber shrinkage will reduce.

The findings indicate that the block without stabilizer (Mix1) had the maximum shrinkage observed at 3.334%. However, Table 4.4 shows that shrinkage was eliminated for Mix5 which had a fiber amount of 1%, and for all other mix designs of both cement-stabilized and sisal-cement stabilized termite soil blocks the amount of shrinkage removed.

The results also indicates that the linear shrinkage of enhanced soil blocks decreased with increase fiber contents. (Bouhicha et al., 2005) observed a similar effect which enhanced the properties of soil block with barley strew. The addition of the fiber reduces the shrinkage and the fiber opposes the deformation of soil matrix through friction.

Another contributing factor is the plasticity binder, as soil 1 with plastic index of 12.87 had less shrinkage. (Walker, 1995) found that the soil with a plasticity index less than 20, will

have marginal linear shrinkage, compared to a plasticity index greater than 20, so this is consistent with the studied finding.

Table 4.11:-Linear Shrinkage Test Result

Mix type	Original Length (mm)	Final length (mm)	Linear Shrinkage (%)
Mix1	24	23.2	3.334
Mix2	24	23.5	2.084
Mix3	24	23.7	1.25
Mix4	24	23.8	0.834
Mix5-24	24	24	0

4.4.8. Erosions Test Result

Erosion testing can also be performed specifically on soil blocks to evaluate their erosion resistance. The procedure for the test can vary depending on the specific requirements of the project, further steps used to determine erosion resistance was attached on Appendix H. The result presented in figure 4.11 show the rapid reduction in erosion with increase fiber content up to 0.5 wt. %, this then levels off and increases slightly after 0.75 wt. % fiber content for the soil. There was 50-70% reduction for erosion of fiber reinforced soil blocks compared to the unreinforced block. The increase resistance of reinforced soil blocks can be explained by fiber ability to protect the soil particles from been washed away, thereby reducing the eroding effect on the blocks. The behavior of the fiber in the soil is similar to the roots protecting earth from erosion(Huat & Kazemian, 2010; Michalowski & Zhao, 1996). This test important, particularly for higher rainfall areas, where erosion of building is common. There is how ever a requirement to develop more climate appropriate benchmark as propose by(Bui et al., 2009).

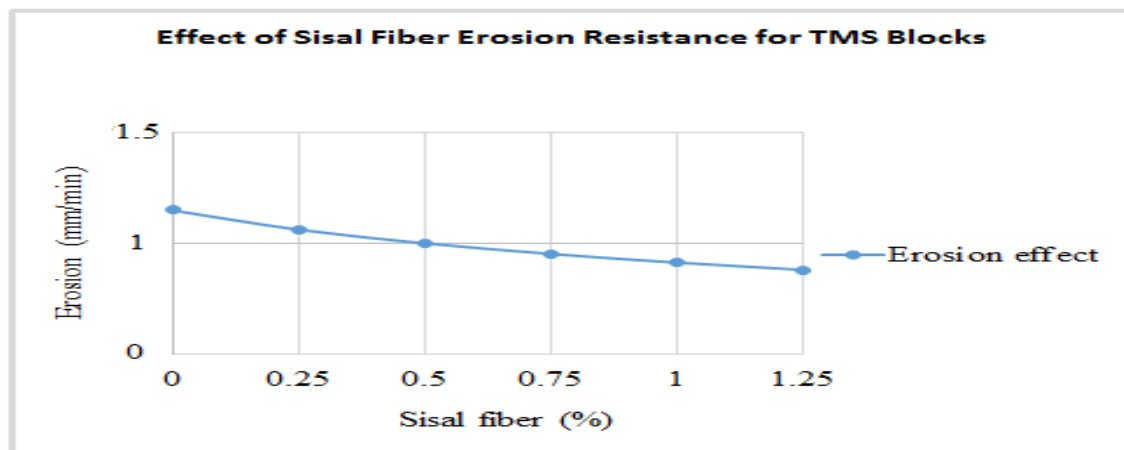


Figure 4.11 effect of sisal fiber on erosion resistance

4.4.9. Comparison of optimal Block Properties Test Result with Standards

Table 4.11 describe about comparing the optimal block test results. It showed that the optimal value of block test result had comparable value with ASTM CEB/90.

Table 4.12:-Comparison of Block Test Result with Standards

Block Property Tests	Mix Code		ASTM CEB/90 Standard	Remarks on Optimum
	Control (Mix 1)	Optimum Mix (Mix17)		
Compressive Strength (MPa)	3.33	10.33	Min 3.5 and Max 13.5	Between Range
Water Absorption (%)	-100	14.63	Not Exceed 15%	Satisfied standard
Density (gm/cm ³)	1.586	1.552	Not Exceed 1.6	Satisfied standard
Weight (gm)	5712.575	5486.75	Not specified	
Shrinkage (%)	3.33	0	Not Exceed 0.1%	Satisfied standard
Erosion (mm/min)	1.25	0.65	Not Specified	

4.8. Price Analysis

In this research work, the production cost of termite mound soil blocks are produced using manual compacting machine mold of size 10cm*15cm*25cm were used for production of this block. Prices of raw materials used for the production of the blocks are from the current price indexes of construction materials and the quantity of materials needed were calculated based on the optimum mix design of this research. The material cost of produced single termite soil block was calculated for the optimum mix design.

4.8.1. Daily Production

Daily production ranges from 90 to 100 blocks per person using a simple manual compacting machine. In this research work 95 blocks per day per person is taken as a daily production.

4.8.2. Details for Price Calculation

In this section the cost calculation details are provided. The costs include labor, which covers workers' salaries, water (representing approximately 30% of the mix), cement (with an optimal weight of 10% for cost calculations), fiber (with an optimal weight of 1% for cost calculations), and soil, which includes the costs related to excavation, loading, unloading, and transportation.

4.8.3. Unit cost calculation

After adding the costs together, the resulting total is then divided by the number of blocks produced, giving the unit cost. This allows for setting the price of the blocks at a reasonable level by adding a profit margin to the unit cost. As there can be fluctuations in the current market, the price of ingredients was informally collected in May 2023 through interviews with local suppliers.

Table 4.13: Unit Cost Calculation

Materials & Labor	Quantity (kg/mold)	Price (Birr/kg)	Birr/Block
Soil	6.24	0.0986	0.616
cement	0.624	14	8.74
fiber	0.0624	55	3.43
water	2.013	0.04	0.081
Labor and machine	–	3	3
Total Price of optimum			15.87
Total Price of Control			3.70

4.7.4. Price Comparison of FRCSTMSBs with Mud Blocks and Conventional HCB

Fiber Reinforced Cement Stabilized Termite Mound Soil Blocks are similar to traditional mud blocks but with the addition of natural fibers for reinforcement. The fibers, such as Sisal improve the tensile strength and crack resistance of the blocks. This reinforcement allows for better structural stability and durability. When comparing these blocks with control block there was increase in price up 73.32%. The observed data showed amount of price variation was very high, but have good strength than the control. Therefore using FRCSTMSBs too expensive but showed preferable strength. Hollow Concrete Blocks (HCB) are the most frequently used material for making walls, and their cost varies depending on the class and thickness of the block. The price of Stabilized Termite Soil (TMS) blocks was compared to that of HCB using base prices of materials from the local market in Adama city, and the results are shown below in table 4.13. The class of HCB affects its cost, while keeping other expenses such as labor, plastering, and finishing constant. A comparative analysis of the cost between Stabilized Termite Soil (TMS) blocks and HCB was conducted, with the results showing that for the optimal mix design mix17, the cost of TMS blocks is 13.87 birr. This implies a cost reduction of 47.11% and 36.52% for Class A, 36.52% and 31.00% for Class B, and 31.00% and 20.65% for Class C, for 20cm and 15cm thick HCB, respectively. According to cost calculations, using Mud

block is more economical than the other two blocks and also using TMS blocks is more economical than HCB and leads to a reduction in prices.

Table 4.14: Cost comparison of Control, Optimum and Conventional HCB; where the Price of HCB based on the Current Rate from Adama City Market in 05-21-2023 G.C

Blocks	Mud Block	FRCS TMSBs	20cm thick HCB			15cm thick HCB		
			Class A	Class B	Class C	Class A	Class B	Class C
Cost	3.70	15.87	30	25	23	25	23	20
Variation of Optimum (%)	-	-	47.11	36.52	31.00	36.52	31.00	20.65
Variation of Control (%)	-	73.32	87.66	85.20	83.91	85.20	83.91	81.50

The table 4.14 shows that the control block is the least expensive option, but it is also the least strong and durable. The stabilized block and hollow concrete block are more expensive, but they are also stronger and more durable. Therefore, it is important for users to consider their budget and their needs when choosing a block for their construction project.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The aim of this research was to create an alternative and sustainable construction material using termite mound soil (TMS) blocks while considering water absorption, strength, shrinkage and cost. Relevant tests were carried out on load capacity, shrinkage, erosion, density and water absorption capacity in line with applicable standards. Based on the research conducted, several conclusions were drawn:

- The study found that soil type is a crucial factor in compressive development, with soils high in clay performing better in most of the tests. For this reason, termite mound soil was chosen due to its fine texture and performance. However, sisal fiber is also a crucial element in the resistance to cracking and erosion.
- The study found that unstabilized TMS blocks and cement-stabilized blocks failed quickly without warning, while fiber-stabilized blocks deformed gradually under ultimate load. The stabilized TMS blocks demonstrated a compressive strength ranging from 2.9-10.325 MPa, which proved to be quite satisfactory compared to the minimum strength requirements of HCB set by ESC.
- Increased cement and sisal fiber content played a significant role in reducing weight and eliminating shrinkage.
- Adding sisal fibers to termite soil blocks can decrease the density and linear shrinkage of the blocks, resulting in lighter structures with reduced cracking. However, this can also increase water absorption, which may be an issue for dampness inside the building. This can be improved through cement stabilization mechanisms. The addition of cement had a positive effect on water absorption, while sisal fiber in TMS blocks had the opposite effect.
- TMS block is cost-effective as the cost comparison shows for the optimum mix design mix 17, 56.88% and 46.1% cost reduction from class A 15 cm thick block and class A 20 cm thick HCB respectively.

The study arrived at the finding that an optimal fiber content of 1% and cement content of 10% were needed to produce TMS blocks that satisfy both compressive strength and water absorption requirements. Therefore, it can be inferred that fiber-reinforced cement-stabilized TMS blocks and control can be utilized as an economical walling material in the

construction of low-cost housing in developing nations, particularly in Ethiopia where termite mound soil and sisal fibers are easily available and inexpensive. but for control block the ability to resist dampness and

5.2. Recommendations

Based on the research findings and discussions, the following recommendations are made:

- Termite soils can be stabilized with cement and fiber to make suitable wall materials.
- For exterior walls, 10% cement and 0.25%-1% sisal should be used for stabilized blocks that pass strength and water absorption tests.
- For interior walls, 5% stabilized blocks can be used.
- The study's findings suggest that Sisal fiber content exceeding 1% should be avoided, as it can impact the dry density of the blocks negatively. Since density is critical in block production and has a significant influence on the strength and durability of the blocks, high fiber usage could result in negative outcomes. Therefore, it is recommended to keep the fiber content at or below 1%.
- Entrepreneurs interested in TMS block production should invest in manual pressing machines and fiber chopping instruments to increase block production and achieve higher strength.

Future Works

Based on the TMS soil blocks used for wall construction, there are several aspects that could be explored in future studies.

- One suggestion would be to examine the overall Global behavior performance of TMS blocks, rather than only analyzing specific site.
- Future research could focus on investigating the mortar needed for connecting TMS block walling materials.
- Using plant resin instead of cement as a binding agent can be a significant step towards creating a cement-free environment. However, it is essential to focus on certain factors such as the melting temperature of the resin, its mix ability with soils, and its interaction with water. In addition, the use of resin can potentially lead to the development of molds in the constructions, so this factor must also be taken into account.

- Studies on the spreading the market for Termite mound soil blocks and building confidence in the construction industry will enable many manufacturers to invest in this technology which will further enhance the social acceptance.

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APPENDICES

APPENDIX A: TEST ON SOIL

A1. Determination of Specific Gravity of Soil

According to ASTM D854- 92 Specific gravity of soil is the ratio of the weight in air of a given volume of material at stated temperature to the weight in air of an equal volume of distilled water at the stated temperature.

The Following Data are The Results of The sieve Test

		Soil ₁		Soil ₂		Soil ₃	
Soil Specimen Number		20	2	8	15	14	17
Density Bottle Weight Empty (A)		61.88	54.8	61.15	58.98	51.52	55.74
Density Bottle +Soil (B)		86.9	79.8	86.19	83.99	76.52	80.76
Density Bottle+ Water (C)		160	173	159.8	174.1	166.3	173.3
Density Bottle +Soil +Water (D)		176.3	188	176.11	190.6	182.3	188.1
	GS	2.86	2.53	2.87	2.92	2.76	2.44
Gs Average		2.695		2.895		2.6	

$$G_s@T_X^{\circ}C = \frac{(C - A) * G_T}{(C - A) + (C - D)}$$

Where, G_T:-specific gravity of water =1

G_s@T_X[°]C: - specific gravity of soil at attests temperature

The procedure for determining the specific gravity of soil according to ASTM D 854 92:

1. Obtain a representative soil sample and weigh it in air to determine its dry weight (mass A).
2. Fill a pycnometer with distilled water and weigh it (mass B).
3. Place the soil sample in the pycnometer without disturbing the water and weigh it (mass C).
4. Record the temperature of the water (T), the temperature of the air (T₁), and the barometric pressure (P).

5. Pour distilled water from the pycnometer into a beaker and place it on the balance.
6. Fill the pycnometer with distilled water again and reweigh it (mass D).
7. Repeat steps five and six to obtain at least three measurements of mass D.
8. Calculate the density of water using its known value at the appropriate temperature and barometric pressure.
9. Calculate the apparent specific gravity of the soil by using formula:

$$G_{sa} = [(C - A) / (D - B)] * [\text{density of water} / (\text{density of water} - \text{density of air})]$$
10. Compute the bulk specific gravity from equation: $G_{sb} = [(G_{sa} \times n) - 1] / [(1/n) - G_{sa}]$
 Where $n = \text{mass of dry sand to fill pycnometer} / \text{mass of water used to fill the pycnometer}$
 If you also want to find the particle density, then use equation: $G_{sp} = G_{sb} / (1 + (G_{sb} \times \text{moisture content}))$, Where moisture content is expressed as a decimal

A2. Grain Size Analysis

A2.1. Dry Sieve Analysis (Standard ASTM D422)

Gradation test for soil one

Sieve Size (mm)	Weight of Sieve (gm)	Weight of Sieve + soil (gm.)	Weight of Retained (gm.)	Percentage of Retained (%)	Cumulative Percentage of Retained (%)	Percentage of Passing (%)
12.5	0	0	0	0	0	100
9.5	0	0	0	0	0	100
4.75	0	0	0	0	0	100
2.36	334.66	335.48	0.82	0.433	0.433	99.567
2	319.08	319.08	0	0	0.433	99.567
1.18	280.28	280.68	0.4	0.211	0.644	99.356
0.6	392.28	397.02	4.74	2.5	3.144	96.856
0.425	377.59	385.58	7.99	4.215	7.359	92.641
0.3	261.83	284.96	23.13	12.201	19.56	80.4
0.15	265.4	345.07	79.67	42.024	61.584	38.416
0.075	257.02	322.83	65.81	34.714	96.298	3.7
pan	247.23	254.25	7.02	3.703	100.001	-0.001

Gradation test for soil two

Sieve Size (mm)	Weight of Sieve (gm)	Weight of Sieve + soil (gm.)	Weight of Retained (gm.)	Percentage of Retained (%)	Cumulative Percentage of Retained (%)	Percentage of Passing (%)
12.5		0	0	0	0	100
9.5	312.01	336.33	24.32	9.98	9.98	90.02
4.75	721.49	757.78	36.29	14.892	24.872	75.128
2.36	335	376.66	41.66	17.095	41.967	58.033
1.18	280.62	297.23	16.61	6.816	51.614	48.386
0.6	393.33	417.18	23.85	9.787	61.401	38.599
0.425	377.99	388.6	10.61	4.354	65.755	34.245
0.3	262.16	274.07	11.91	4.887	70.642	29.358
0.15	265.72	295.54	29.82	12.237	82.879	17.121
0.075	257.05	297.94	40.89	16.78	99.659	0.341
pan	247.52	248.35	0.83	0.341	100	0

Gradation test for soil three

Sieve Size (mm)	Weight of Sieve (gm)	Weight of Sieve + soil (gm.)	Weight of Retained (gm.)	Percentage of Retained (%)	Cumulative Percentage of Retained (%)	Percentage of Passing (%)
12.5	291.62	315.24	23.62	7.995	7.995	92.005
9.5	312.36	343.22	30.86	10.446	18.441	81.559
4.75	721.19	779.04	57.85	19.582	38.023	61.977
2.36	334.82	361.41	26.59	9.001	47.024	52.976
1.18	280.45	290.31	9.86	3.338	51.672	48.328
0.6	393.19	411.1	17.91	6.063	57.735	42.265
0.425	377.7	388.46	10.76	3.642	61.377	38.623
0.3	262.01	276.81	14.8	5.01	66.387	33.613
0.15	265.62	309.74	44.12	14.935	81.322	18.678
0.075	256.92	310.44	53.52	18.117	99.439	0.561
pan	247.41	249.07	1.66	0.562	100.001	-0.001

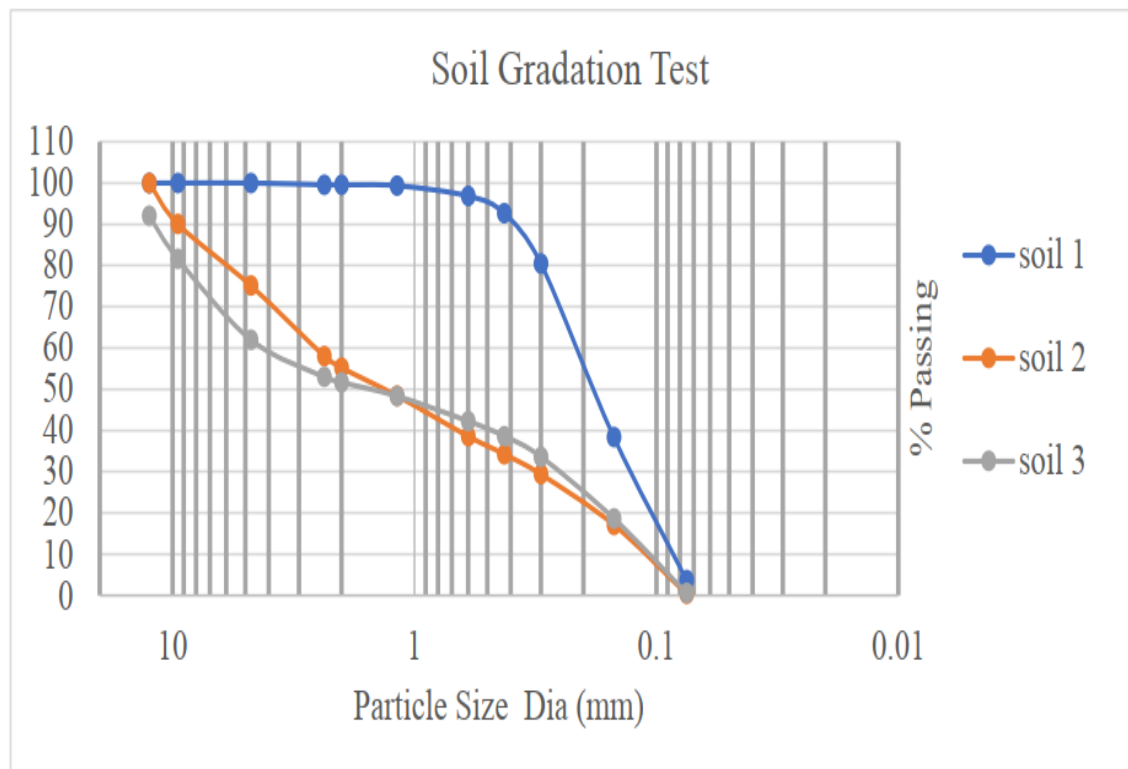


Figure of particle size Analysis

The procedure as per ASTM D6913 – 04 (Reapproved 2009) standards for particle size analysis of soils by sieve analysis:

1. Collect the soil sample and prepare it for testing by air-drying it and removing any rocks or debris.
2. Weigh a representative subsample of the soil sample, typically between 100 and 500 grams depending on the expected particle size range.
3. Transfer the subsample to the top of the set of sieves arranged from coarse to fine, with a cover on top.
4. Shake the sieves with an appropriate mechanical or manual laboratory shaker for a specified period, typically 10 minutes for fine-grained soils and up to 30 minutes for coarse-grained soils.
5. Weigh and record each soil fraction that is retained on each sieve.
6. Calculate percent passing and percent retained for each sieve and plot a particle size distribution curve.
7. Report the particle size distribution in terms of percent passing for each sieve, and report other properties of interest such as coefficient of uniformity, coefficient of curvature, etc.

A3.Compaction Test

A3.1.Standard Proctor Test method- ASTM D 698

A common compaction test is known as the standard proctor test. The basic premise of the test is that a soil sample is compacted in a 4- or 6-in (101.6-or 152.5-mm) diameter mold by dropping a 24.4-N hammer onto the sample from a height of 305mm, producing a compaction effort of 600 KN-m/m³.the volume and the weight of the mold is944cm³ and 4795gm respectively.

Soil 1								
Amount of Water Added	8%		15%		25%		30%	
Trial	1		2		3		4	
Can No	T11	T12	T21	T22	T31	T32	T41	T42
Can Wet(gm)	38	38	41	37	40	40	37	40
Can+Wet Soil (gm)	76	85	82	62	73	76	80	90
Can+Dry Soil (gm)	70	78	74	57	65	67	68	76
Mold+Sample (gm)	6264		6593		6622		6583	
Sample Weight (gm)	1469		1798		1827		1788	
MDD	1.556		1.91		1.935		1.894	
Water Content % (W)	5	6	8	5	8	9	12	14
Average	5.5		6.5		8.5		13	

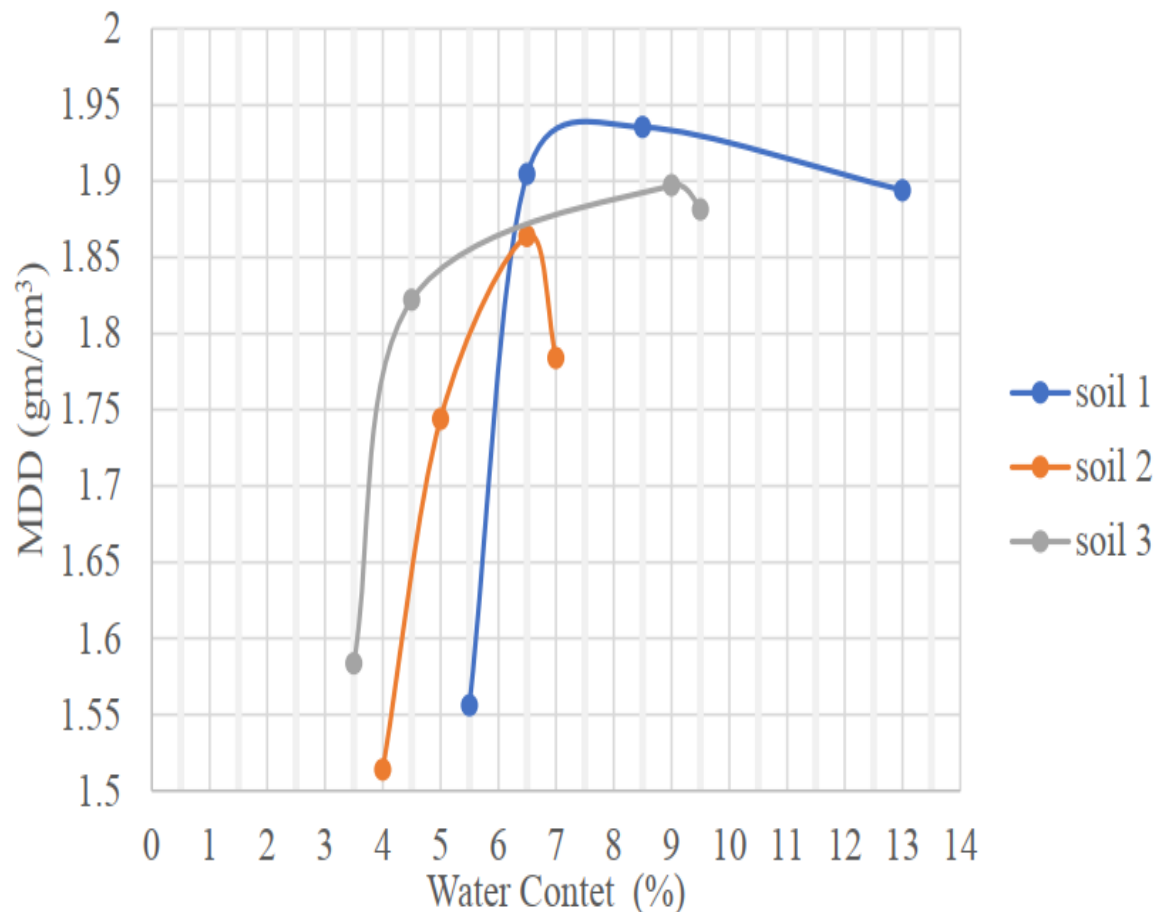
Soil 2								
Amount of Water	8%		15%		25%		30%	
Trial	1		2		3		4	
Can No	T11	T12	T21	T22	T31	T32	T41	T42
Can Wet(gm)	40	40	37	42	40	40	40	39
Can+Wet Soil (gm)	70	75	60	70	84	69	79	70
Can+Dry Soil (gm)	67	71	56	65	73	62	68	62
Mold+Sample (gm)	6290		6515		6586		6571	
Sample Weight (gm)	1495		1720		1791		1776	
MDD	1.583		1.822		1.897		1.881	
Water Content % (W)	3	4	4	5	11	7	11	8
Average	3.5		4.5		9		9.5	

Soil 3								
Amount of Water Added	8%		15%		25%		30%	
Trial	1		2		3		4	
Can No	T11	T12	T21	T22	T31	T32	T41	T42
Can Wet(gm)	37	41	40	37	41	38	40	39
Can+Wet Soil (gm)	61	70	67	71	69	63	63	65
Can+Dry Soil (gm)	58	65	63	65	62	57	56	58
Mold+Sample (gm)	6224		6441		6555		6479	
Sample Weight (gm)	1429		1646		1760		1684	
MDD	1.514		1.744		1.864		1.784	
Water Content % (W)	3	5	4	6	7	6	7	7
Average	4		5		6.5		7	

The procedure for the laboratory compaction soil test according to ASTM D 698 - 00a:

1. Obtain a representative soil sample from the field and dry it until it reaches a constant weight.
2. Sieve the soil through a 19 mm sieve and discard any particles retained on the sieve.
3. Calculate the mass of soil needed to fill the mold for each trial. This can be done by multiplying the volume of the mold by the dry density of the soil and air taken from the moisture-density curve to determine the mass.
4. Prepare the mold for compaction by cleaning and lightly oiling its inside surfaces.
5. Preheat the compaction hammer and mold to 60°C (140°F).
6. Place one-third of the required soil mass into the mold in three evenly distributed layers and compact each layer with 25 blows from the compaction hammer.
7. Determine the moisture content of the compacted soil using a suitable measurement method, such as oven-drying, calcium carbide method, or other.
8. Repeat steps 6-7 using different moisture contents at least four more times, increasing or decreasing the moisture content in successive trials in accordance with your laboratory's soils compaction protocol or until maximum dry density is obtained.

9. Calculate the dry density of each compacted specimen from its weight and volume.
10. Plot your data on a graph with dry density on the x-axis and moisture content on the y-axis to develop a moisture-density curve.
11. Determine the moisture content that resulted in maximum dry density.



A4. Atterbergs Limit Test

A4.1. Determination of Plastic Limit by using large glass plate (Standard ASTM D 4318-00)

This experiment is to determine the plastic limit of fine-grained soil. Plastic limit is determined by rolling a soil paste, then finding the water content when the 3mm diameter paste starts crumbling.

Plastic limit						
Soil Sample	Soil1		Soil2		Soil 3	
Soil Specimen Number 123	S14	S15	S24	S25	S34	S35
Mass of empty container gm(M1)	36.22	35.55	35.98	36.17	41.64	40.45
Mass of container +wet soil(M2)	38.56	37.77	39.3	39.29	44.38	43.19
Mass of container +dry soil(M3)	38	37.5	38.5	38.5	44	42.5
mass of water in gm (Mw)	0.56	0.27	0.8	0.79	0.38	0.69
mass of dry soil in gm (Ms)	1.78	1.95	2.52	2.33	2.36	2.05
water content % (W)	31.46	13.84	31.746	33.90	16.10	33.65
Plastic limit	32.825		22.653		24.88	

Mass of water (Mw) = M2-M3, Mass of dry soil (Ms) = M3-M1

The water content and the plastic limit shall be calculated as follows:

Water content in % (W) = $\frac{M_2 - M_3}{M_3 - M_1} \times 100$, plastic limit is the ratio of weight of trial 1 and weight of trial 2 times hundred.

A4.2. Determination of Liquid Limit of Fine-Grained Soil by Using Cassagrande Cup Method (Standard ASTM D 4318)

This method covers the determination of the liquid limit of a sample in its natural state or a sample from which materials passing through No.40 or 0.425 mm test sieve.

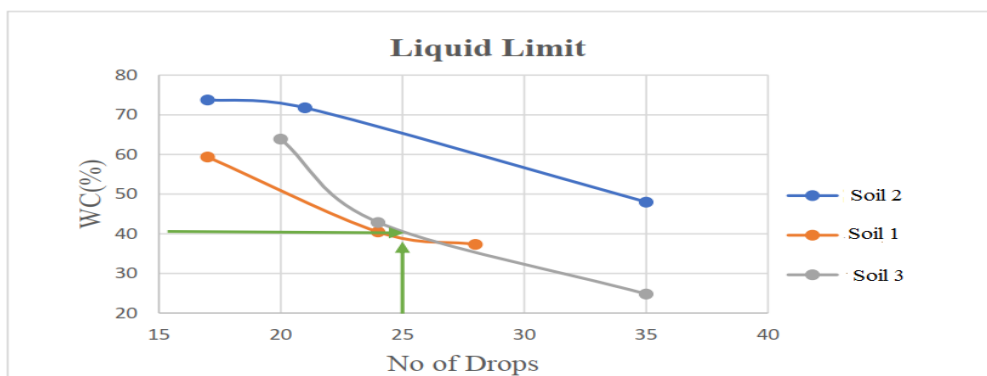


Figure of Liquid limit

Table used to determine Liquid limit.

	SOIL 1			SOIL 2			SOIL 3		
soil specimen number 123	S11	S12	S13	S21	S22	S23	S31	S32	S33
Mass of empty container gm (M1)	40.46	37.43	40.2	39.41	39.79	39.55	38.22	37.21	36.82
Mass of container+ wet soil gm (M2)	60.03	59.85	65.17	56.14	54.39	56.21	59.8	54.3	51.64
Mass of container+ dry soil gm (M3)	53	52.5	57	49.5	49.5	50	51	47.5	45.5
Mass of water in gm (Mw)	7.03	7.35	8.17	6.64	4.89	6.21	8.8	6.8	6.14
Mass of dry soil in gm (Ms)	12.54	15.07	16.8	10.09	9.71	10.45	12.78	10.29	8.68
number of drops	17	21	35	17	24	28	20	24	35
water content % (W)	73.76	71.76	48	59.35	40.46	37.32	63.9	42.88	24.8
Aveage	45.71090103			64.50887021			43.85833333		

Plot the number of drops in the X-axis and the percentage of water content in the Y-axis.

Finally, the liquid limit can be taken as the water content corresponding to 25 numbers of drops. Then plasticity index (PI) can be calculated as, subtracting the plastic limit (PL) from the liquid limit (LL) Plasticity Index (PI) = LL – PL.

The procedure for determining the liquid limit and plastic limit of soils according to ASTM D 4318-05, using the dry preparation method:

1. Obtain a representative soil sample, typically between 100-150 grams based on the expected range of the soil's plasticity index.
2. Air dry the soil sample until it reaches a constant weight.
3. Crush all visible clods in the soil and pass it through a 2-mm sieve.
4. Weigh out 100 grams $\pm$ 0.1 gram of the sieved soil into a mixing bowl.

5. Add water slowly while kneading the soil until it reaches a uniform consistency. The kneading process should last for approximately five minutes. The water content added during this process should be such that the soil consistency is suitable for rolling it into a thread having a diameter of 3 mm.
6. Take a golf ball-sized piece of the prepared soil and roll it onto a glass plate with your palms to form a log-shaped thread approximately 3 mm in diameter.
7. Use an appropriate device such as a grooving tool to cut a groove down the center of the thread at right angles to its long axis, for a length of about 10 mm.
8. Lift one end of the thread with a spatula and note the number of drops it required to close that gap when it touches together for a distance of 13 or 12 mm, the distance varies depending on whether you are measuring the liquid limit or plastic limit, respectively.
9. Repeat steps 6 to 8 to obtain at least two more thread specimens from the same soil and average the number of blows required for each gap closure.
10. Record the average blows in a data table.
11. Change the moisture content of your soil mixture and repeat steps 6-10 until you have determined the liquid limit and plastic limit.

APPENDIX B: TEST ON FIBER

B1. Water Absorption Test (Archimedes Principle)

Water Absorption Test				
Sample no	dry mass (gm)	soaked mass (gm)	oven dry mass	Water Absorption (%) ($w_2 - w_1$) * 100 / w_1
f1	25.07	75.81	23.66	202.394
f2	28.09	82.16	26.21	192.489
			Average	197.4415

B2. Density of Fiber (Archimedes Principle)

Sample	Dry Mass (gm)	Volume of Fiber (ml)	Density of Fiber (gm/cm ²)
f1	25.97	60	0.433
f2	35.19	80	0.44
		Average	0.4365

B3. Specific Gravity (Standard ASTM D854- 00)

Specific Gravity		
Bottle No	11	18
Empty Bottle Mass (M1)	61.47	61.13
Fiber +Density Bottle (M3)	66.86	66.09
Fiber +Density Bottle +Water(M3)	162.64	161.28
Density Bottle +Water (M4)	160.11	159.37
Specific Gravity	0.68	0.72
Average	0.7	

To measure the density, specific gravity, and water absorption of sisal fiber, I had follow these steps:

1. Cut the sisal fibers into small pieces (e.g. 2-5 cm length).
2. Weigh a sample of the sisal fiber on a balance with an accuracy of 0.01 grams and record the mass as 'm1'.

3. Fill a container with water and record its weight as 'm2'. This water container should be large enough to completely submerge the sisal fibers.
4. Place the sisal fiber sample gently into the water-filled container and push it down with a spatula to ensure it is completely submerged.
5. After one minute, remove the sisal fibers from the water and place them on a paper towel or cloth, allowing any excess water to drain off.
6. Weigh the container with residual water as 'm3'.
7. Calculate the density of the sisal fiber using the formula: $\text{density} = m1 / (Vf)$, where Vf represents the volume of fibers (in cubic meters).
8. The specific gravity is calculated by dividing the density of sisal fibers by the density of water (1000 kg/m³).
9. Determine the percentage of water absorption using the formula: $\text{water absorption} = ((m3 - m2) / m1) \times 100\%$.
10. It's worth noting that specific testing methods may vary depending on the specific application or research context. Consult relevant literature and/or experts for guidance in your specific case.

APENDEX C: MIX DESIGN

C 1.Mix Design Procedure

Mix1 (100% soil, 0%fiber&0%cement) Control Mix

Step 1: - Estimation of Soil Amount

The maximum dry densities (MDD) of soil obtained from the standard compaction test corresponding to the OMC were used to determine the amount of soil. The MDD of soil were 1.9gm/cm³.

The proportion of material for the trial mixes in 4 blocks are calculated below but before we proceed with the required quantity of each material let us calculate the total required volume of mold for trail mix:

$$\begin{aligned}\text{Volume of mold} &= 10*15*25*4 + 10\%\text{wastage} \\ &= 14,850 \text{ cm}^3\end{aligned}$$

The amount of soil = 1.9g/cm³*18,450cm³=**28.0445kg**

Step 2: - Estimation of Water

The amounts of water used for this mix were optimum moisture content plus 5 % of OMC. This additional water was obtained from workability test result and it was added to achieve workabilityand self-compacting nature of soil. The optimum moisture content was 25%.

$$\text{Amount of water} = 30\%*29.213\text{kg}=8.764\text{kg}$$

Fiber =0%soil=0kg

Cement =0%of soil=0kg

So, the required quantity martial per mold were calculated below:

weight (Ingredients	Soil (kg)	Fiber (kg)	Cement (kg)	Water(kg)
Mix ₁	28.044	0	0	10.517

Mix2 up to mix5 has the same calculation

Mix2: - (0.25%fiber+0%cement+soil)

Step 1: - estimation of soil amount

Here in this mix the amount of soil used were 100%-0.25% sisal fiber which is 99.75%. The maximum dry density (MDD) of soil obtained from the standard compaction test corresponding to the OMC was used to determine the amount of soil. The MDD of soil were 1.9gm/cm³.

$$\begin{aligned}\text{Volume of mold} &= 10 * 15 * 25 * 4 + 10\% \text{wastage} \\ &= 14,850 \text{ cm}^3\end{aligned}$$

The amount of soil = soil from the control mix - 0.25% of soil from mix 1 = 34.97kg

Step 2: Estimation of water

The amounts of water used for this mix were optimum moisture content plus 5 % of OMC plus the water absorption of sisal fiber.

Step3: Estimation of fiber

$$\text{Fiber amount} = 0.25 * \text{amount of soil from mix 1} = 0.25\% * 34.97 = 0.087 \text{ kg}$$

Step 4 Adjustment for water absorption

The water absorption capacity of fiber from laboratory test result were 197.44% Total water required = 30% * soil + 197.44% * amount of fiber used

$$= 30\% * 34.97 + 197.44 * 0.087 \text{ kg} = \underline{8.889 \text{ kg}}$$

So, the required quantity material per mold were calculated below:

weight (Ingredients)	Soil (kg)	Fiber (kg)	Cement (kg)	Water(kg)
Mix2	27.04	0.087	0	10.66

Mix7 (0%fiber+5%cement+soil)

Step 1: - estimation of soil amount

Here in this mix the amount of soil used were 100%-5% of cement which is 95%. The maximum dry density (MDD) of soil obtained from the standard compaction test corresponding to the OMC was used to determine the amount of soil. The MDD of soil were 1.9gm/cm³.

$$\begin{aligned}\text{Volume of mold} &= 10 \times 15 \times 30 \times 4 + 10\% \text{wastage} \\ &= 14,850 \text{ cm}^3\end{aligned}$$

$$\begin{aligned}\text{The amount of soil} &= \text{soil from the control mix} - 5\% \text{ of soil from mix 1} \\ &= 28.044 - 5\% \times 35.055 \text{ kg} \\ &= 26.44 \text{ kg}\end{aligned}$$

Step 2: Estimation of Cement amount

$$\begin{aligned}\text{The amount of cement for this trial mix were } &5\% \text{ of the dry density of soil} \\ \text{Amount of cement} &= 5\% \times \text{mix 1 (the control mix)} \\ &= 5\% \times 35.055 \text{ kg} \\ &= 1.75 \text{ kg}\end{aligned}$$

Step 3: Estimation of water

The amount of water used for this mix were optimum moisture content plus 5 % of OMC plus the required water cement ratio 0.3% of cement.

$$\begin{aligned}\text{Total water required} &= 30\% \times \text{soil} + 0.3\% \times \text{cement} \\ &= 30\% \times 27.04 + 0.3\% \times 1.75 \text{ kg} = \underline{9.99 \text{ kg}}\end{aligned}$$

So, the required quantity material per mold were calculated below:

weight (Ingredients)	Soil (kg)	Fiber (kg)	Cement (kg)	Water(kg)
Mix 7	26.44	0	1.75	9.99

Mix 8 : (5 % cement + 0.25 % fiber + soil)

Step 1: - estimation of soil amount

Here in this mix the amount of soil used were 100% - 5% of cement - 0.25% fiber which is 94.75%. The maximum dry density (MDD) of soil obtained from the standard compaction test corresponding to the OMC was used to determine the amount of soil. The MDD of soil were 1.9 gm/cm³.

$$\begin{aligned}\text{Volume of mold} &= 10 \times 15 \times 30 \times 4 + 10\% \text{wastage} \\ &= 14,850 \text{ cm}^3\end{aligned}$$

$$\begin{aligned}\text{The amount of soil} &= \text{soil from the control mix} - 5.25\% \text{ of soil from mix 1} \\ &= 35.055 - 5.25\% \times 35.055 \text{ kg} = 26.57 \text{ kg}\end{aligned}$$

Step 2: Estimation of Cement amount

The amount of cement for this trial mix were 5% of the dry density of soil Amount of cement=5%*mix 1(the control mix)

$$=5\%*35.055\text{kg} =1.75\text{kg}$$

Step3: Estimation of fiber

Fiber amount =0.25*amount of soil from mix 1

$$= 0.25\%*35.055=0.0876\text{kg}$$

Step 4: Estimation of water

The amount of water used for this mix were optimum moisture content plus 5 % of OMC plus the required water cement ratio 0.3%of cement and water absorption of sisal fiber.

Total water required =30%*soil amount +0.3%*cement+197.44%fiber

$$=30\%*33.215+0.3\%*1.75\text{kg}+197.44\%*0.0876 =\underline{10.142\text{kg}}$$

So, the required quantity martial per mold were calculated below:

weight (Ingredients)	Soil (kg)	Fiber (kg)	Cement (kg)	Water(kg)
mix 8	26.57	0.0876	1.75	10.142

Mix13:- (10% cement+0% fiber+soil)

Step 1: - estimation of Soil amount

Here in this mix the amount of soil used were 100%-10% of cement-1%fiber which is 94.75%. The maximum dry density (MDD) of soil obtained from the standard compaction test corresponding to the OMC was used to determine the amount of soil. The MDD of soil were 1.9gm/cm³.

$$\begin{aligned}\text{Volume of mold} &= 10*15*30*4 + 10\%\text{wastage} \\ &= 14,850 \text{ cm}^3\end{aligned}$$

The amount of soil =soil from the control mix-10% of soil from mix1

$$=28.044-10\%*35.055\text{kg} =25.24\text{kg}$$

Step 2: Estimation of Cement amount

The amount of cement for this trial mix were 10% of the dry density of soil Amount of cement=10%*mix 1(the control mix)

$$=10\%*28.044\text{kg} =3.5055\text{kg}$$

Step3: Estimation of fiber

Fiber amount =0*amount of soil from mix 1

$$= 0\%*35.055=0\text{kg}$$

Step 4: Estimation of water

The amount of water used for this mix were optimum moisture content plus 5 % of OMC plus the required water cement ratio 0.3%of cement and water absorption of sisal fiber.

Total water required =30%*soil amount +0.3%*cement+197.44%fiber

$$=30\%*31.312+0.3\%*0\text{kg}+197.44\%*0.35055 =\underline{10.08\text{kg}}$$

So, the required quantity martial per mold were calculated below:

weight (Ingredients)	Soil (kg)	Fiber (kg)	Cement (kg)	Water(kg)
mix 13	25.24	0	3.5055	10.08

Mix17:- (10% cement+1% fiber+soil)

Step 1: - estimation of soil amount

Here in this mix the amount of soil used were 100%-10% of cement-1%fiber which is 94.75%. The maximum dry density (MDD) of soil obtained from the standard compaction test corresponding to the OMC was used to determine the amount of soil. The MDD of soil were 1.9gm/cm³.

$$\begin{aligned}\text{Volume of mold} &= 10*15*25*4 + 10\%\text{wastage} \\ &= 14,850 \text{ cm}^3\end{aligned}$$

The amount of soil =soil from the control mix-11% of soil from mix1

$$=28.044-11\%*35.055\text{kg} =24.96\text{kg}$$

Step 2: Estimation of Cement amount

The amount of cement for this trial mix were 10% of the dry density of soil Amount of cement= 10%*mix 1(the control mix)

$$= 10\%*35.055\text{kg} =3.5055\text{kg}$$

Step3: Estimation of fiber

Fiber amount =1*amount of soil from mix 1
 $= 1\% \times 35.055 = 0.35055 \text{ kg}$

Step 4: Estimation of water

The amount of water used for this mix were optimum moisture content plus 5 % of OMC plus the required water cement ratio 0.3%of cement and water absorption of sisal fiber.

Total water required =30%*soil amount +0.3%*cement+197.44%fiber
 $= 30\% \times 31.199 + 0.3\% \times 0.35055 \text{ kg} + 197.44\% \times 0.35055$
 $= 10.056 \text{ kg}$

So, the required quantity martial per mold were calculated below:

weight (Ingredients)	Soil (kg)	Fiber (kg)	Cement (kg)	Water(kg)
mix 17	24.96	0.35055	3.5055	10.05 6

All the other mix design were performed like the above procedure

Mix No	Cement (%)	Fiber (%)	Soil (kg)	Fiber (kg)	Cement (kg)	water(kg)
mix1	0	0	28.044	0	0	8.414
mix2		0.25	27.974	0.071	0	8.533
mix3		0.5	27.904	0.141	0	8.65
mix4		0.75	27.834	0.211	0	8.767
mix5		1	27.764	0.281	0	8.885
mix6		1.25	27.694	0.351	0	9.002
mix7	5	0	26.642	0	1.403	7.997
mix8		0.25	26.572	0.071	1.403	8.116
mix9		0.5	26.502	0.141	1.403	8.234
mix10		0.75	26.432	0.211	1.403	8.351
mix11		1	26.362	0.281	1.403	8.468
mix12		1.25	26.292	0.351	1.403	8.585
mix13	10	0	25.24	0	2.805	7.581

mix14		0.25	25.17	0.071	2.805	7.7
mix15		0.5	25.1	0.141	2.805	7.817
mix16		0.75	25.03	0.211	2.805	7.935
mix17		1	24.96	0.281	2.805	8.052
mix18		1.25	24.89	0.351	2.805	8.169
mix19	15	0	23.838	0	4.207	7.165
mix20		0.25	23.768	0.071	4.207	7.284
mix21		0.5	23.698	0.141	4.207	7.401
mix22		0.75	23.628	0.211	4.207	7.518
mix23		1	23.557	0.281	4.207	7.635
mix24		1.25	23.487	0.351	4.207	7.752
total			618.382	4.22	46.283	186.259

APPENDIX D: COMPRESSIVE STRENGTH TEST RESULT

Mix1(0%fiber&0%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5585.5	5778.2	5799.5	5687.1	5712.575
Density (gm/cm3)	1.551	1.604	1.611	1.579	1.586
Compressive Strength (MPa)	3.75	3.35	2.72	3.5	3.33
Mix2 (0.25%fiber&0%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5583.5	5444.5	5892.5	5569.5	5622.5
Density (gm/cm3)	1.552	1.514	1.639	1.546	1.563
Compressive Strength (MPa)	3.01	3.61	3.95	3.53	3.525
Mix3 (0.5%fiber&0%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5508.26	5485.5	5594.99	5498.78	5521.8825
Density (gm/cm3)	1.529	1.523	1.556	1.528	1.534
Compressive Strength (MPa)	4.58	5.3	4.26	4.58	4.68
Mix4 (0.75%fiber&0%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5255.5	5426	5485.5	5499.5	5416.625
Density (gm/cm3)	1.46	1.508	1.524	1.528	1.505
Compressive Strength (MPa)	5.64	4.49	4.41	5.5	5.01
Mix5 (1%fiber&0%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5314	5293.5	5302	5289.5	5299.75
Density (gm/cm3)	1.477	1.471	1.473	1.47	1.473
Compressive Strength (MPa)	6.23	5.68	6.5	6.15	6.14
Mix6 (1.25%fiber&0%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5124.5	5109	5086.5	5198.5	5129.625
Density (gm/cm3)	1.424	1.42	1.413	1.445	1.425
Compressive Strength (MPa)	4.8	4.25	4.01	3.95	4.2525
Mix7 (0%fiber&5%cement)					

Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5782.8	6001	5944.4	5760.5	5872.175
Density (gm/cm3)	1.607	1.667	1.652	1.601	1.632
Compressive Strength (MPa)	2.65	2.96	3.05	3.31	2.9925
Mix8 (0.25%fiber&5%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5914.4	5878	5752	5720.5	5816.225
Density (gm/cm3)	1.643	1.633	1.598	1.59	1.616
Compressive Strength (MPa)	3.01	3.4	3.55	2.95	3.2275
Mix9 (0.25%fiber&5%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5687	5689.5	5763.5	5678.5	5704.625
Density (gm/cm3)	1.58	1.581	1.601	1.578	1.585
Compressive Strength (MPa)	3.67	4.01	4.5	4.8	4.245
Mix10 (0.75%fiber&5%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5477	5661.5	5483	5566.5	5547
Density (gm/cm3)	1.522	1.573	1.524	1.547	1.541
Compressive Strength (MPa)	6.12	5.8	6.05	7.5	6.3675
Mix11 (1%fiber&5%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5372.6	5318.5	5703.6	5430.5	5456.3
Density (gm/cm3)	1.493	1.478	1.585	1.509	1.516
Compressive Strength (MPa)	10.94	10.85	8.15	9.56	9.875
Mix12 (1.25%fiber&5%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5295.5	5159	5237.5	5301.5	5248.375
Density (gm/cm3)	1.471	1.434	1.455	1.473	1.458
Compressive Strength (MPa)	7.8	6.92	9.1	7.89	7.9275
Mix13 (0%fiber&10%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5968	5845	6015.5	5912.5	5935.25

Density (gm/cm ³)	1.658	1.624	1.671	1.643	1.649
Compressive Strength (MPa)	3.5	3.31	3.7	2.95	3.365
Mix14 (0.25%fiber&10%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5532.6	5913.8	6036.8	6105	5897.05
Density (gm/cm ³)	1.537	1.643	1.677	1.696	1.639
Compressive Strength (MPa)	5.43	4.37	4.21	4.15	4.54
Mix15 (0.5%fiber&10%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5735	5871	5642.8	5786	5758.7
Density (gm/cm ³)	1.594	1.631	1.568	1.608	1.6
Compressive Strength (MPa)	5.03	4.5	6.09	5.56	5.295
Mix16 (0.75%fiber&10%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5493	5580.2	5798.6	5683	5638.7
Density (gm/cm ³)	1.526	1.551	1.611	1.579	1.567
Compressive Strength (MPa)	8.21	7.91	6.11	7.52	7.4375
Mix17 (1%fiber&10%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5586	5638.5	5594	5597	5603.875
Density (gm/cm ³)	1.545	1.559	1.553	1.551	1.552
Compressive Strength (MPa)	10.53	9.731	11.02	10.02	10.32525
Mix17 (0.75%fiber&10%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5425	5535	5489	5498	5486.75
Density (gm/cm ³)	1.505	1.534	1.527	1.528	1.523
Compressive Strength (MPa)	10.3	9.76	8.94	8.09	9.2725
Mix19 (0%fiber&15%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	6442.5	6381.4	6323.6	6256.5	6351
Density (gm/cm ³)	1.79	1.773	1.757	1.738	1.765
Compressive Strength (MPa)	5.19	5.83	5.33	5.56	5.4775

Mix20 (0.25%fiber&15%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	6224.6	6215.6	6323.5	6256	6254.925
Density (gm/cm3)	1.73	1.727	1.757	1.738	1.738
Compressive Strength (MPa)	5.31	5.5	5.8	5.86	5.6175
Mix21 (0.5%fiber&15%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	6045.4	6194.2	5905	6185.5	6082.525
Density (gm/cm3)	1.68	1.721	1.641	1.719	1.69
Compressive Strength (MPa)	5.96	5.28	5.9	6.25	5.8475
Mix22 (0.75%fiber&15%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5914	6045	6058.8	5868.5	5971.575
Density (gm/cm3)	1.643	1.68	1.683	1.631	1.659
Compressive Strength (MPa)	6.35	5.75	6.02	6.25	6.0925
Mix23 (1%fiber&15%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5835.5	5778.5	5823.5	5789.1	5806.65
Density (gm/cm3)	1.621	1.606	1.618	1.609	1.613
Compressive Strength (MPa)	8.03	6.09	6.95	6.05	6.78
Mix24 (1.25%fiber&15%cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5765	5685	5869.78	5782.98	5775.69
Density (gm/cm3)	1.603	1.579	1.628	1.608	1.605
Compressive Strength (MPa)	6.4	5.5	4.96	5.02	5.47

The procedures for conducting the compressive test on blocks in a laboratory setting according to the ASTM C67 standard.

1. First, gather the necessary equipment and materials, including a testing machine with a capacity of at least 5000 lbf (22.24 kN), compression plates, and a measuring device capable of measuring deformation to at least 0.001 inch (0.03 mm).
2. The blocks should be dried in an oven at a temperature of $105 \pm 5^{\circ}\text{C}$ for a minimum of 24 hours before being tested.
3. Once the block has been dried, measure its dimensions and record them.
4. Position the compression plates on the testing machine's cross-head and base.
5. Place the block between the compression plates, aligning it so that it is centered and level.
6. Apply sufficient force to stabilize the block, but not enough to cause any deformation.
7. Start loading the block at a rate of 20 ± 5 lbf/s (0.089 kN/s) until failure occurs.
8. Record the maximum load achieved just before the block fails.
9. Calculate the compressive strength of the block by dividing the maximum load by its cross-sectional area.
10. Record all relevant data, including the maximum load achieved, compressive strength, and any observations about the characteristics of the block during testing.

APPENDIX E: WATER ABSORPTION TEST RESULT

Mix1 (0%Fiber&0%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5488	5717.5	5512	5501	5554.63
Immersed Block Weight (gm.)	0	0	0	0	-
Water Absorption (%)	-100	-100	-100	-100	-100
Mix2 (0.25%Fiber&0%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5546.5	5509	5512.5	5324	5473
Immersed Block Weight (gm.)	0	0	0	0	-
Water Absorption (%)	-100	-100	-100	-100	-100
Mix3 (0.5%Fiber&0%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5352.5	5377.5	5296.5	5385	5352.88
Immersed Block Weight (gm.)	0	0	0	0	-
Water Absorption (%)	-100	-100	-100	-100	-100
Mix4 (0.75%Fiber&0%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5280.5	5115	5226	5186	5201.88
Immersed Block Weight (gm.)	0	0	0	0	-
Water Absorption (%)	-100	-100	-100	-100	-100
Mix5 (1%Fiber&0%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5120.5	4997.8	5098	5103	5079.83
Immersed Block Weight (gm.)	0	0	0	0	-
Water Absorption (%)	-100	-100	-100	-100	-100
Mix6 (1.25%Fiber&0%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	4998	4876	5018	4986	4969.5
Immersed Block Weight (gm.)	0	0	0	0	
Water Absorption (%)	-100	-100	-100	-100	-100
Mix7 (0%Fiber&5%Cement)					

Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5807.5	5755.5	5645	5603	5702.75
Immersed Block Weight (gm.)	0	0	0	0	
Water Absorption (%)	-100	-100	-100	-100	-100
Mix8 (0.25%Fiber&5%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5632.5	5665	5528	5639	5616.13
Immersed Block Weight (gm.)	0	0	0	0	
Water Absorption (%)	-100	-100	-100	-100	-100
Mix9 (0.5%Fiber&5%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5515	5476	5413	5498	5475.5
Immersed Block Weight (gm.)	0	0	0	0	
Water Absorption (%)	-100	-100	-100	-100	-100
Mix10 (0.75%Fiber&5%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5519.5	5474.5	5361.5	5485	5460.13
Immersed Block Weight (gm.)	0	0	0	0	
Water Absorption (%)	-100	-100	-100	-100	-100
Mix11 (1%Fiber&5%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5213	5376	5276	5341	5301.5
Immersed Block Weight (gm.)	5488	5386	5305	5378	
Water Absorption (%)	5.276	0.187	0.55	0.693	1.677
Mix12 (1.25%Fiber&5%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5159	5286	5135	5215	5198.75
Immersed Block Weight (gm.)	5239	5315	5310	5385	
Water Absorption (%)	1.551	0.549	3.408	3.26	2.192
Mix13 (0%Fiber&10%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5723.4	5734	5710	5789	5739.1

Immersed Block Weight (gm.)	6337	6389	6331	6298	
Water Absorption (%)	10.721	11.424	10.876	8.793	10.454
Mix14 (0.25%Fiber&10%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5559	5799.5	5506	5614	5619.63
Immersed Block Weight (gm.)	6283	6239	6163	6253	
Water Absorption (%)	13.024	7.579	11.933	11.383	10.98
Mix15 (0.5%Fiber&10%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5623.5	5734	5610	5689	5664.13
Immersed Block Weight (gm.)	6441.5	6485	6422	6474	
Water Absorption (%)	14.546	13.0973	14.4742	13.7986	13.98
Mix16 (0.75%Fiber&10%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5559	5799.5	5506	5614	5619.63
Immersed Block Weight (gm.)	6384.5	6604	6318	6430	
Water Absorption (%)	14.85	13.872	14.748	14.536	14.502
Mix17 (1%Fiber&10%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5461	5510.5	5478	5486	5483.88
Immersed Block Weight (gm.)	6259	6326.5	6287	6271	
Water Absorption (%)	14.613	14.809	14.769	14.31	14.626
Mix18 (1.25 %Fiber&10%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	5415	5521	5497	5498	5482.75
Immersed Block Weight (gm.)	6210	6336	6310	6296	
Water Absorption (%)	14.682	14.762	14.79	14.515	14.688
Mix19 (0%Fiber&15%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	6239	6286.5	6129.5	6202	6214.25
Immersed Block Weight (gm.)	6629	6711.5	6085	6731.5	
Water Absorption (%)	6.252	6.761	-0.726	8.538	5.207

Mix20 (0.25%Fiber&15%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	6184.5	6178.5	6158	6039	6140
Immersed Block Weight (gm.)	6514	6647.5	6524	6637	
Water Absorption (%)	5.328	7.591	5.944	9.903	7.192
Mix21 (0.5%Fiber&15%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	6105	6103	5986	6058	6063
Immersed Block Weight (gm.)	6530	6575.5	6505	6533	
Water Absorption (%)	6.962	7.743	8.671	7.841	7.805
Mix22 (0.75%Fiber&15%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	6061.5	6039.5	5968	6125	6048.5
Immersed Block Weight (gm.)	6585.5	6567.5	6498	6640	
Water Absorption (%)	8.645	8.743	8.881	8.409	8.67
Mix23 (1%Fiber&15%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	6057	6084.5	6012.5	5989.5	6035.88
Immersed Block Weight (gm.)	6639	6630.5	6610	6525	
Water Absorption (%)	9.609	8.974	9.938	8.941	9.366
Mix24 (1.25%Fiber&15%Cement)					
Sample No	m1	m2	m3	m4	average
Dry Block Weight (gm.)	6015	6150	6131	5946	6060.5
Immersed Block Weight (gm.)	6525	6789	6849	6476	
Water Absorption (%)	8.479	10.391	11.711	8.914	9.874

Water absorption was calculated using equation (1)

$$W_A (\%) = 100 \times (W_A - W_D)/W_D \dots\dots\dots (1)$$

Where: -

W_A , water absorption,

W_S , saturated mass of block and W_D , oven dry mas of the block

The procedures for conducting the water absorption test on blocks in a laboratory setting according to the ASTM C67 standard:

1. First, gather the necessary equipment and materials, including a measuring device capable of measuring mass to at least 0.01 g, a container large enough to fully submerge the block, a cloth or paper towel, and a drying oven.
2. The blocks should be dried in an oven at a temperature of $105 \pm 5^{\circ}\text{C}$ until constant mass is obtained.
3. 3. Once the block has been dried, cool it down to room temperature and weigh it to the nearest 0.01 g. Record this mass as M1.
4. 4. Fill the container with distilled or deionized water to a depth sufficient to fully immerse the block.
5. 5. Place the block in the container and let it soak for 24 hours at a temperature of $23 \pm 2^{\circ}\text{C}$.
6. 6. After 24 hours, remove the block from the container and use the cloth or paper towel to gently remove any excess water from its surface.
7. 7. Weigh the block again, immediately after removal from the container, to the nearest 0.01 g. Record this mass as M2.
8. 8. Calculate the percentage water absorption as follows:
9. $[(M2 - M1) / M1] \times 100\%$
10. 9. Place the block in the drying oven and dry it at a temperature of $105 \pm 5^{\circ}\text{C}$ until constant mass is obtained.
11. 10. Weigh the block again to determine its dry mass, recording this mass as M3.
12. 11. Calculate the percentage water absorption by volume as follows:
13. $[(M2 - M3) / (M3 - M1)] \times 100\%$

APPENDIX F: WORKABILITY TEST PROCUDURES

The procedures for conducting a workability test for blocks. Here are the instructions:

1. First, gather the necessary equipment and materials, including the blocks, a tamping rod, a rectangular container, and a scoop.
2. Prepare the mix for the blocks according to the required proportion and mix design specified by your organization and the manufacturing process of the blocks.
3. Place the rectangular container on a flat and level surface, and fill it with a known volume of freshly mixed block material.
4. Level off the surface of the block mixture with the scoop.
5. Start compacting where the block mixture using a tamping rod with steel face diameter of between 25 and 30 mm (1 to 1.2 inches).
6. Compact each layer of block material using 25 blows of the tamping rod applied in a uniform manner over the entire surface of each layer.
7. Continue compacting in this manner until you have completely filled the rectangular container with three layers.
8. Record the number of blows required to completely fill each layer and the total number of blows required for all three layers.
9. Remove excess block material from around the edges of the container using a knife or straightedge.
10. Carefully remove the rectangular container from around the compacted block material.
11. Measure the height of the compacted block material to the nearest 0.5 mm (0.02 inch) using a ruler.
12. Record all relevant data including number of blows, total number of blows, and height of the compacted block material.
13. Repeat Steps 3-12 with additional samples to ensure precision in conducting this test and compare results across multiple samples.

APPENDIX G: SHIRINKAGE TEST PROCUDURES

The procedure for the shrinkage checking test for blocks:

1. Select a set of blocks to be tested and measure their dimensions accurately.
2. Place the blocks in a drying oven at a temperature of $60^{\circ}\text{C} \pm 2^{\circ}\text{C}$ until a constant weight is achieved.
3. Remove the blocks from the oven and allow them to cool to room temperature.
4. Measure the dimensions of each block and record the initial measurements as "before" dimensions.
5. Immerse the blocks in water at room temperature for 24 hours, remove them, and wipe off any excess water with a damp cloth.
6. Measure each block again and record these measurements as "after" dimensions.
7. Calculate the percentage change in length, width, and depth for each block using the "before" and "after" measurements.

APPENDIX H: EROSION TEST PROCEDURES

Jet erosion is a test used to determine the resistance of soil blocks to water erosion. The test involves directing a high-pressure jet of water at the surface of the block and measuring how much material is eroded away over a set period of time. The following are the steps typically used to determine jet erosion for soil blocks:

1. Preparation of soil blocks: Soil blocks are typically prepared in molds and compacted to a specified density using a controlled amount of moisture.
2. Curing of soil blocks: Soil blocks are allowed to cure for a set period of time under specific humidity and temperature conditions, typically ranging from one to seven days.
3. Jet erosion testing: Soil blocks are placed in a test tray, and a high-pressure jet of water is directed at the surface of the block. The jet is set to a specified pressure and flow rate, and the testing duration is typically set at 5-20 minutes.
4. Collection of eroded material: The material that is eroded away from the soil block during the testing process is collected and weighed.
5. Calculation of erosion rate: The rate of erosion is calculated by dividing the mass of eroded material by the area of the test surface and the duration of the test.
6. Interpretation of results: The jet erosion test provides information on how well the soil block resists water erosion, with lower erosion rates indicating better performance. Results are typically compared with standard guidelines or specifications to determine if the soil block meets the required performance criteria.

Overall, jet erosion testing provides valuable information on the resistance of soil blocks to water erosion, which is an important consideration for their use in various engineering applications.

APPENDIX I: SOME SELECTED PHOTOGRAPHS

Some Selected Photographs during Proceeding Soil and Block Tests.





















