Experimental Investigation on the Properties of Compressed Soil Blocks Stabilized with Filter Cake, Marble Dust, and Cement

Yosef Fanta Deressa

A Thesis Submitted to

Department of Civil Engineering

School of Civil Engineering and Architecture

Presented in partial fulfillment of the requirements for the degree of Master's In Civil Engineering (Specialization in Construction Engineering and Management)

Office of Graduate Studies

Adama Science and Technology University

June, 2022

Adama, Ethiopia

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Advisor:
Bahiru Bewket (Ph.D.)

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I hereby declare that this Master's thesis entitled "Experimental Investigation on the Properties of Compressed Soil Blocks Stabilized with Filter Cake, Marble Dust, and Cement" is an independent work of mine that has not been plagiarized from any other source. All sources of material used in this thesis are duly acknowledged through citation. I undersigned below checked that this thesis project is my sole work of mine.

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LIST OF ACRONYMS AND ABBREVIATIONS

Al_2O_3	Alumina
AMASSASC	Awash Melkassa Aluminum Sulfate & Sulfuric Acid Share Company
ARS	African Regional Standard
ASTM	American Society for testing materials
ASTU	Adama Science and Technology University
BS	British standard
C_2S	Dicalcium silicate
C_3A	Tricalcium aluminate
C_3S	Tricalcium silicate
C_4AF	Tetracalcium aluminoferrite
$Ca(OH)_2$	Calcium hydroxide
$CaCO_3$	Calcium carbonate
Cao	Calcium oxide
CO_2	Carbon dioxide
CSB	Compressed stabilized soil block
CSH	Calcium silicate hydrate
fc,d	Dry compressive strength, [MPa]
Fe_2O_3	Iron oxide
ISB	Improved soil blocks
MgO	Magnesium oxide
N_2O	Nitrous oxide
OPC	Ordinary Portland cement
SCM	Supplementary Cementitious Material
SEMs	Scanning Electron Microscope Images
SiO_2	Silica (Silicon Dioxide)

ABSTRACT

The expansion of the construction industry all over the world is in needs of alternative building materials since conventional materials are in short supply and also cause greatest damage on environment due to huge consumption of scarce resource and energy as well as large volume emission of carbon dioxide. Concerning these issues, scientists searching for sustainable and eco-friendly building materials for the conservation of the environment and this motivates the application for the development of compressed stabilized soil blocks. The study presented in this thesis is intended to investigate compressed stabilized soil blocks introduced as an alternative construction material. The study of soil block blended effect of filter cake and marble dust with cement and the lonely effect of each stabilizer on the soil of Adama town has a lack of study for soil block production. Hence, The study investigates specific properties of compressed stabilized soil blocks to make an earnest contribution toward the development of this building material. Laboratory tests conducted on the soil of the Adama area used for the study provided detailed information on the suitability of soil for soil block and the result proved that the soil is suitable for block production. In the study, three different types of stabilizers were used: cement, marble dust, and filter cake with 5%, 10%, and 15% replacement of soil. Additionally, marble dust and filter cake were mixed with cement with 2.5%, 5%, and 7.5% of each to improve their efficiency. The Compressed soil block with dimensions of 290mm × 140mm × 100mm was prepared and cured for 28 days. Finally, the compressive strength, dry density, and water absorption of the block were analyzed. Cement and Marble dust stabilized blocks had better compressive strength and density and low water absorption rate. While filter cake stabilized blocks exhibited poor strength and density and high water absorption but these properties were improved when filter cake was blended with cement. The investigation result has revealed that from the blocks produced at the varying total stabilizer contents from 5% up to 15%, the blocks stabilized with cement in combination with either marble dust or filter cake have high compressive strength and low water absorption rate than the block produced solely with cement, filter cake and marble dust. The economic viability of the block is also assessed. In General, the study examined the interplay between constituent materials used (cement, filter cake, marble dust, soil, and water) to assess their effects.

Keywords*: - sustainable development; stabilization; Filter cake; Marble Dust; compressed stabilized soil block*

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The construction industry is responsible for a significant part of the depleted resource levels, atmospheric pollution, and the level of CO_2 concentration in the atmosphere. Pollution resulting from the construction industry should be controlled, renewable energy sources should be utilized and the ecology should be conserved to ensure sustainable development. The introduction of the sustainable development concept within the construction industry led to a change in the focus of development projects which concerned with the sustainable consumption of natural resources. The idea of sustainable development is not unique to the 21st century although it presently receives renewed attention (Malherbe, 2016).

Sustainable development is a relevant organizing principle in this era. It has been used and further strengthened in various fields such as politics, architecture, technology, and transportation. Sustainable development helps us to reflect on our role within the ecosystem, implies the effects of human activity on the environment, and provides us a chance to see the world from a new perspective (Yip et al., 2017).

The increased awareness of the environmental impact of the construction industry led to the introduction of the sustainable development concept, which aims to reduce resource and energy consumption, and carbon dioxide emissions within this industry. In recent years environmental degradation was the most concerning issue in the world. This environmental pollution caused due to CO_2 emissions and the burning of fossil fuels to heat kilns during industrial production of some end products of construction material and deforestation for use as construction material. Concerning this issue, scientists are searching for sustainable and eco-friendly building materials. Compacted Stabilized Soil Block (CSB) allows energy-efficient, eco-friendly, agriculture-friendly, and sustainable development. The production of this Compacted Stabilized Soil Block (CSB) minimizes the production and emission of harmful gases to the environment (Sarker, 2018).

As Shiferaw, (2008), stated that over half of the world's people now reside in cities, and the increase in the absolute number of people now living in cities is causing the scarcity of houses, and the ever-increasing cost of construction. Urban development is occurring in many Sub-Saharan African cities and rapid urbanization is underway in the East African cities of Ethiopia. According to the Ethiopian Urban Sector Study, the Ethiopian population is currently estimated to be 110 Million; 80% of these live in substandard housing units and environmentally unfit living conditions in slum neighborhoods (Tekle & Dinku, 2018). This fact coupled with the high urbanization rate and other urban development challenges left urban areas with complex and rooted physical, economic and social problems where the urban poor, who reside in slums, are most vulnerable.

This high demand for houses increases the idea to improve the earth to make it durable by using different materials like natural fibers in the traditional way of mixing without considering the percentage usage of the fibers. This idea develops in the usage of different stabilizers for soil blocks which have different properties. Conventional materials such as cement, aggregates, steel, and bricks are not produced in sustainable ways, are imported, and are quite expensive. Hence, the need to find alternative local low-cost construction materials which do not require special skills and special machines and equipment for their construction became the main criteria (Ali et al., 2020a).

According to Malkanthi & Perera (2018), there are many studies carried out in the last few decades to make soil blocks durable or to increase the ability to remain serviceable for at least the required lifetime of the structure of which it forms a part. However, many structures do not have a well-defined lifetime, and in such cases, the durability of such structure remains serviceable more or less indefinitely, given reasonable maintenance. Therefore most of the time to fit the lifetime of the structure we use the soil stabilization method in different ways by replacing other selected materials.

Soil stabilization aims at improving soil strength and increasing resistance to softening by water through bonding the soil particles together and waterproofing the particles or a combination of the two. Mechanical, physical, and chemical stabilization is the mainly performed techniques to enhance the soil block durability and to limit the damage imputed to this drawback. Dynamic compaction and chemical stabilization by cement considerably improve the mechanical performance of soil blocks. In addition, the soil composition affects directly the stabilized soil blocks' durability (Benidir, 2018).

The use of compacted stabilized soil blocks is however hindered by the paucity of knowledge and specifications about the soil block. This study was intended to investigate the properties of compressed stabilized soil blocks as a structural material to promote the development of such specifications by measuring several material properties for compacted stabilized soil blocks manufactured from Adama area materials. It was aimed to specify the improved soil blocks (ISB) that are more desirable than the traditional types of soil blocks by stabilizing with material that have high binding properties. To produce such better-compressed soil block locally available byproducts were used. And the chemical composition of these waste materials also revealed that they are good binders to resist the deterioration of soil blocks caused due to climatic conditions.

The block produced during this research work was blended with cement. This means there is a sharp reduction of cement for block production. But, it still does not limit the problem of greenhouse gas emissions. Therefore, the researcher is analyzing the lone effect of filter cake and marble dust as stabilizers and mixed with cement for the production of CSB. Marble dust used for this study is a waste product of the marble stone industry. This dust is produced in the process of cutting and polishing marble stone. Marble dust was obtained from the Sof Umar marble production industry located in Gelan, Ethiopia. And filter cake is a by-product of Awash Melkassa aluminum sulfate and sulfuric acid share company (AMASSASC).

The successful application of filter cake and marble dust in this manner can assist in reducing the environmental impact of both filter cake and marble dust. And the construction industry with a material suitable and inexpensive for use in sustainable development applications.

1.2 Statement of the Problem

In Ethiopia, most of the construction material is based on cement production which produces greenhouse gases that destroy the environment and huge agricultural land every year. Most of these conventional construction materials are not sustainable and eco-friendly. Because the production of these conventional materials like concrete production contributes about 5% of the world's carbon dioxide (CO_2) emissions and the major part of these emissions are in cement production. Cement is not an eco-friendly material and a sharp decrease in its use is highly needed to improve sustainable construction (Joshua et al., 2017).

Another issue discouraging its use is the rising cost and also it's very expensive for low-income people who afford to live in the structure built from these materials. This makes the low and middle class live in slums. These slum houses are constructed by "Chicka" (mud and wood construction type) and spontaneous settlements made of temporary materials. This has resulted in finding a series of housing materials to manage the rising cost of housing. One of the ways of achieving this is by the use of soil blocks stabilized by waste material and blended cement with these byproducts to reduce the quantity of cement needed to meet the global concrete demand. The other great challenge is the production process of conventional materials like cement, steel, and gravel is based on a resource that is scarce and not available everywhere (Ali et al., 2020b). This scarce resource is nonrenewable material that causes scarcity of resources for most developing countries like Ethiopia.

The vast majority of developing countries are today faced with an ever-increasing problem of providing adequate yet affordable housing in sufficient numbers. Ethiopia is one of the developing countries in which most lower-income families face a lack of reasonable and quality housing stock and difficulty obtaining housing finance. The majority of Ethiopians live in poorly built, dilapidated, and cramped houses which lack even the basic facilities, such as toilets and ventilation. Only 30% of the current housing stock in the country is in a fair condition, with the remaining 70% in need of total replacement (Taffese, 2012).

Therefore, to solve this problem the researcher was using filter cake and marble dust with cement to produce better quality CSBs. Both filter cake and marble dust have good chemical oxide composition. The study related to the blended effect of filter cake and marble dust with cement and the lonely effect of each stabilizer on the soil of Adama town has a lack of study for soil block production. Hence, the researcher used filter cake and marble dust lonely and by mixing with cement to investigate their properties to give remark in a sharp decrease of cement during CSBs production. And this research is aimed at an earnest contribution toward producing high-strength soil block as most cement block has a strength of less than 4.5Mpa (Tekle & Dinku, 2018).

This experimental study on CSBs intended to investigate the properties of compressed soil blocks stabilized with filter cake, marble dust, and cement and also consider the effect of cement partial replacement with filter cake and marble dust to increase awareness of its extensive use of it as the main building material and stabilizer for soil masonry production which helps to develop technologies that are energy-saving, eco-friendly, and sustainable.

1.3 Objectives of the study

1.3.1 General objective

The main objective of this study is to investigate the Properties of Compressed Soil Blocks Stabilized With filter cake, marble dust, and cement

1.3.2 Specific objectives

a) To investigate the characterization of suitable soil for the production of compressed stabilized soil block.
b) To examine mechanical and physical properties of compressed stabilized soil block manufactured using filter cake, marble dust, cement, and cement in combination with either filter cake or marble dust blocks.
c) To assess the economic and environmental advantages of using filter cake, marble dust, and cement as a stabilizer.

1.4 Significance of the study

This research is aimed at making an earnest contribution towards the development of alternative Walling materials within Adama town by investigating specific properties of compressed stabilized soil blocks and contributing to its hitherto development. The long-term goal of the manifestation of this building material was to aware all Ethiopian populations, specifically, the low-income class of people use the byproduct of factories to produce sustainable, safe, and durable CSBs to get affordable and decent housing systems. And also aid in reducing the housing deficit, while reducing the environmental impact of the construction industry. The research also inspired people living in informal housing and slums to use CSBs to have a structure that conforms to local land use planning or zoning ordinances. This was create residents to have a legal claim to occupy the house or land. The environmental impact of factories' by-products like marble dust and filter cake were reduced and the overall cost of cement could be minimized because the production of CSBs was not used above the cement demand of the world. In addition to this, the CO_2 emission due to the high demand for concrete is replaced by eco-friendly material and the houses will have a healthy indoor climate by using CBSs.

1.5 Scope of the study

The research covers only the compressive strength, block water absorption, dry density, and cost analysis of stabilized soil blocks using filter cake, marble dust, cement, and cement in combination with either filter cake or marble dust blocks. Relevant and most crucial data are acquired for cement from the manufacturers, marble dust and filter cake data were checked and analyzed in the laboratory, scanning electron microscope of the block, and index properties of the raw materials and compressive strength tests to check suitability were conducted at Adama Science and Technology University. Block production and curing are conducted at the construction laboratory.

1.6 Limitations of the research

The research is limited to soil samples from a specific site, from the Adama area and around Adama town soil, because of time and budget constraints. It was not assessed wearing test and abrasive test of bock as environmental condition effect on compressed soil block take a long period. It is relevant to study less time-consuming investigations to examine durability.

1.7 Structure of the Research

When alternative building materials are investigated. It is necessary to give comprehensive details on the production processes, design data, and design methodology. To fulfill the above requirements, comprehensive experimental and design studies have been conducted for the alternative materials and systems introduced in this research work. The following approach has been employed to achieve the objectives:

Chapter 1 comprises the introduction part, which includes the background of the study, problem statement, and objectives of the study, significance, and scope of the study.

A broad overview of the research topics contributing to the relevance of this study is described in Chapter 2. These topics include sustainable building materials, the environmental impact of the construction industry, the concept of the soil block production process, soil as a building material, and the classification of suitable soil for block production.

Chapter 3 provides background information on the constituent materials used in the manufacturing of the compressed stabilized soil block. A brief description of the stabilizers used and the properties of industrial residue materials that are used in the production of the block were discussed in this chapter.

The results obtained from the numerous tests conducted and comparative discussions of the results, their typical physical and mechanical properties, and the factors influencing these properties in terms of cost and energy, are discussed in Chapter 4.

This research is concluded in Chapter 5 with recommendations for future studies based on observations made and knowledge gained from this investigation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Sustainable building materials

The production of construction materials like cement, steel, and crushed stone for conventional building materials cause excessive consumption of natural resource and the emission of a huge volume of carbon dioxide into the atmosphere (Malherbe, 2016). However, for a long period, people are using a conventional form of construction material. As the awareness raised for the conservation of the environment motivates the application of sustainable development practices within the construction industry. This sustainable construction practice encouraged alternative building technologies that assist in developing building materials that are more energy-efficient and affordable (Waziri et al., 2013).

Using Earth as a construction material is the oldest building practice known, with documented cases of the use of earth bricks in Mesopotamia around 10,000 BC. Earth can be regarded as a sustainable building material due to the savings in energy, transport, and ecofriendly. Earth construction offers economic and environmental benefits, especially when used in developing countries where material costs overlap labor costs and where other construction materials and technologies may not be available (Costa, 2019).

As the awareness of the technological improvement increased societies started to use Compressed stabilized soil block (CSB) for the construction of sustainable housing systems. CSBs were selected as a potential substitute for conventional building materials by applying new technology to local building materials that can facilitate the improvement of traditional techniques in local communities. This technological improvement solves safety arrangements for those areas threatened by major natural phenomena like durability and deterioration of soil blocks by climatic conditions (Bredenoord, 2017).

In Ethiopia, different traditional construction materials need little improvement to make sustainable materials. Most of these materials proved to be suitable for a wide range of buildings and have a great potential for increased use in the future. One of such material is the compacted stabilized earth block. The main ingredient in CSB is one of the most available building materials, used for centuries throughout the world; soil. The soil is mixed and compressed in a pressing machine to make CSB and produce a durable block. However, there are essential processes in the production that highly affect the quality of the blocks and require consideration. One of these processes is choosing the right soil for production. And the selected soil needs to be pulverized and screened before being mixed with the other components. After pulverizing and screening the soil is mixed and pressed in a block machine immediately after being wet-mixed to fabricate the block. Then the blocks were cured for approximately 28 days before being used in production (Afkari, 2010).

In addition, to increase the durability of construction materials, sustainable building materials also stems from other motivations, specifically protecting the environment, the climate, and the natural resources. Often, the governments and the residents need housing that does not contribute to climate change or emissions of greenhouse gases like CO_2 gas. If the import of concrete building materials and the associated high transport costs can be avoided, the environmental benefits are gained. Because the use of concrete is not sustainable as a lot of energy is used in the production of cement and the transport of cement, gravel, and sand to the construction site. Therefore, one should try to minimize the use of cement and concrete. The safety of the buildings must always have priority. Moreover, fire safety should be taken into consideration. In all cases, adequate building codes and building control must be available and applied, which is not always the case (Bredenoord, 2017).

2.2 Sustainable development and environmental impact of the construction industry.

Many researchers are provided simplified but meaningful definitions for sustainable development. Among these Yip et al., (2017) defined Sustainable development as a relevant organizing principle in this era. It has been used and further strengthened in various fields such as politics, architecture, technology, and transportation. Sustainable development helps us to reflect on our role within the ecosystem, implies the effects of human activity on the environment, and provides us a chance to see the world from a new perspective.

The initiation of the sustainable development concept within the construction industry led to a change in the focus of development projects. Development projects are concerned with the sustainable consumption of natural resources, which means the focus of the industry is directly on the wise consumption of natural resources and reducing the environmental impact to satisfy human needs and improve the general quality of life. The sustainable development concept subdivides sustainability into environmental, social, and economic sustainability, which are all viewed to be of equal importance as shown in figure 2.1 below (Malherbe, 2016).

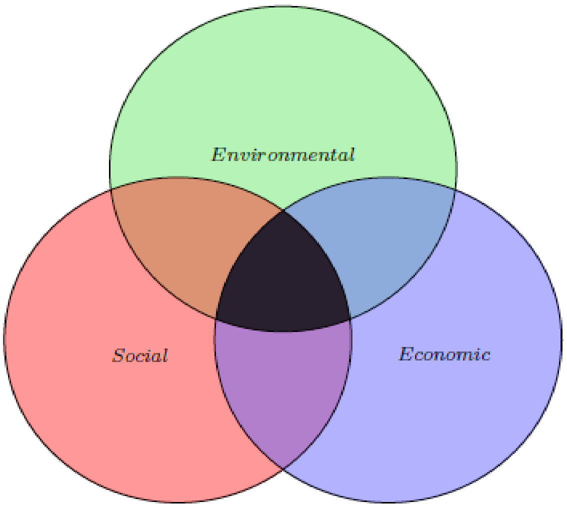


Figure 2.1: A representation of the interaction between environmental, social, and Economic Sustainability (Malherbe, 2016).

Environmental sustainability is concerned with how natural resources are wisely extracted and consumed. The construction industry is responsible for a significant part of the Depleted natural resource levels, atmospheric pollution, and the increment of CO_2 concentration in the atmosphere. Environmental Pollution resulting from the construction industry should be controlled, renewable energy sources should be utilized and the ecology should be conserved to ensure environmental sustainability. The adoption of sustainable building practices is encouraged worldwide to allow a reduction in the environmental impacts resulting from energy, water, and material consumption. These resources should be consumed in such a manner that the earth's carrying capacity is not exceeded.

An ever-increasing world population places excessive demand on the natural resources currently available. The current world population of 7.2 billion is estimated to reach 9.6 billion in 2050 and 10.9 billion by the end of the 21^{st} century. The increased population will result in the annual production of approximately 18 billion tons of concrete by 2050 (Malherbe, 2016).

Ethiopia is one of the most populous countries in the world with a current projection of 110 million people. This population needs opportunities to obtain decent, sustainable, and affordable housing. The housing demand of this population has been supplied by both the private and public sectors however, the supply is unable to meet the ever-growing demand because of massive people's mobility from rural to urban areas (Alemu, 2021).

2.3 Energy consumption of the construction industry

The energy consumed during the operational phase of building construction is the largest portion of the energy consumed throughout the life cycle of the building. This energy consumption is however not only during the operation of buildings but also during the production of convention materials like reinforcement and cement. These conventional materials are extensive energy materials in the construction industry. So decreasing the quantity of this material in construction is reduce environmental pollution and greenhouse gas emission. This decrease in quantity causes a reduction in the energy consumed during the material production phase (Jayasinghe, 2011).

The energy consumption of a building throughout its lifetime is a major concern that has a significant effect on the selection of building materials. This energy is related to the embodied energy of construction materials. The embodied energy is an important tool for a holistic evaluation of the environmental impact a building makes on the environment. The embodied energy includes direct and indirect energy consumed for the entire production process (Shukla et al., 2009). Construction materials have different embodied energy that is used for the selection of materials that have low energy. As the embodied energy of materials are dissimilar from one material to the other as shown on figure 2.2. The development of alternative building materials is aimed at creating a material that allows a reduction in the amount of energy consumed. Renewed interest has been shown in earth construction due to the low embodied energy of this building material, which is related to both the materials used and the production methods utilized (Venkatarama Reddy et al., 2014).

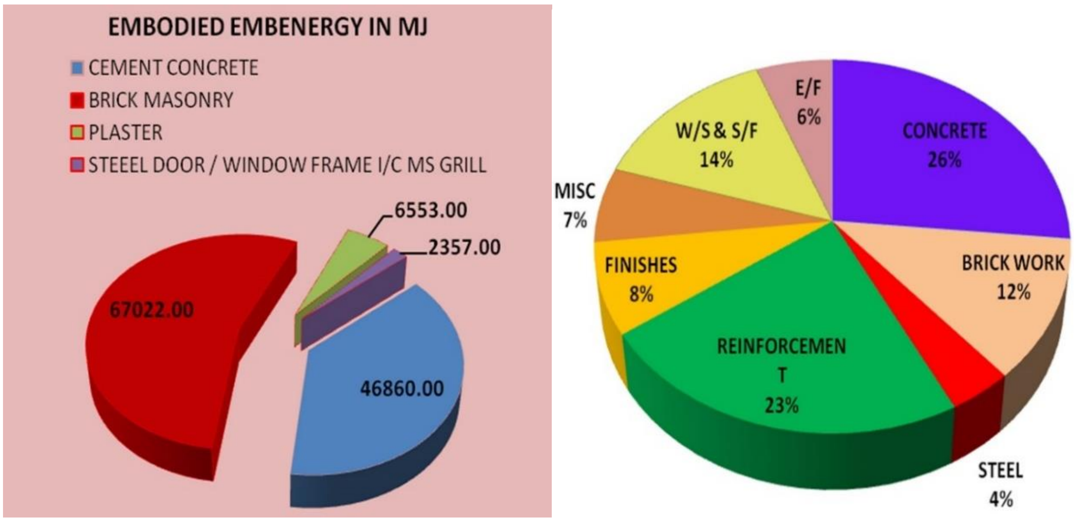


Figure 2.2: Amount of embodied energy for major activities and percentage share of construction cost on various heads (Gupta et al., 2013).

2.4 Concepts of soil block production process

Using soil as a construction material is not a new concept. Many ancient civilizations around the world are using soil as construction material by making rammed earth and soil blocks. Soil block is one of the earthen construction materials that have different constituent parts. This includes soil, water, stabilizers, natural fibers, and other waste products.

Stabilized soil blocks were successfully used for the construction of road and pavement sub-bases from 1920 to 1950. However, the use of compacted stabilized soil (using cement/lime binders) for building construction can be seen after the 1940s. Initially, a rammed earth wall was used for building construction later this concept developed into stabilized soil block that is produced by hand compaction. These blocks are used for the construction of load-bearing masonry. In the period from 1940 to 1950, and before the invention of machines for compacted soil block production, hand-compacted soil blocks were used for the construction of stabilized soil block walls. Cement-stabilized hand-compacted blocks were used for the construction of 260 houses in Bangalore in 1949 and wooden molds were used to manufacture these stabilized soil blocks for walls (Venkatarama Reddy, 2012).

In recent years, people are using a variety of presses to produce stabilized blocks from the soil. The first machines for compressing earth probably date from the 18th century. These pressing machines are developed with technology. The motor-driven presses, led to the emergence today of a genuine market for the production and application of the compressed earth block. The production technique of CSBs differs from rammed earth. CSBs are mostly produced in small pieces in which the mason or local skilled labor is installed onto the wall by hand using mortar made of a soupy version of the same clay mix and spread or brushed very thinly between the blocks for bonding. But, rammed earth is a larger formwork into which earth is poured and tamped down, creating larger forms such as a whole wall or more at one time (Shiferaw, 2008).

2.4.1 Characteristics of soil for CSBs production

Soil is an assemblage of discrete particles in the form of a deposit, usually of mineral composition, but sometimes of organic origin, which can be separated by gentle mechanical means, and which include variable amounts of water and air (British Standards Institution, 1990). As the characteristics of soil can affect the performance of a CSB production, the review of different literature discussed in this section will focus on the composition of soils and classification of soil.

Soil is composed of a varying proportion of gravel, sand, silt, and clay (Das, 2019). For the purposes of the tests soils shall be grouped as cohesive or cohesionless, Each of these types is grouped as Fine-grained soils (Soils containing not more than 10 % retained on a 2 mm test sieve); Medium-grained soils (Soils containing more than 10 % retained on a 2 mm test sieve but not more than 10 % retained on a 20 mm test sieve); and Coarse-grained soils (Soils containing more than 10 % retained on a 20 mm test sieve but not more than 10 % retained on a 37.5 mm test sieve) (British Standards Institution, 1990).

Soil classification represents a powerful tool to facilitate soil identification and predict its possible behavior. This classification system is written and decided by various authors and technical committees. Based on their criteria soil is classified by either one or a combination of the following: particle size distribution, plasticity, and cohesion. Unfortunately, soil classification systems are not yet uniformly applied internationally. At the moment, the two classification systems widely used are based on the particle size distribution and the plasticity of the soil. According to these two methods, the soil size grading and its plasticity are divided into clearly defined ranges. For each range, a descriptive name and letter are assigned to the identified soil type to distinguish it from the others (Moreno-Maroto et al., 2021).

2.4.2 Water used for mixing and curing method

Water is the main ingredient required at two critical stages in the production of CSBs: during the mixing of soil with cement, and other byproducts (waste materials) that are used as stabilizers and during the wet curing of green blocks. Existing CSB literature appears to place more emphasis on the quantity of water required, rather than on its quality. Water is needed for the hydration reaction leading to the gradual hardening of Portland cement. Therefore, both the quality and quantity of water ought to be given equal consideration. In most developing countries where CSBs are to be used, water is still a scarce resource, forcing many producers to use raw water from a variety of sources. So suitability and source of water study are necessary for block production (Kerali & Masce, 2001).

Curing green blocks may be the last stage in the production process but remains one of the most consequential. The wet CSBs in all instances were covered with plastic sheeting or tarps to prevent sudden loss of moisture after molding. Curing is essential for the eventual strength of the blocks. The rate at the moisture evaporates from the surface should not be greater than the rate at which it can diffuse through the fine pores of the green brick. When the surface moisture loss is sudden the blocks are susceptible to cracking (Wachira, 2018).

2.5 Methods of stabilization and materials for Soil block production

Earthen buildings are suffering from certain deficiencies, like strength, water resistance, and durability. To overcome that, the technique of stabilization is used to enhance the durability and strength of the soil. Stabilization of soil is a method of alteration of its properties in such a way that the soil does not lose strength and improves soil properties by mixing other materials. Improvements include increasing the dry unit weight, bearing capabilities, volume changes, and the performance of soil to generate an improved construction material (Firoozi et al., 2017).

There are three soil stabilization processes: mechanical stabilization, physical stabilization, and chemical stabilization. This stabilization is the mainly performed technique to enhance the soil block durability and to limit the damage imputed to soil construction. Dynamic compaction and chemical stabilization considerably improve the mechanical performance of soil blocks. In addition, the soil composition affects directly the stabilized soil blocks' strength and durability (Taallah & Guettala, 2016).

Mechanical stabilization involves compacting the soil by using a heavyweight to bring about a reduction of porosity and an increase in the density of the soil. The main aim of compaction of the soil is to increase its strength and reduce its permeability. Similarly, Physical stabilization involves the modification of soil properties by introducing the missing size fractions. The texture of soil can be altered by calculated and controlled mixing of the different fractions together. On the other hand, Chemical stabilization carries out by the addition of binder and bonding agents such as cement, lime, marble dust, bitumen, fly ash, bagasse, and gypsum is used (Kerali & Masce, 2001). Chemical stabilization of soil comprises changing the physico-synthetic around and within clay particles whereby the earth obliges less water to fulfill the static imbalance (Afrin, 2017).

2.6 Stabilizers used for soil block

Due to the deterioration of soil block construction, people are started to improve soil with different stabilizers. Among these stabilizers the commonly used as an admixture to stabilize the soil widely are the following:

2.6.1 Cement

Soil cement stabilization is a process by which soil particle bonding is caused by hydration of the cement particles which grow into crystals that can interlock with one another giving a high compressive strength. In order to achieve a successful bond, the cement particles need to coat most of the material particles. To provide good contact between soil particles and cement, and thus efficient soil cement stabilization, mixing the cement and soil with certain particle size distribution is necessary. Cement stabilization is done when the compaction process is continuing. As the cement fills the void between the soil particles, the void ratio of soil is reduced (Afrin, 2017).

2.6.2 Lime

One of the major alternative stabilizers is lime stabilization. By adding lime to the soil, four basic reactions are believed to occur: Cation exchange, flocculation and agglomeration, carbonation, and pozzolanic reactions. The pozzolanic reaction is believed to be the most important and it occurs between lime and certain clay minerals to form a variety of cementitious compounds. Lime is a suitable stabilizer for clay soils (Shiferaw, 2008).

In soil modification, as clay particles flocculate, transform natural plate-like clay particles into needle-like interlocking metalline structures. Clay soils turn drier and less susceptible to water content changes. And also lime is cheaply available than Portland cement in Ethiopia. Lime provides an economical way of soil stabilization. The types of lime used in the soil are hydrated high calcium lime, monohydrated dolomite lime, calcite quick lime, and dolomite lime. The quantity of lime used in most soil stabilizers is in the range of 5% to 10% (Afrin, 2017).

2.6.3 Bitumen

The action of bitumen mixing with soil is to act as a water repellent. It is used for reducing the dimensional changes and loss of strength and surface erosion associated with wetting due to climate conditions. When bitumen is used for stabilization it is necessary to heat it to make it soluble with soil because it is viscous and does not distribute at room temperature (Afrin, 2017).

2.6.4 Gypsum

Gypsum is a traditional material found in many Mediterranean and Middle Eastern countries. The earliest civilizations used gypsum for building purposes, mainly for plasters and mortars. The advantage that gypsum has over Portland cement and lime is that it requires a low calcination temperature (about 1/7th of that needed for cement and 1/5th of that needed for lime). Besides its agricultural and chemical uses, the main use of gypsum in Ethiopia is in the production of Portland cement where it retards the setting of the cement. Gypsum is a good stabilizer for sandy soils (Shiferaw, 2008).

2.6.5 Fly ash

Fly ash stabilization is gaining more importance in recent times since it has widespread availability and it increases the pozzolanic characteristics, shear strength, and bearing capacity of the organic soil. This method is inexpensive and takes less time than any other method. It has a long history of use as an engineering material. Fly ash is a byproduct of coal-fired electric power generation facilities; it has little cementation properties compared to lime and cement. Most of the fly ashes belong to secondary binders; these binders cannot produce the desired effect on their own. However, in the presence of a small amount of activator, it can react chemically to form a cementations compound that contributes to the improved strength of soft soil (Afrin, 2017).

2.6.6 Pozzolanas

The term Pozzolanas originally referred to calcined earth and volcanic ashes that, in the presence of water and at ambient temperatures, would react with lime. Pozzolanas are fine silica and alumina-rich materials that when mixed with hydrated lime produce cementitious materials suitable for stabilization and construction needs. Pozzolanas are found in their natural state as volcanic ash or pumice or they can be manmade (Shiferaw, 2008).

2.7 Development of Compressed Stabilized Soil Blocks

The compressed earth block is the modern descendent of the molded earth block, more commonly known as the adobe block. The idea of compacting earth to improve the quality and performance of molded earth blocks are, however, distant history. Earth for Compressed earth blocks has been used as a building material in the world for centuries. Notably rammed earth walls, cob, and wattle walls have been used to construct structures that are still currently in existence. Earth can be regarded as a sustainable building material due to the savings in energy, transport, and ecofriendly. Earth construction offers economic and environmental benefits, especially when used in developing countries where material costs overlap labor costs and where other construction materials and technologies may not be available (Costa, 2019).

Due to this, the new technology was focusing deeply on the development of compressed stabilized soil blocks by incorporating an industrial by-product material. This method also contributes to the reduction of the cost of the stabilized earth masonry building brick and the added environmental advantage of utilizing industrial by-products available in the country will further improve the sustainability profile of masonry brick production. The use of a cement replacement material with a lower environmental burden offers opportunities for significant reductions in energy use and carbon dioxide emission (Deboucha & Hashim, 2008).

The first CSBs were manufactured by making use of wooden tamps and this method dates back to the 18th century. Then through progressive modification, a new machine of CSBs for construction purposes was created in 1952 by Raul Ramirez, which marked the turning point for the creation of the machine, known as the CINVA-Ram as shown in figure 2.3, and then it was followed by numerous devices of a similar nature. Continuous development of the production technology of CSBs along with the application thereof resulted in increased attractiveness of this building technique within the construction industry. This has led to a renaissance of the tradition of earthen architecture and construction-a revival, which is benefiting from the results of scientific research (Deboucha & Hashim, 2008)

Figure 2.3: The first Manual press, CINVARAM (Shiferaw, 2008)

The compressed stabilized soil block is the modern descendent of the molded soil block, more commonly known as the adobe block. The idea of compacting earth to improve the quality and performance of molded soil blocks is, however, far from the use of wooden tamps to produce compressed soil blocks.

2.7.1 Nature of Soil used for Compressed Block

The Soil is the outer layer covering the earth's surface called the pedosphere. Soil serves as a medium of plant growth, the liberation of volatile substances, and a suitable ecologically area where organisms are living including human beings. This Soil is the result of the transformation of the underlying rock under the influence of physical, chemical, and biological processes related to biological and climatic conditions (Koshila Ravi et al., 2019).

Soil is the predominant constituent part that has the most profound effect on the final product of soil block. Soil selection may be regarded as the most fundamental step in the compacted soil block production process as earth blocks are comprised of approximately 90% soil. The selected soil affects the percentage of stabilizers required, the structural integrity of the block upon extrusion, the compressive strength, and the durability characteristics of the block. Careful selection of the soil and the appropriate soil tests will reduce the amount of trial and error mixes required to obtain a suitable soil mixture for compacted soil block production (Shiferaw, 2008).

The appropriate soil for soil block production is soil that contains suitable proportions of gravel, sand, silt, and clay. The soils generally selected for the production of CSBs contain limited clay and too much sand content, or excessive quantities of sand, clay, silt, or clay + silt. Though these soil samples were found to be outside the recommendation, therefore soils are often reconstituted by blending two or more soils that are taken from different areas or adding stabilizers to arrange the right proportion of the soil (Danso, 2018). In addition to this, the soil has different colors based on the composition of the parent rock and the formation of soil as shown in figure 2.4. But, these color does not affect the soil composition and grain size distribution of soil used in compressed stabilized soil block (CSB) production.

Figure 2.4: Different types of soil and their color (Schildkamp, 2009)

2.8 Soil classification systems for soil block production

A correct classification can be essential from an engineering point of view. Because considering unsuitable soil as a suitable material for use in the construction industry case dangerous structural material may fail or deteriorate in a few ages. Soil classification systems are powerful tools to carry out soil identification and predict its possible behavior. Most of the time researchers arbitrarily use particle size distribution for coarse-grain soil. However, this method is not applicable for classifying fine-grained soil which has clay and silt contents. Due to this, the measurement of plasticity is a more appropriate parameter than particle size distribution. This fact has led various authors and technical committees to develop fine-grained soil classification systems based on plasticity. However, there is still a disparity in criteria (Moreno-Maroto et al., 2021).

2.8.1. Classification by grain size

Unfortunately, there is yet no uniform soil classification system internationally, but at the moment particle size distribution and plasticity are applicable to classify soil. According to particle size distribution the soil is classified based on the size of the particle existing in the soil, the term particle refers to an individual mineral grain within the disturbed soil mass and plasticity gives a clearly defined range and a descriptive name and letter to identify a soil and distinguish one soil type from the other (Kerali & Masce, 2001).

Particle size distribution also known as grain size gives information on the soil's ability to pack into a dense structure. The particle sizes are classified as gravel, sand (fine and coarse), silt, and clay. There are different recommendations for soil particle sizes that are suitable for different techniques of earth building. Among this ASTM classification shown in table 2.1is one of the recommendations used in soil classification (Danso, 2018).

Table 2.1: The grain size classification based on (ASTM D 2487, 2008) Standards.

Pebbles	Gravel	Sand	Silt	Clay
200 to 20 mm	20 to 2mm	2 to 0.006mm	0.06 to 0.002 mm	0.002 to 0mm

Gravel is a particle that has a large size and does not use in compressed stabilized soil production as it leads to a poor (rough) surface finish. A suitable soil will contain a mixture of sand, silt, and clay-sized particles. The properties of each of these three fractions influence the properties of the block (Tekle & Dinku, 2018). Among these suitable mixtures of soil, the most important component of soil used in earth construction is the proportion of clay particles, since these particles are responsible for binding the larger sand particles together. A decrease in the grain size of the soil generally increases the compressive strength of earth masonry units. However, limitations concerning the number of fine particles are recommended (Malherbe, 2016).

The above Table 2.1 show that the size bands that are placed for each range are used to determine the fraction of a soil's particles. If a dense block is to be produced, the soil used must be "well-graded". The theoretical distribution of particle sizes to provide a perfectly packed structure is called the fuller curve (Gooding, 1993). The fuller distribution is an ideal model and never occurs naturally. This Fuller distribution is a term related to a different size that exists in the soil to fulfill the void that exists in soil particles However, a natural soil that has an even distribution of particle size, termed well-graded is a good approximation. The fuller curve is based upon the assumption that all of the particles are spherical and that the largest particles just touch each other, while there are enough intermediate particles to fill the voids between the largest, but without holding them apart.

The well-graded type of soil gives a dense block for the production of cement-stabilized soil block with a low specific surface area. A dense structure is important for several reasons. A densely packed arrangement will have a higher number of contacting particles, giving a better load-bearing skeleton. The number and size of the inter-particle voids will be reduced as will the number of linked voids, these will reduce the porosity of the soil and hence also its permeability, thereby reducing susceptibility to water penetration. As the interlocking calcium silicate matrix extends through the soil voids, a more compact void system requires less cement to provide a matrix of equal efficiency (Shiferaw, 2008).

Similarly, if it is imagined that cement coats the surfaces of soil particles, a high specific surface area soil will need a high amount of cement for blinding, or a lower specific surface area soil will require less cement to provide the same particle surface coverage and consequently the same strength and durability.

The upper and lower limit to the soil's grading also needs to be considered. A soil may be considered well graded with a uniform distribution of particles from fine silt to coarse sand (coarse soil). The coarse soil will have a lower specific surface area than the fine soil, as the same mass of soil will contain fewer and larger particles. From the above consideration of specific surface area, it might be concluded that the more coarse soil would produce strong blocks with lower cement content than that needed for the fine soil. This is however only the case when the blocks are kept within the mold to cure (Shiferaw, 2008).

2.8.2 Classification by plasticity (Fine content)

Plasticity is also a classification system for a fine grain of soil. This Plasticity estimates the clay minerals that are present in the soil. It can provide a means for objectively and broadly classifying soil for a given location. For construction purposes, the soil used for plasticity pass through a 425µm sieve for determining the liquid and plastic limits. These two boundaries (limits) have different values and differences. Plastic limit (Wp) is the moisture content at which a soil will begin to crumble and crack when rolled into a thread of about 3mm in diameter. While liquid limit (WL) is the moisture content at which the soil changes from plastic to liquid states and begins to flow. From these two limits, the plasticity index (Ip) is calculated as the difference between the plastic limit and the liquid limit (wp-wL=Ip) (Danso, 2018), and the plasticity index is used for construction purposes to classify a suitable soil type.

Khedari et al., (2005) stated that the plasticity index of soil suitable for the production of CSBs stabilized with cement, should fall between 5 and 15. Soils with a plasticity index above 20–25 are not suited to cement stabilization using manual presses, due to problems with excessive drying shrinkage, inadequate durability, and low compressive strength. Thus, the high amount of clay content leads to high plasticity and causes the reduction of compressive strength and durability of stabilized soil blocks. So, to increase durability for masonry units stabilized with cement increasing the amount of cement content and decreasing clay is necessary.

The range of suitable liquid limits for earthen construction is 32 to 46. Soils used to manufacture CSBs should preferably be inorganic clays with medium or low plasticity. Inorganic silt with adequate compressibility would also be suitable for selection. Soils used for adobe construction are generally more plastic than those used for rammed earth or CSB construction (Malherbe, 2016).

2.9 Suitable Soil Type and available Criteria for Stabilized Soil Block

The suitability of the selected soil, for use in construction, is difficult to establish due to the natural variability of soils. A variety of soils can be situated within a relatively small area, therefore soil obtained from the same area can be dissimilar in properties. So to check suitable soil types several soil tests are conducted throughout the earth block production process to ensure the soil properties can be defined as accurately as possible (Malherbe, 2016).

There are different recommendations that state the suitability of soil for soil block production. Among these recommendations, few are used together in this study to classify soil for checking the suitability of soil for block production. The data of their studies and their values were compiled into figures and then compared with the upper limits of these criteria and requirements. Out of the comparison, a suitable soil application technique for the soil samples based on the requirements was recommended. This helped in determining the suitability of the soil for earth construction.

2.9.1 Criteria based on African Regional Standards

A. Granular composition of soil

To classify soil type as a suitable material for constructions it is necessary to carry out a particle size distribution test of the soil. Using the laboratory test result it is possible to classify soil. Based on African Regional Standards and experiences laboratory test result of particle size distribution is used for classifying soil as construction material, if the granular composition of soil falls within the limits of the recommended shaded area of Figure 2.5 of the gradation curve, the soil is usually considered as suitable for stabilized soil block production. Types of soil composition which fall outside the shaded area may still give acceptable results, but it is recommended that they be subjected to a series of tests enabling their suitability to be assessed.

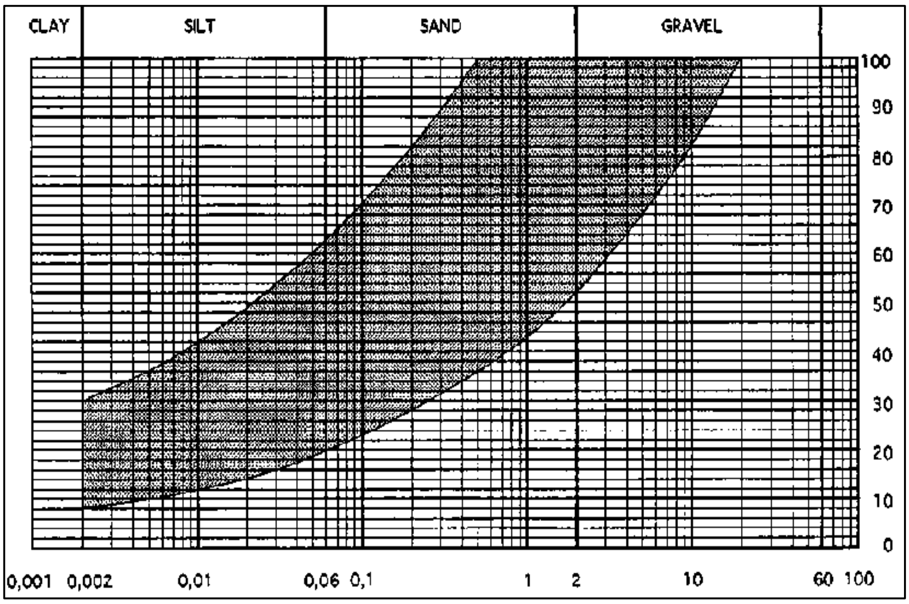


Figure 2.5: Diagram of texture based on African Regional Standardization, (1996)

B. Plasticity

Silt and clay is the fine particle in the soil that has a great effect on the plasticity test. It is responsible for the cohesion of soil and this fine grain provides the fresh block to have a shape that handles able during production before the cement gets its initial setting time. The degree of cohesion of the block is not only dependent on fine-grain existing in the soil. But also, the degree of compaction or compactive effort applied to the soil has a high role in cohesion (Gooding, 1993).

The plasticity (Atterberg limits) test estimates the clay minerals that are present in the soil. This estimation of clay in the soil is used for determining the suitability of soil that needs a binder to function satisfactorily as a building material. Based on plasticity various authors' recommendations of soil used various zone on the graph using these index values. This means some types of soil are unsuitable for building houses, while some will need certain stabilizers to improve their geotechnical properties (Danso, 2018).

The liquid limit and plastic limit test for suitable soil fall preferably within the limits of the recommended shaded area of the diagram of plasticity as shown in Figure 2.6 below, the soil is considered suitable for soil cement block production. The soil which falls outside the shaded area may still give acceptable results, but it is recommended that they be subjected to a series of tests enabling their suitability to be assessed

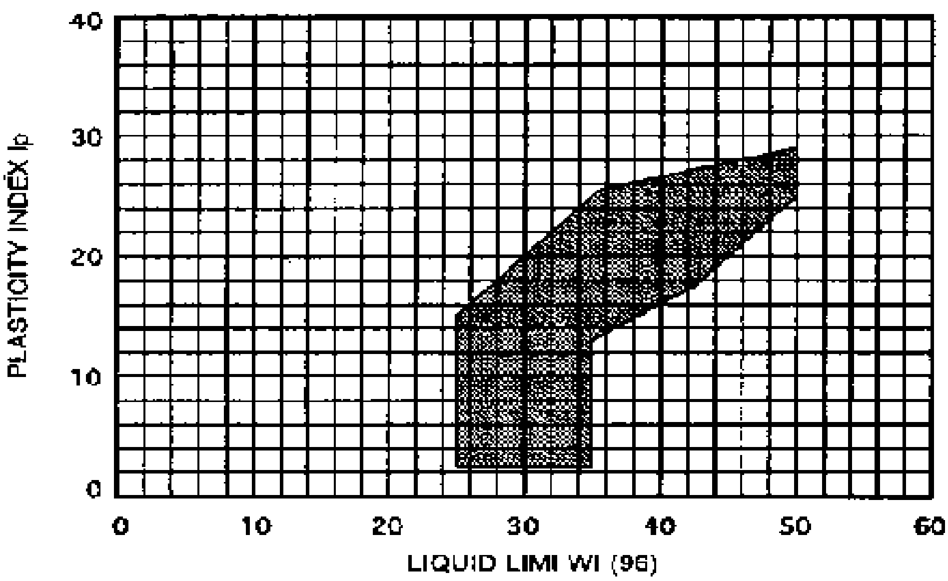


Figure 2.6: Diagram of Plasticity (African Regional Standardization, 1996)

2.9.2 Criteria based on Spence, R.J.S & Cook, D.J.1983, Building Materials in Developing Countries

A. Particle size for soil cement block

The suitability criteria of soil for soil cement block production have variations between different authors. Spence and Cook are among the authors who set the criteria for soil cement block production. The shaded portion of the chart shows the recommended particle size suitable for soil stabilization, which is in the range of 0% to 25% for clay, 0% to 25% for silt, and 60 to 90% for sand constituents. Space and Cook include a graphical plot on a triangular U.S. Bureau of public Road particle size graph (Danso, 2018). If the particle composition of the soil falls within the limits of the recommended shaded area in Figure 2.7, the soil is considered suitable for stabilized soil block production. A shaded area indicates soil most suitable for soil stabilization.

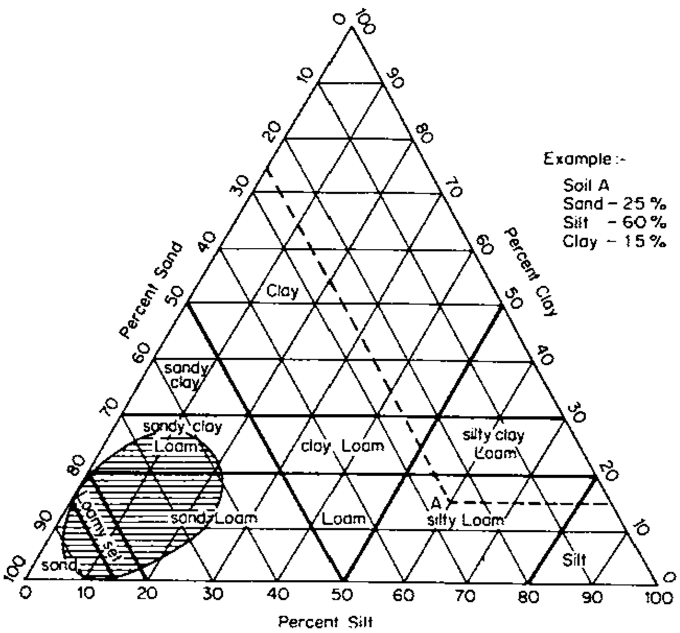


Figure 2.7: Triangular chart for particle size classification (Danso, 2018)

B. Plasticity criteria for stabilization

If the plasticity test result of the soil fall preferably within the limits of the recommended shaded area of the plasticity chart as shown in Figure 2.8 below, the soil is considered suitable for soil cement block production. Figure 2.5 applies only to the fraction of soil finer than 0.4 mm, roughly between the limits; Plasticity index 0- 22 %, liquid limit 7-40%. The sand content of the soil is at least greater than 50%, preferably closer to 75% and low plasticity and clay content (typically less than 25% clay) are necessary for a suitable soil type (Gooding, 1993).

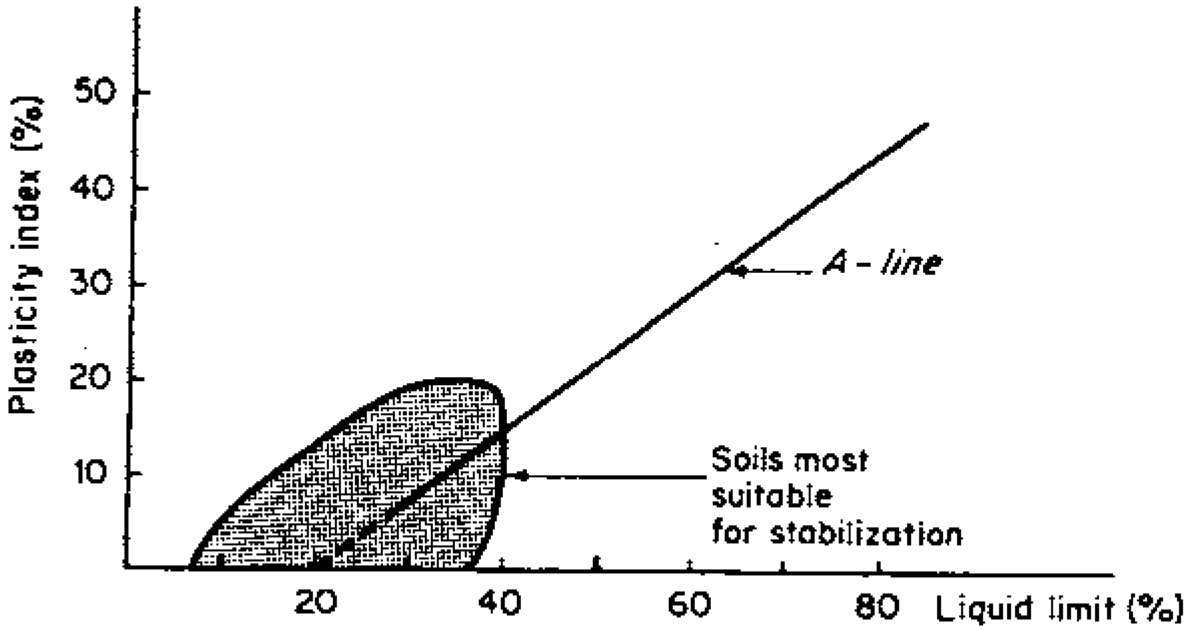


Figure 2.8: Plasticity chart showing soil most suitable for stabilization (Gooding, 1993)

2.10 Summary of literature review and research gap

This research was address some missing points in the current state of knowledge. The researcher has learned through a literature review that there are many stabilization tests of compacted stabilized soil blocks by using waste materials and byproducts of factories. The stabilized soil block produced in these methods became durable and safe for housing units, for this reason, the idea of stabilization by waste products became the more crucial in the construction industry. The byproduct of awash melkasa sulfuric acid and aluminum sulfate which is called filter cake has good chemical oxides and may become a very necessary stabilizer for soil block production in the future. It was found that no study has been conducted for soil block production by this stabilizer.

Simultaneously, there are many stabilizations of soil blocks that are done in small villages, different regions, arid zones, and countries of the world. However, the soil has different nature from one region to another region, Even in the same area may cause different soil types (Kerali & Masce, 2001); (Furgasa et al., 2021). These properties of soil need a study to make a soil block. So that this is the main study gap for a researcher. Therefore this study has a location gap in that no one was carrying out stabilization of soil block in Adama town of Ethiopia and around it.

Due to urbanization and the great increment of the population around the world, the urgency to provide an immediate practical solution for the lack of housing for people who are living in slums and the informal house is making scientists for searching new construction materials that are sustainable and have low co_2 emission to the environment. These shortages of conventional construction materials and the associated environmental problem call for an urgent investigation into the possibility of using economically and environmentally friendly locally available materials (Shiferaw, 2008); (Taffese, 2012); (Bredenoord, 2017).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Overview of the natural conditions of the study area

Adama is one of the fastest-growing city that found in the eastern Shoa zone, in the Oromia regional state of Ethiopia. It is a comfortable city for living with an occasionally a little bit hot (warm) throughout the year. The main road that connects the capital of Addis Ababa and the eastern cities of Ethiopia (Dire Dawa and Harar) pass through this city. It is about 98km away from Addis Ababa in the southeast direction. Its approximate location is 8°33`35``N - 8°36`46``N latitude and 39°11`57``E - 39°21`15``E longitude. The city has an average altitude of 1,712m (5,617ft) above mean sea level.

Adama is one of the most developing towns that have a suitable business area, a conference center, and a tourist resort in Ethiopia. According to the 2007 population and housing census of Ethiopia, it is a city that has a total population of 155,321 of which, 76,325 (49.14%) were female and 78,996 (50.86%) were male (Kassahun, 2013). As the population of this town is very dense there are no adequate houses. Most houses that are built without quality called Chicka houses are seen widely in many parts of the town. This type of house requires modification for a low-income class of people who need to live in affordable houses.

Adama is a town found within the Wonji Fault Belt, which is one of the main structural systems in the Ethiopian Rift Valley. Its physiographic condition is mainly the result of volcano-tectonic activities that occurred in the past and also partly the result of the deposition of sediments, which are considered largely of fluvial and lacustrine origin. Adama is considered a seismically active area concerning earthquake hazards. The altitude of Adama varies from about 1600m to 1970m a.m.s.l. The only perennial river in the area of Adama is awash in which all the streams in the town for water supply are originated (Kassahun, 2013). The soil used in this study was brought from different areas of Adama town to consider deeply their properties for soil block production. The soil is extracted from the sub-soil level and not from the top-soil level. It is extracted from about 30 cm downwards from the surface to avoid the inclusion of organic matter. For this study manual extraction involving laborers using basic hand tools such as shovels and picks has used.

3.1.1 Map of Adama area

Adama is one of the largest and most populated towns of eastern Shoa of Oromia National Regional State as shown in Figure 3.1. The city has a total area of about 13,000 hectares, which has been subdivided into 19 urban kebeles administrations.

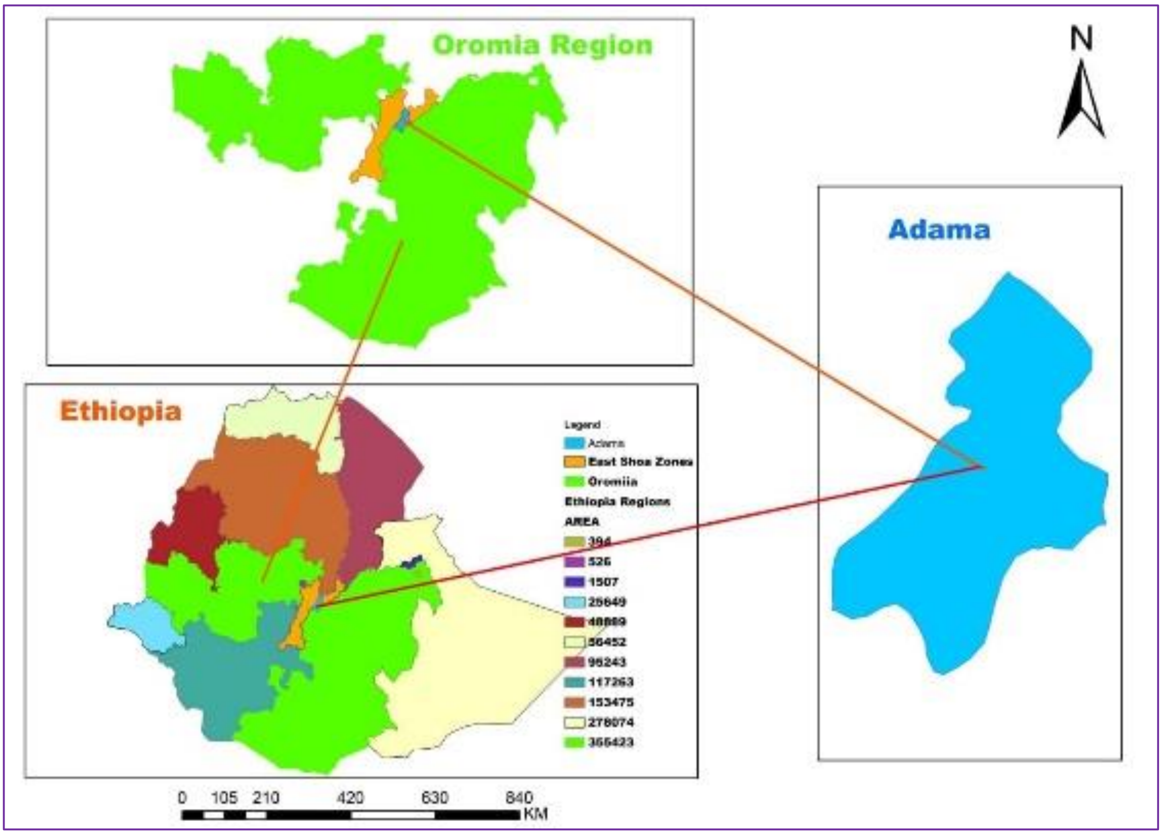


Figure 3.1: Adama town in its national and regional setting (Author)

3.2 Materials used for the Production of CSBs

In this research, the materials used in the investigation are described concerning their sources and their physical and chemical properties. All laboratory investigations on materials were carried out in the Adama science and technology university (ASTU) department of civil engineering in the Construction and Geotechnical laboratory. The study adopted a mixed approach by referring to secondary data results of previous studies result extracted and analyzed. The geotechnical properties of soil samples used in previous studies were compiled and compared with various criteria and requirements to ascertain the soil block's suitability for construction purposes.

The properties of the ingredient materials in the manufacturing of compressed stabilized soil blocks (CSBs) were obtained from laboratory tests to ensure the adequate design of soil mixtures. The designed soil mixtures were developed through trial and error to ensure the production of blocks with a quality representative of those that will be used for the construction of housing developments in Adama, Ethiopia. The constituent material properties, and the methods applied to prepare the CSBs, are discussed in this chapter.

3.2.1 Soil

Soil is one of the main constituent materials used for manufacturing the compressed stabilized soil block. The soil used in this research was brought from different areas of Adama town to consider deeply their properties for soil block production. This soil was kept fixed, with different percentage compositions of gravel, sand, silt, and clay being used as shown in Figure 3.2. As several block types of nominal dimensions were produced for the experiments, keeping the soil type the same for all specimens is help to increase the reliability of the tests. By keeping the soil type the same at all times for all specimens, better consistency, repeatability, and controllability are achieved. The selected soil composition had to fulfill the suitability criteria for soils for CSB production. The optimum composition of soil fractions for more effective stabilization with cement, marble dust, and filter cake was selected.

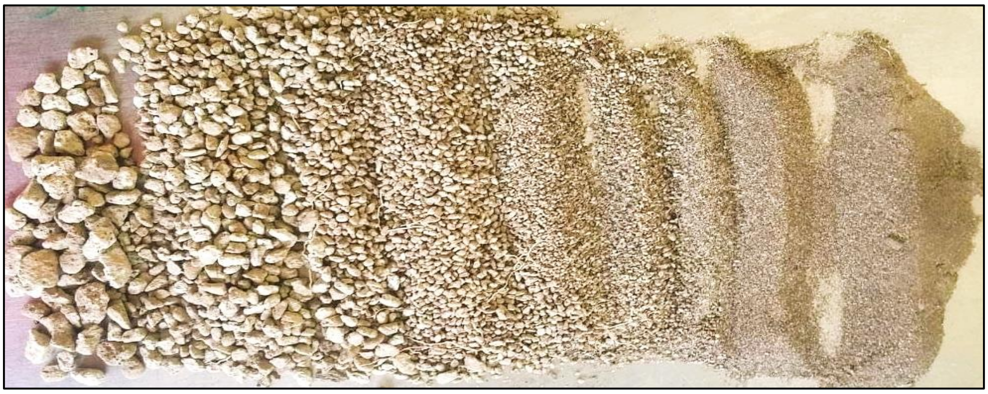


Figure 3.2: Soil composition of Adama town

The chemical composition of the soil used in this research work was analyzed at the Geological Survey of Ethiopia; Geochemical laboratory. The result of the chemical composition shown in Table 3.1 has the most dominant chemical oxide silica (Sio_2). This is an important oxide of the soil as it gives strength to the block by reacting with CaO existing in the cement and silica is the basic oxide in the formation of dicalcium silicate and tri-calcium silicate. Excess silica in soil and cement causes slow setting when compared with cement paste during this research work. The national cement of OPC type in this research work when mixed with water form cement paste which set in few hours.

Table 3.1: Chemical composition of the Adama area soil

Chemical oxides of the soil and their chemical Composition									
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	P_2O_5
64.66	16.84	6.95	1.03	0.36	1.68	3.82	0.18	0.42	<0.01

P_2O_5	H_2O	SO_3	LOI	Cl^-	PH
<0.01	0.22	0.09	4.27	<0.01	7.34

3.2.2 Ordinary portland cement (OPC)

The stabilizer type and amounts were varied based on mix proportion. The predominant stabilizer type used was ordinary Portland cement of class 42.5N, supplied from the national cement of Dire Dawa cement factory as shown in Figure 3.3 below. The effect and properties of cement used in soil block production were seriously investigated. During the research work, the following aspects of cement were examined. As water is added to cement the cement initially transforms from a cement paste to a material that has strength following the setting time of cement this implies that the cement in the soil block starts to react with chemical oxides existing in the soil and harden (set).

The hydration reaction that results when water is added to unreacted OPC particles follows two distinct phases: setting, followed by hardening. The duration of OPC stabilized block to get hardening effectively is about 28 days after the initial contact with water. After about 28 days the cement stabilized block still gets further strength in decelerating rate (British Standards Institution, 1990). At 28 days, the paste, and by implication, the block should be hard enough to be used.

According to (Kerali & Masce, 2001), the cement proceeds through different chemical reactions but the primary reaction involves the hydration of cement with water, and The hydration reaction between cement and water results in the formation of hydrated cement paste. The secondary reaction also results in the formation of a binder-like by-product (Spence & Cooke, 1983). Hence the OPC used in this research work carried out a chemical reaction with cement replacing material to give strength for compressed stabilized blocks as it was mixed with water and other additives during this research work. The chemical composition of the OPC cement is shown in Table 3.2.

Hydraulic cement (Portland cement): The term hydraulic means that the product gets strength when mixed with water. Portland cement is the most important hydraulic cement. It is produced by pulverizing Portland cement clinker, consisting essentially of hydraulic calcium silicate, usually by intergrading with small amounts of calcium sulfate compounds to control reaction rates. It may be used in combination with one or more supplementary cementations material such as fly ash, blast furnace slag, silica fume, or calcined clay.

Table 3.2: Composition and properties of cement produced in Ethiopia (Shiferaw, 2008).

Cement Source	**Mean Chemical Oxides Of Clinker (%)**					
	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3
Dire Dawa	65.81	22.31	4.95	4.03	1.84	0.70
	Mean Chemical Compounds Of Clinker (%)					
Dire Dawa	C_3S	C_2S	C_3A	C_4AF	Total	% of Silicates
	57.4	20.7	6.3	12.3	96.6	78.1
	Mean Chemical Oxides Of OPC (%)					
Dire Dawa	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3
	63.54	20.56	4.79	3.90	1.21	2.51

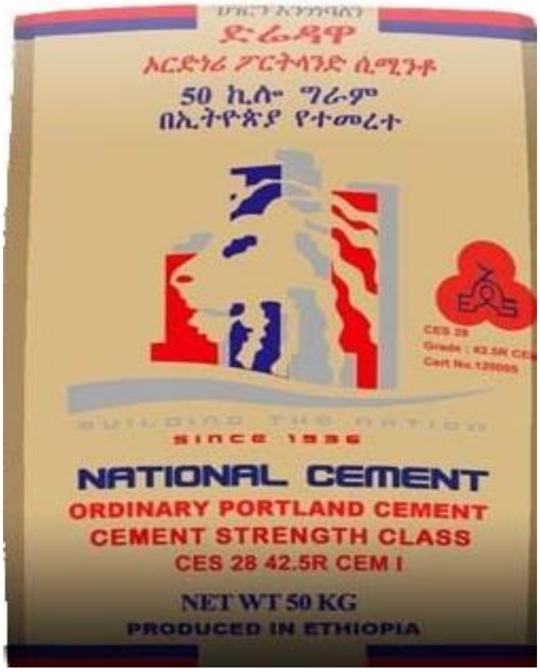


Figure 3.3: Ordinary portland cement used for block production

3.2.3 Filter Cake

The other stabilizer used in combination with cement was filter cake. The effect of this byproduct on properties of compressed stabilized soil block was examined lonely and also use in combination with cement for a sufficient number of specimens. The objective of such combinations was to evaluate the effect of filter cake on soil block. The filter cake used for this research is a byproduct of Awash melkasa chemical factory. This by-product is spread widely around the factory. It has white color as shown in Figure 3.4d. The chemical oxide result of energy dispersive X-ray spectrometry of filter cake shows that the most dominant oxide in this material is silica and CaO as shown in Table 3.3 below. Oxygen and silicon were major components of filter cake powder.

Table 3.3: Chemical composition of filter cake

Chemical oxides of the filter cake and their chemical Composition											
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	H_2O	SO_3
51.65	1.04	<0.01	39.43	0.08	0.07	0.05	<0.01	0.42	1.03	5.26	0.51

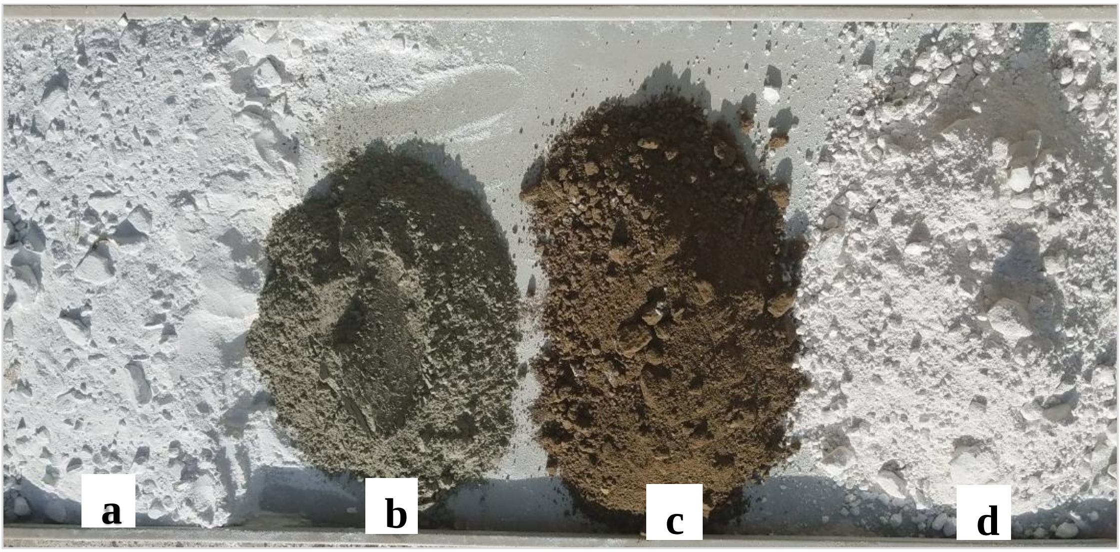


Figure 3.4: a) Marble Dust, b) Cement, c) Soil, and d) Filter Cake

3.2.4 Marble Dust

Marble stone production is industrial activity that prepares marble for decorating and smoothing of construction as marble is durable and hardwearing and resistant to shattering. It is a production process including mining, processing, and finishing. This marble production has contributed to the development of several major environmental risks. One of these risks is the disposal of marble dust wastes that are raised during the production and polishing of marble slabs as shown in Figure 3.5. Currently, the availability and the reasonably high volume of a generation of marble dust have attracted several researchers to conduct investigations on the possibility of utilizing this waste material as a partial replacement for cement. This research work also used marble dust as a stabilizer and as a partial replacement for cement for the production of compressed soil blocks.

The main advantage of replacing cement with this byproduct comes from the reduction in the cost of the mixture, and CO_2 emission related to the production of cement. The marble used for this research work is collected from Sof Umar marble industry that is thrown as a waste product. The chemical composition of marble dust showed that the most dominant oxide existing in marble was CaO as shown in Table 3.4. This oxide is very necessary especially in cement hydration to give early strength. Sio_2 and Mgo are also the other oxides that are too much in percentage than other oxides. The marble dust for this research work is blended with soil from 5% up to 15% as presented in Figure 3.5a.

Table 3.4: Chemical composition of Marble dust

Chemical oxides of the marble dust and their chemical Composition											
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	H_2O	LOI
17.86	<0.01	<0.01	44.68	2.36	<0.01	<0.01	<0.01	0.02	0.03	0.04	35.29

(a) (b)

Figure 3.5: Marble dust used in Laboratory (a) and marble dust deposit at the field (b)

3.2.4 Water

Throughout the investigation tap water, which is supplied by the Adama town water supply system of the city, is used. This water was used during soil block production and for curing purposes. Water is used for hydration reaction as it leads to gradual hardening of the cement.

3.3 Experimental design and specimen preparation

The properties of the constituent materials used for the production of compressed stabilized Soil blocks (CSBs) investigated in this study, were obtained from laboratory tests to ensure the adequate design of soil mixtures. The designed soil mixtures were developed through trial and error to ensure the production of blocks with a quality representative of those that were used for the construction of housing developments in Adama town.

In this research, the experimental design to fabricate specimens for a laboratory test and the material notation associated with each CSB type, the constituent material properties, and the methods applied to prepare the CSBs, are clearly explained. A sufficient number of CSB samples from which statistical Generalization can be made is produced and quantitative experimental results from samples with various inputs are analyzed. During data analysis for the designed specimen, the effects of the main input variables in CSB production and the experimental data obtained with theoretical predictions and other available data on CSB variables are also investigated.

The laboratory tests had to be completed within a limited time. For this reason, the number of samples produced as described in this research was meant to satisfy only a minimum number of samples required for the tests. For all laboratory tests, attempts were made to ensure that the results obtained satisfied three basic conditions: accuracy, reliability, and reproducibility. Only standard methods were used in the production of CSB samples. The measurements made on block samples were limited to dimensions, weight, shape, and the specimens were then marked and labeled for further extensive tests.

3.3.1 Experimental design

Variation of the quantity and ingredient from which the specimen is fabricated can influence the accuracy and reliability of the test. Therefore, in this research similar constituent materials and stabilizers were used to fabricate all specimens for further laboratory tests. For a meaningful experiment, it is unsupportive to vary all the input variables at the same time. The experimental design was therefore based on fixing some of the variables while varying others by a different percentage. The control (independent) variables were taken as the composition variables (soil type, stabilizer, water) and process variables (compaction pressure, curing conditions). The main variable fixed was the soil type as the soil is the most constituent part of the block as presented in Table 3.5. All block samples were made using the soil of fixed composition.

In this way, the effect of varying the stabilizer type and content, compaction pressure, mix-water content, and curing conditions on the properties of the soil block could be easily monitored. It was also considered necessary to specify the number of observations, the values of the control variables at every observation, and the order of observations. The main variables that affect the experimental investigation are the type of stabilizer, mix proportion, compaction pressure, and water absorption. In this investigation, the properties of the traditional block type and improved block type are compared. The performance of the improved block was also analyzed in terms of composition and strength to show the necessity of stabilizers to increase the age and strength of the block.

The basis of the percentage usage of each stabilizer was a pilot study prior to the test. This pilot study test is based on the dry density of the block which was developed through trial and error. The test shows that the mass of block blended with more than 15% filter cake is decreased and the mass of block containing cement above 10% has not had that much difference from 10% of cement. But, as more marble dust is added to the soil block dry density increase. Therefore, to assess the effect of all stabilizers the same percentage and similar trend are used from 5% to 15% for all stabilizers added to the soil. The amount of filter cake is fixed from 5% up to 15% as the more amount of filter cake makes the block less in dry mass. The same is true for cement because to assess the optimum amount of cement less than 15% amount of the cement is used in the test. And also the same procedure was applied to marble dust to fix its percentage usage. The dry mass of soil and stabilizers is fixed as presented in Table 3.6 below.

Table 3.5: The main constituent materials and input variables used in the production of soil block specimens.

s/n	Input variable	Amount (%)		Experimental design	
				Fixed	varied
1	Soil			✓	
2	stabilizers				
	OPC	5%, 10%, 15%			✓
	Marble dust	5%, 10%, 15%			✓
	Filter cake	5%, 10%, 15%			✓
	OPC & Marble dust	2.5%, 5%, 7%			✓
	OPC & Filter cake	2.5%, 5%, 7%			✓

In this research different experimental design was carried out by varying quantities of the stabilizing materials expressed as a percentage of the dry mass of the blended soil, and the corresponding binder total of each group.

Table 3.6: The stabilizing material and the associated binder content are expressed as a percentage of the dry mass of the blended soil.

Specimen notation	OPC cement	Marble dust	Filter cake	Total binder used	Soil	Water content
CSB_0	-	-	-	0	100%	20%
CSB_1	5	-	-	5	95	20%
CSB_2	10	-	-	10	90	20%
CSB_3	15	-	-	15	85	20%
CSB_4	-	5	-	5	95	20%
CSB_5	-	10	-	10	90	20%
CSB_6	-	15	-	15	85	20%
CSB_7	-	-	5	5	95	20%
CSB_8	-	-	10	10	90	20%
CSB_9	-	-	15	15	85	20%
CSB_{10}	2.5	2.5	-	5	95	20%
CSB_{11}	5	5	-	10	90	20%
CSB_{12}	7.5	7.5	-	15	85	20%
CSB_{13}	2.5	-	2.5	5	95	20%
CSB_{14}	5	-	5	10	90	20%
CSB_{15}	7.5	-	7.5	15	85	20%

The first nine groups of CSBs contain a binder content of 5%, 10%, and 15%. The stabilizers used in the first group are used solely by mixing with soil. The second six group of CSB contains both cement and filter cake or marble dust as stabilizers. These six groups were determined based on the half of maximum dry mass achieved by stabilizers and the same trend was applied for cement partially replaced material starting from 2.5% to 7.5%. The maximum mass of the filter cake block is obtained at around 13% and the maximum mass for the cement block is 14% . as the marble dust block mass increases. A maximum of 15% is taken as the maximum dry mass of all stabilizers.

3.3.2 Preparation of soil sample for soil block production

The planned experiments required a large number of specimens developed by different stabilizers which have accuracy and consistency. So, extra care is required during different stages of Block production. These stages of the block production process include; soil preparation, mixing, compression, and curing of the samples.

Since the preparation of specimens was considered to be one of the most important stages in the execution of the experiments, extra care was taken with the soil, cement mix, marble dust mix, filter cake mix, moisture content, compression, curing, and sizing of the samples. The high levels of accuracy, reliability, and consistency demanded by the experiments be maintained throughout the testing regimes, and for all the different types of tests conducted. Specimen preparation describes the raw materials used, the mix proportions, and the addition of moisture, the compression method used, the curing regime, and the dimensions of the samples.

Patowary et al., (2015) point out that the soil would have an optimum raw materials composition of sand 70%, fines (silt and clay) 20% of the fines, and at least not less than 10% has to be clay. The actual mix then used consisted of: Sand, Silt, and Clay were identified. A particle size distribution test by sieve analysis and a simplified sedimentation test were used to confirm the limits for the different constituents. The actual composition of Adama area soil showed 68.5% sand, 10.5% silt, and 20% clay. Proportioning the mix of the soil raw material with the cement, marble dust, and filter cake was done in varying quantities.

3.4. Determination of soil texture and soil sampling

The soil sample is taken from different points and the soil texture of the study area was determined by a triangular soil profile after calculating the percentage of clay, silt, and sand. Soil texture refers to the relative proportion of particles or it is the relative percentage by weight of the three soils separates like sand, silt, and clay, or simply refers to the size of soil particles (Das, 2019). Depending on laboratory results and percentage calculation of clay, silt, and sand the soil texture of the study area was determined. A lot of soil samples are collected from various selected points at 0-1 m depth of soil. These soil samples are analyzed at Adama Science and Technology University in the Geotechnical Laboratory.

3.5 Curing condition

The freshly molded block was immediately placed under a plastic shelter, then the blocks were shielded from direct sunlight and strong winds using this plastic sheeting. In addition to covering the block with a plastic sheet, it is necessary to place an area where sunlight does not directly apply to the block. In this study the block is shielded with a plastic sheet and the upper surface is covered with thick material to control the temperature of the block. Then, the covered block is cured once every 24 hours. The blocks were placed in the curing room until the day of testing, to carry out the test on the block sample prepared for this purpose was taken from the curing room and a test proceeded on the block directly after a few minutes. Unless specified purpose the block must not remove from the curing room. It is possible to use the curing conditions following the air dry conditioning method specified in BS EN 772-1 for different studies. This standard specifies that the methods of curing for masonry units are putting the compressed soil block in a storage temperature above 15°C and relative humidity below 65%. This should be maintained for a minimum of 14 days to get a good block.

3.6 Laboratory test on suitability study of soil for the production of the soil block

The fundamental laboratory tests were carried out for determining suitable soil types for the successful production of soil blocks. This study critically examines and analyzes soil properties in laboratory tests to decide the results for soil suitability.

Based on laboratory results, the suitability of the soil was checked based on African Regional Standard (ARS). As per ARS 680:1996 Code of practice for the production of compressed earth blocks. This standard has a graphical representation that specifies a suitable soil type for soil block. The criteria of soil block set by Spence and Cook were also checked to determine the suitability of soil for block production. This standard specifies suitable soil on a graphical plot on a triangular U.S Bureau of public Road particle size graph and plasticity chart. In order to check the suitability of the soil to be used as construction material for soil blocks, its geotechnical properties are required to be assessed. The purpose of this study was also to investigate soil samples and compare them with soil suitability criteria and for selecting suitable soil for compressed soil blocks.

Several physical properties and chemical compositions of the soil were analyzed and processed. These properties are the main properties used to characterize the soil samples. For particle size distribution and Atterberg limits of soil samples, their values and the techniques used were compiled in tables and then compared with the upper limits of various criteria and requirements. Out of the comparison, a suitable soil application technique for the soil samples based on the requirements was recommended. This helped in determining the suitability of the soil for soil blocks used as a construction material.

3.6.1 Sieve Analysis

A sieve analysis is an analytical technique used to investigate the grain size distribution existing in soil having a diameter of greater than 75 micrometers. This method helps to determine the particle size distribution of the soil material passing through a series of vertically stacked sieves that progressively had smaller mesh sizes. The smaller grain size of the soil retained at the bottom and all the sieves stacked from the bottom to top are in order of increasing sieve size. The sample of soil is poured into a set of sieves arranged according to their size and each particle in a set of sieves is shaken for ten minutes until the allowable size made them pass through and lastly retained according to their size. The test was carried out per the ASTM D422 – Standard Test Method for Particle- Size Analysis of the Soils.

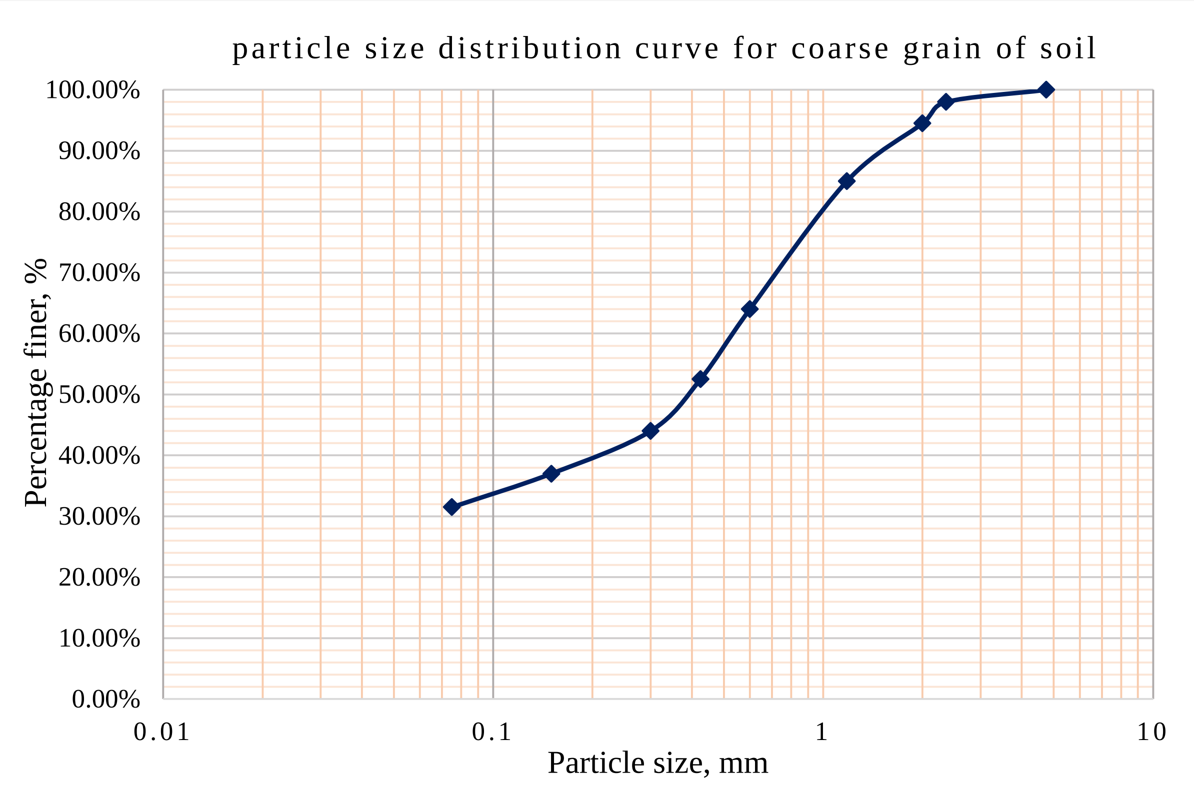


Figure 3.6: Sieve analysis of soil

3.6.2 Hydrometer Analysis

Since the soil is not purely found as sand, clay, or silt it is necessary to investigate the particle size distribution of fine-grained soils that are retained on the pan during sieve analysis. The particle size distribution of soil contains a significant number of finer particles which cannot be analyzed only by carrying out a sieve analysis. This fine soil most of the time retained on the pan and pass through the number 200 sieve. This fine-grain soil that is retained on the pan is not able to be classified only by sieve analysis. Therefore, the classification of such fine-grain soil is performed using the soil hydrometer analysis test. This hydrometer or sedimentation method is carryout by putting a hydrometer into the soil slurry solution and by reading each graduated hydrometer value for the required time of settlement. The hydrometer analysis is based on Stokes' law to calculate the size of soil particles from the speed at which they settle out of suspension from a liquid. This test is used for calculating the sample finer than the No. 200 (75µm) sieve and retained on the pan. Results from the test shown in Figure 3.7 the grain size distribution for soils and, when combined with a sieve analysis, offer a complete gradation profile of soils containing finer and coarser materials.

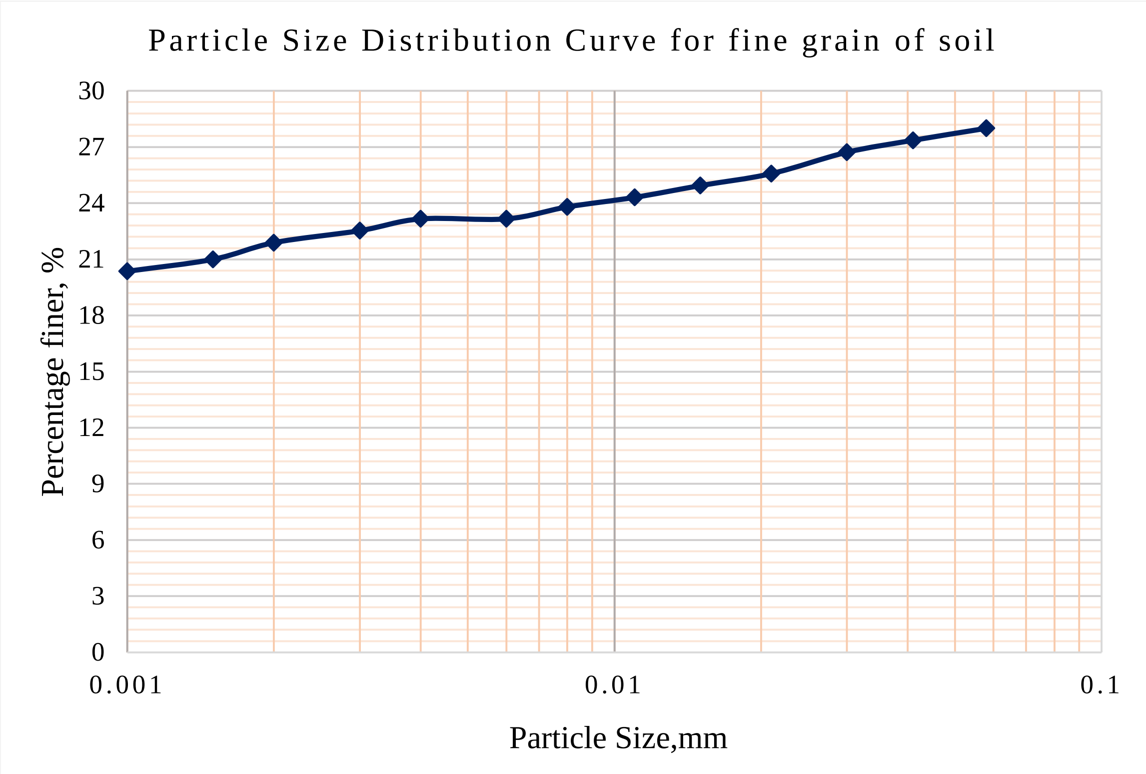


Figure 3.7: Hydrometer analysis of soil

3.6.3 Atterberg Limits

Atterberg limit is a borderline of soil state at which different water content can change the state of soil from one state to the other. This range has a limit at its end border. The end border is a limit that the test is carried out to determine the state of soil for one state is the end and the next state is the starting bound.

This investigation is performed to determine the plastic and liquid limits of fine-grained soil. The Atterberg limits are based on the water content of the soil. The state from semi-solid to plastic state is the plastic limit. It is the water content that defines where the soil changes from a semi-solid to a plastic (flexible) state. And also the limit that is found between plastic and liquid state is the liquid limit. It is the water content that defines where the soil changes from a plastic to a viscous fluid state. The liquid limit of Adama soil is presented in Figure 3.8. and its liquid limit is 32.324 at 25 blows. And also the plastic limit of the soil is the average water content at which the soil is crumbled. Adama soil has a plastic limit of 21.93.

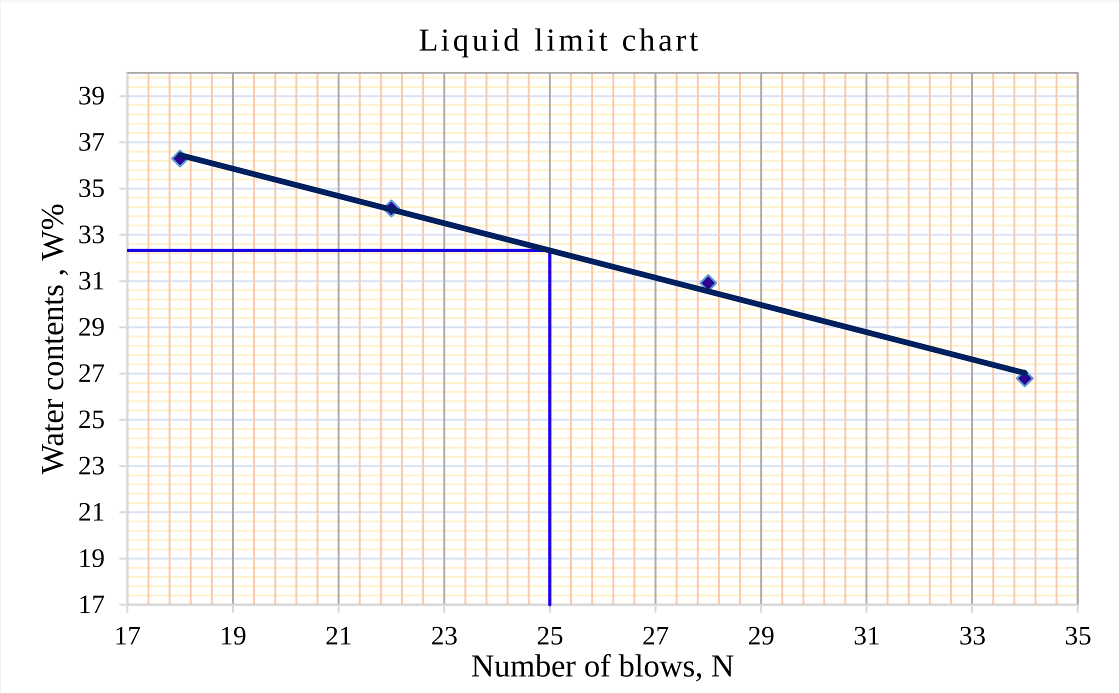


Figure 3.8: Liquid limit graph of Adama area soil

3.6.4 Specific Gravity

Specific gravity is the value calculated by the ratio of the unit weight of soil at a stated temperature to the unit weight of the same volume of gas-free distilled water at a stated temperature. The test is considered a room temperature to analyze the specific gravity of soil. It is a test that is carried out by taking distilled water as a reference point because distilled water has a specific gravity of 1g/cm^3. This laboratory investigation follows the ASTM D 854 Standard for laboratory results of the Adama area soil used for stabilized block and the soil of Adama has a specific gravity of 2.60.

$$GS = \frac{(M2 - M1)}{(M4 - M1) - (M3 - M2)GT}$$

Where, M1=Weight of density bottle

M2=Weight of density bottle +Soil

M3=Weight of density bottle +Soil + Water

M4=Weight of Water + density bottle

GT=Specific gravity of distilled water.

3.6.5 Proctor compaction test

The standard proctor test was used to determine the optimum water content of the soil at which it can reach its maximum dry density. The test carried out was the standard proctor per ASTM D698 Standard Test Methods for Laboratory Compaction test. The soil was air-dried and placed in a mold and compacted in three layers with 25 blows per layer from a standard hammer of 5.5 pounds dropped from a height of 12 inches. At the end of the test, a sample is removed, and the water content and dry density are determined. A set of results are then plotted using dry unit weight versus water content. From the plotted curve, the maximum dry density and optimum water content were determined as shown in Figure 3.9.

This test is used in soil blocks for two main reasons. The first reason to proceed with this test is to calculate the maximum amount of water used for mixing each block during the fabrication of the block. It means the compressed soil block dry density is reached when optimum moisture for soil during compaction is attained. Therefore, during soil block production through compressing machine the same amount or less than optimum moisture calculated from compaction is used. The second reason to carry out this test during soil block experimental investigation is to classify the range of suitable soil types. Researchers used different ranges of suitability studies. To approve these ranges the test was used as a measured way to identify soil whether is suitable or not.

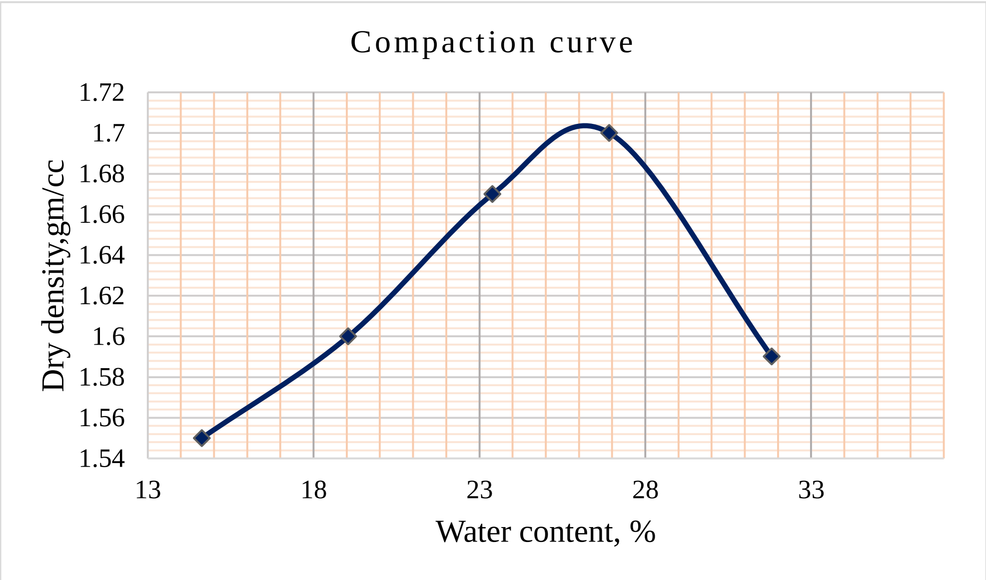


Figure 3.9: Standard proctor test graph of Adama area soil

3.7 Mechanical characteristics and physical properties of soil block.

This research investigated the mechanical characteristics of the block produced in the laboratory by considering the forces applied by man or using a compression machine. The specific reaction of the soil block to these forces is a critical area of interest. The basic mechanical and physical tests proceed in the laboratory to examine the load resistance ability of stabilized soil blocks including - Compressive strength test, Effect of compaction pressure, Water absorption test, Dry density, and Scanning Electron Microscope Images (SEMs**).**

Physical properties can be used for proper monitoring of materials. To evaluate material resistance in extreme weather conditions. And also Mechanical properties determine how the materials perform when different forces are applied to them. Mechanical properties like compressive strength and the effect of compaction pressure are properties that are determined by applying static and dynamic load on material to calculate its performance.

3.7.1 Compressive strength test of the stabilized soil block

The compressive strength test is used for many construction materials as a measure of the quality and strength of a material. Computation models generally use compressive strength to determine the size of a structure. As compressive strength is regarded as one of the main structural material characteristics, it is often considered to be a measure of quality for all building materials. Therefore, the same is true for soil blocks.

Soil block is construction material used for the construction of housing that should be able to bear the loading applied. The total amount of vertical load a soil block will be able to carry can be established if the compressive strength of the unit is known. This compressive strength test is obtained by compression machine through vertical applying a load and then the block under load is failed at the maximum load as shown in Figure 3.10. This is an important parameter as it assists the engineer with the design process and establishes whether the masonry unit is fit for the required purpose. To investigate compressive strength for each addition of stabilizer at least three blocks were produced and around 192 blocks were produced for the whole test of compression strength.

(a) (b)

Figure 3.10: a) compressive strength testing. b) Block failed at maximum load

The fabricated block has an average dimension of 290 x 140 x 100. During the test, the block area and weight are calculated before it enters the compression machine. Because the compression machine needs raw data of the surface area and load increasing per second on the block. This data is used in the compression machine to calculate the maximum load resistance of the block.

Figure 3.11: Stabilized soil blocks that have an average dimension of 290mm x 140mm x 100mm

3.7.2 Capillary water absorption test

The tendency of building material to absorb and transmit water through capillary action is known as the sorptivity of the material. This property can easily be measured by the test method described in BS EN 772-11: this standard points out the Determination of water absorption of aggregate concrete, natural stone masonry units, and the initial rate of water absorption of clay masonry units. This research work is also proceeding test by following this standard to determine the initial rate of water absorption of two CSBs per group. The CSBs subjected to the water absorption test was manufactured in the same way that a block for compressive strength is produced.

Water absorption is one of the main causes of deterioration of soil blocks because as the water enters the inner part of the block it starts to occupy space and create a porous void that decreases the load resistance of the structure. This water also causes swelling up of the block. The main factor affecting the durability of soil block is also water absorption. Hence, the basic principle of stabilization is to prevent water attacks to obtain a durable material. The amount of water absorbed by a masonry unit significantly influences the durability and structural design life of a building. A primary requirement of a soil block is to keep the occupants dry, therefore the outer wall of a house should be able to resist the ingress of rain. The porous nature of soil block masonry units and the imperfections within joints prevent soil block from fully resisting the ingress of moisture. However, the addition of a suitable stabilizer in adequate quantities to the blended soil assists in reducing the percentage of water absorbed.

Water absorption test for soil block is carried out three days before testing, the blocks were removed from the curing room and placed in a thermostatically controlled oven set to a temperature of 105°C for 48 hours. After the period of 48 hours, the soil block reaches a constant mass. Upon the completion of the drying period of 48 hours, the soil block was removed from the oven and allowed to cool at room temperature for a period of 24 hours. The dimensions of the bed face of each cooled soil block were measured and recorded, from which the gross area of the bed face was calculated. The block was placed in a crate in bed face orientation on a rubber mesh or other material that freely circulates water to the bed face of the block as shown in Figure 3.12. Then, Water was slowly poured into the crate until the soil block was immersed at a depth of 5mm ± 1mm. This water level was kept constant throughout the duration of the test.

The soil block is slowly and systematically removed from a crate after a period of 1 hour. Then, the excess water on the surface of the block was wiped off after which they were weighed and then re-immersed. This process was repeated at 3 hours, 6 hours, 24 hours, 48 hours, and after 72 hours on the set of the sample. Within a period of 72 hours, the soil block reached a constant mass and become fully saturated. The recorded masses of each specimen were used to calculate the initial rate of water absorption with:

$$Wi = \frac{Mw, s - Md, s}{As * t}$$

Where

Wi the initial rate of water absorption of the specimen, [kg/ (m2.min)]

Mw, s the mass of the wet specimen after the 72-hour soaking period, [g]

Md, s the mass of the specimen upon the completion of the drying period, [g]

As the gross area of the bed face of the specimen, [mm^2] & t is time in a minute.

(a) (b)

Figure 3.12: a) oven-dried stabilized soil block sample b) water absorption test of soil block.

3.7.3 Compaction pressure on soil sample

The compaction pressure test is a process of applying a given compaction effort to a soil matrix within a mold that causes the expulsion of air and water present in the soil particle. The application of this compaction effort causes the rearrangement of soil particles and the migration of water in the void space. During the compaction pressure test, a mold load of different weights and heights drops upon the block of soil to increase the load resistance of the block. This different weight and height load of mold have a different effect depending on the load applied to masonry units and although the stabilizer content that could be responsible for binding, sealing, reinforcing, and connecting the block has also a great effect on the compressive strength of soil block.

The air expelled through compaction can only exit the mold from the side on which the compaction is applied. A rapid reduction of volume was observable during the test yielding an impermeable and densified solid block. The testing result of this research work showed that the block produced with high compaction pressure has high strength than the block produced by aura press3000. Because manually operated machine-like aura press machine of soil block apply small compaction effort. According to Malherbe, (2016) manually operated machines like the CINVA-Ram, generally, exert a compaction pressure of 2MPa. But most hydraulic machines can exert a compaction pressure of 10MPa. This increasing compaction effort from 2 to 10MPa results in the production of a block 2.4 times stronger than the block produced with a 2MPa compaction pressure. The compaction pressure test of this research work is used 6, 10, and 14MPa compaction efforts.

3.7.4 Dry density

Dry density is also an important test carried out in the laboratory on soil blocks. Prior to proceeding with this test, a soil block placed in a thermostatically controlled oven is removed and the dry density of the block is determined when the mass of the soil block sample within a consecutive 24 hours has no change in weight greater than 0.1% of the initial mass measurements. Then each block's length, height, and width are measured to enable the calculation of the volume and at the point, the soil block reaches equilibrium all blocks were weighed, and their masses are recorded in grams to calculate dry mass. Figure 3.13 below shows the over-drying of the block and its weight for calculating the dry density of the block.

(a) (b)

Figure 3.13: a) oven drying of soil blocks b) weighing soil blocks

A dry density can be increased by adding a byproduct of industrial residues, this method increases the soil mixture to obtain the recommended grading. The marked increase in density was witnessed in improved stabilized blocks due to the inclusion of this industrial residue.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

Several tests were conducted on compressed stabilized soil blocks to develop soil blocks as sustainable construction material. The conducted tests can be divided into suitability study tests, non-structural tests, and structural tests with economic analysis of soil block.

The suitability study tests allowed us to select the best fit soil to develop the block for construction purposes. This Soil selection is regarded as the most fundamental step in the soil block production process as soil blocks are comprised of soil as a major part of the ingredient. To check the suitability of the soil to be used as a construction material for soil block production, its geotechnical properties are required to be assessed. The investigation and evaluation of basic engineering properties of soils are used to understand and interpret how soils will behave in the field and to support as the soil is suitable for successfully producing compressed stabilized soil block.

The structural tests allowed the measurement of the compressive strength, while the non-structural tests allowed the measurement of the material density and water absorption of soil blocks stabilized with various stabilizers. Both structural and non-structural tests are used to approve the performance of the block to fulfill the strength needed for housing material or other types of soil construction.

Since Adama is a town found in a rift valley most of the soil found surrounding the city and the inner of the town are sand soil and sand silt that is used for soil block production by many people who have low and intermediate income. Adama town was the prime target for investigation and testing. The physical and engineering properties of existing soils are essential and can be used as a frame of reference for the behavior of strength characteristics of the soil. So, different characteristics of soil found in Adama town which are likely to have effects on the performance of the structures that are constructed with the soil block are identified before using it for block production.

This research report examined the process of soil selection for compressed stabilized soil block production and classified soil based on the existing standard. The classification of the soil is the first requirement needed to identify the natural components of soil. This classification raises the Knowledge of the soil type and properties to facilitate the optimum use of soil in the development of compressed soil block as a construction material. Soils are classified in various ways depending on the prevailing local or regional standards in a particular part of the world. Whatever the geographic location, some common procedures are usually adopted in the classification of soils.

4.2 Laboratory Test Results for the Suitability of Soil for Earth Construction

Experimental investigations were conducted to provide more precise detailed information on the soil sample. This information helps to check the suitability of the soil to be used as construction material for earthen construction. Based on various criteria and requirements the soil was checked for suitability for construction purposes. These laboratory results have mainly illustrated the manufacture of soil block as a construction material for building by analyzing data obtained in the laboratory to approve the material's performance and whether it fits the objective based on the selection criteria given in chapter 2.

In this research work, the geotechnical properties of soil samples used in the development of the soil block were investigated. These tests include moisture contents, particle size distribution, plasticity, compaction tests, and specific gravity. These tests are basic for Soil classification systems and the results of these tests are powerful tools to facilitate soil identification and predict its possible behavior. While the use of the selection criteria based on particle size distribution applies to coarse-grained soils, and for a soil containing more silt and clay content the measurement of plasticity represents a more appropriate parameter than particle size.

The laboratory tests conducted helps to establish numerical values for the soil sample parameters, even though particle size and plasticity are the two major test that plays a great role in checking the suitability of soil for block production. Primarily the percentage distribution of the different sizes of the soil particles present in soil samples and the plasticity limits values are subsequently used to determine the suitability of the soil sample for block production.

4.2.1 Particle size distribution of soil

Particle size distribution testing by sieving and sedimentation testing has become acceptable practice to evaluate soil for block production. Because the selection of the soil and the appropriate soil tests will reduce the amount of trial and error mixes required to obtain a suitable soil mixture during block production. The combined sieving and sedimentation (hydrometer) tests briefly identified the different size fractions of the soil sample. As the soil sample has a mixture of various grading that has a various effect on the physical characteristics, strength, and durability of the soil block. The results of these tests are plotted in Figure 4.1 below. Detailed raw data and test results are given in Appendix-1.

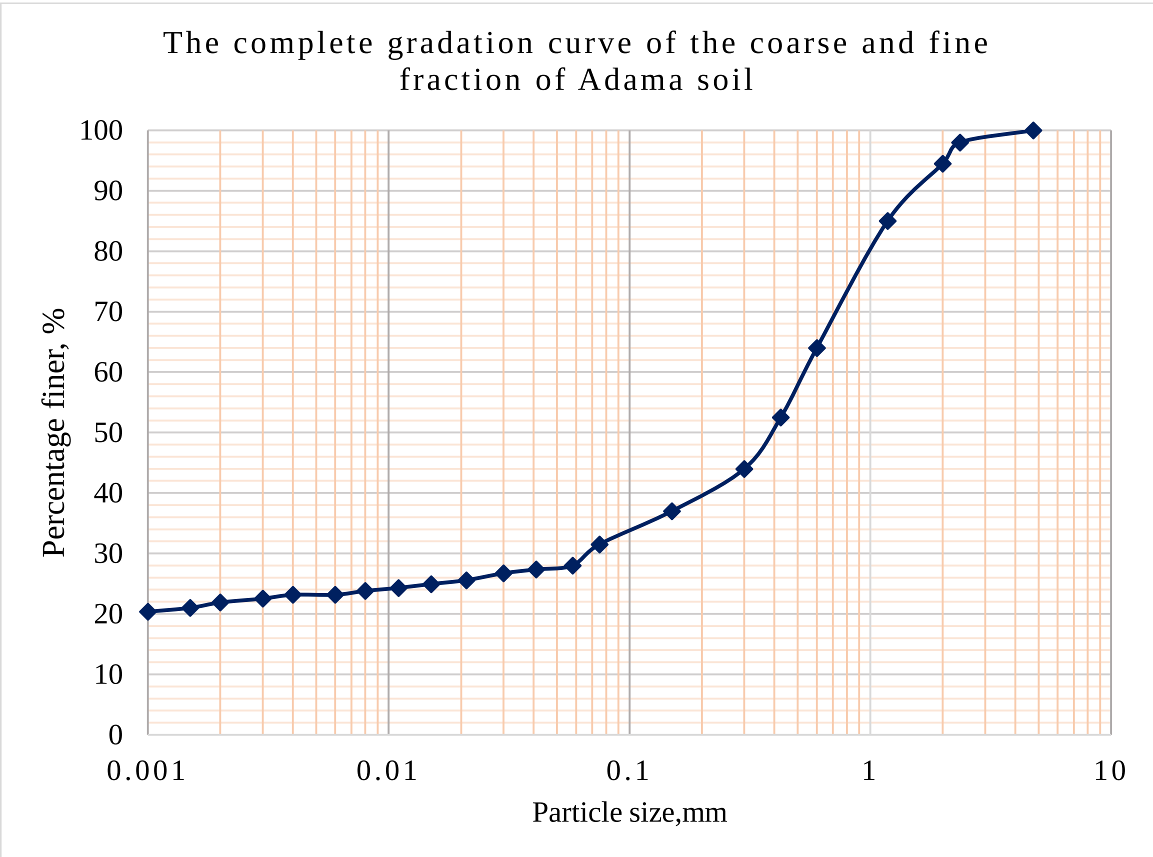


Figure 4.1: Particle size distribution of the soil from Adama town.

The gradation curve of the soil samples from Adama town on the above curve shows the actual composition of the soil used for the production of the compressed stabilized soil block is grouped as follows: Sand -68.5%, Silt -10.50%, and Clay -20%. The soil selected for use in soil block production should meet certain requirements to ensure the production of the high-quality block. Various soils possess some of the properties required for use in stabilized block production. Therefore, to check the suitability of such soils the test result was compared with the upper and lower limits of various criteria and requirements.

Based on the result obtained from grain size distribution, now it is possible to check the suitability of the soil based on the African Regional Standard (ARS). As per ARS 680:1996 Code of practice for the production of compressed earth blocks recommendations, if the granular composition of the soil falls within the dark black area that is shaded on the diagram of texture as shown in figure 4.2, it gives a satisfactory result. The gradation curve of the soil sample used for block production as shown in Figure 4.1 on the previous page falls completely within the shaded area of the diagram of texture as shown in Figure 4.2 below.

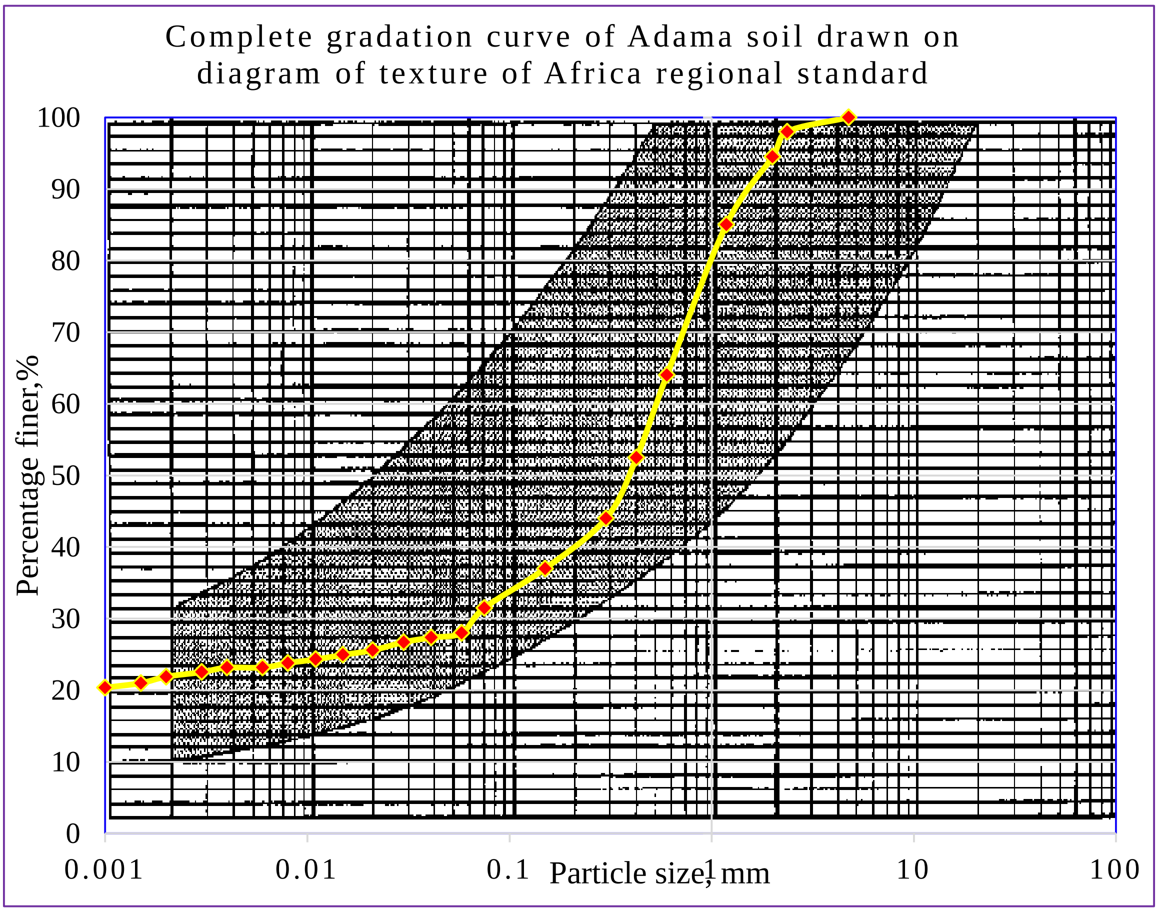


Figure 4.2: Particle size distribution of the sample soil on the diagram of texture

The graph shows that all parts of the soil particle sizes distribution result were found inside the criteria of the suitability of the soil for soil block production. This implies that the sample of soil chosen fulfills this requirement.

4.2.2 Space and Cook modifications on a triangular U.S Bureau of public roads particles size graph

Since there are different types and characteristics of soil in different places, different recommendations are made to provide a suitable grade of soil for construction purposes. One of the recommendations of such standard is space and cook modification of Triangular chart of US bureau of public roads that have a dark black shaded area in Figure 4.3 which indicates soils of most suitable for stabilization. As the soil of this research work was stabilized with different stabilizers like marble dust, cement, and filter cake for block production it is necessary to check its suitability for stabilization. This soil sample has a composition of (68.5% sand, 10.5% silt, and 20% clay).

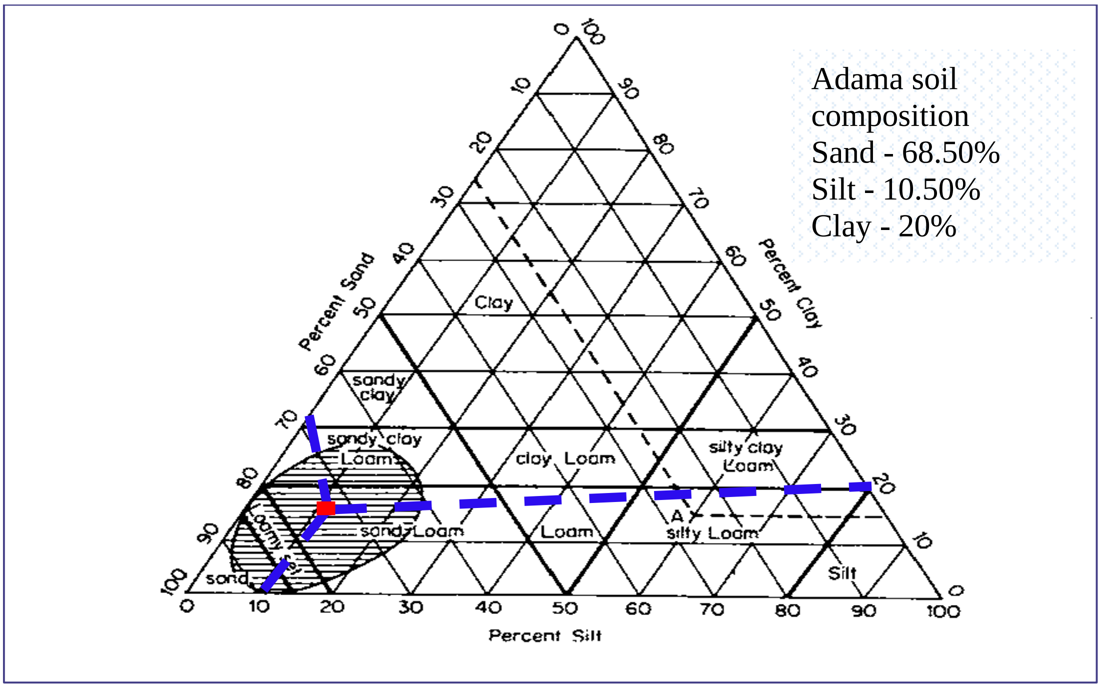


Figure 4.3: Triangular chart for particle size classification of a soil sample from Adama town.

According to Figure 4.3 above the sample of soil from Adama town that was used for this research work falls within the shaded area. This is an indicator of the soil's suitability for soil stabilized with different stabilizers for block production. The soil of Adama town was therefore found to be suitable for stabilization with OPC, filter cake, and marble dust. The soil has sufficient proportions of coarse fraction (fine gravel and sand) for the skeletal frame and body of the block, as well as an adequate proportion of fines (silt and clay). The test method used is fully described in (BS 1377-2, 1990). The particle size graph recommendation of both ARS and Space and Cook modifications on a triangular U.S Bureau of public roads approved the suitability of the soil from the Adama town by analyzing based on the mixture of different particle sizes existing in Adama soil for compressed stabilized soil block production.

4.2.3 Atterberg limit criteria (Plasticity) for soil suitability

The suitability criteria and requirements of soil for soil block production have variations among different authors. It is better to take such criteria as a guide in initial soil selection rather than as a rigid set of rules. Some authors recommend the criteria based solely on sieve analysis and others based on Atterberg limits. As per the recommendation of the literature survey the researcher checked the suitability by using both criteria. The following section discusses the criteria based on the Atterberg limits of the soil sample.

The Atterberg or plasticity test is a limit that the soil state is changed from a solid state to a plastic state and from a plastic state to a liquid state. These boundary points are plastic limit and liquid limit respectively. Both of these limits identify the moisture change boundaries of one state of soil to the next state of the soil. The result of this plastic limit and liquid limit obtained through laboratory tests is mandatory to classify suitable soil for block production and the plasticity index can be found by subtracting the liquid limit from plastic limits. These plasticity tests give an overall idea of the soil's behavior and suitability for stabilization. The test results of the soil sample from Adama town are given in Table 4.1 below but full test measurements and data records are described in appendix- 1.

Table 4.1: Atterberg limit test results of a soil sample from Adama town

Atterberg limit	values
Liquid limit	32.324
Plastic limit	21.93
Plasticity index	10.39

Based on these results it is possible to check the suitability of the sample soil for soil stabilized with cement, filter cake, and marble test for block production. The following two sections are the criteria based on the Atterberg limits of the soil sample.

4.2.4 African Regional Standard (ARS) based on the plasticity of soil

The soil sample is checked for suitability in the plasticity chart as shown below by using the Atterberg limit values from Table 4.1 above. The plasticity index of 10.39 and liquid limit of 32.324 falls in the shaded area on the plasticity chart of Figure 4.4 below. Point "A" is located in the shaded area, which indicates the suitability of the Adama area soil for soil block production.

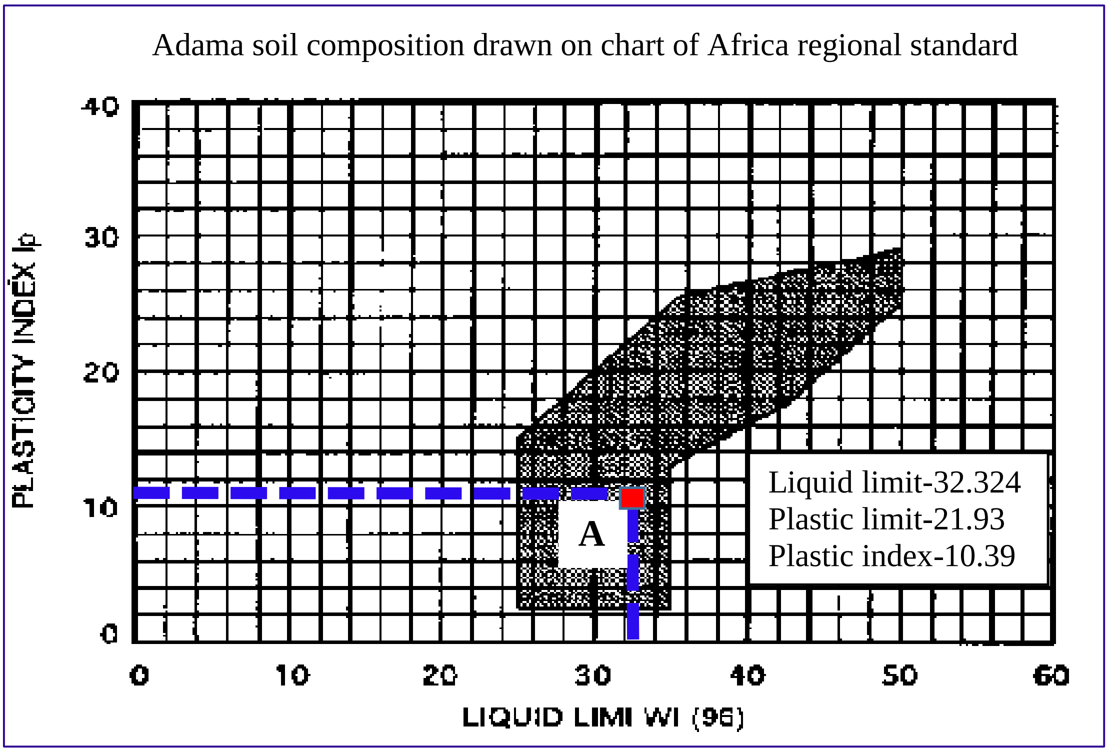


Figure 4.4: Diagram of plasticity

4.2.5 Spence, R.J.S & Cook, D.J.1983 Building Materials in Developing Countries

Spence and Cook proposed an Atterberg limits zone of soil suitability for stabilization on a plasticity chart below as shown in the shaded area in Figure 4.5. The shaded area is allowable for a soil type that has a plasticity index between 0 to 22% and a liquid limit between 7 to

39%. Since Adama soil has a liquid limit of 32.324 and a plasticity index of 10.39 it is within the range of suitable type of soil recommended by Spence and cook.

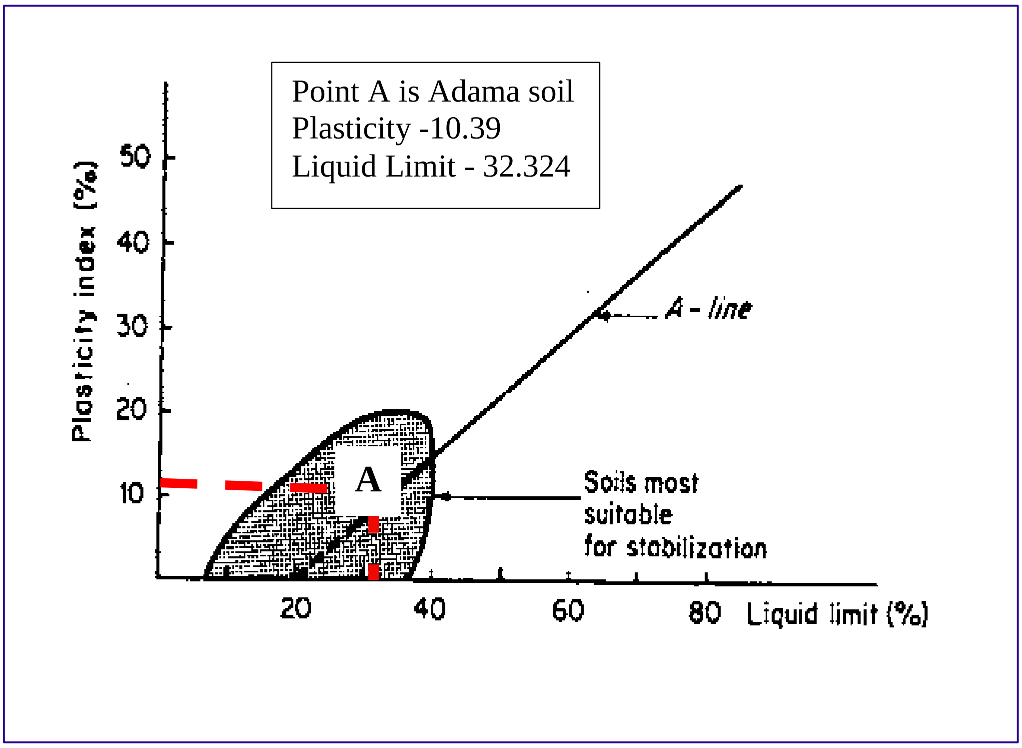


Figure 4.5: Plasticity chart

Point ‘’A’’ is located in the shaded area, which indicates the suitability of the Adama town soil for stabilized soil production.

4.2.6 Suitability criteria based on soil compaction

The index properties of soil that have graphical recommended shaded area have been checked for the soil suitability for the production of stabilized soil block and the result shows that Adama area soil is included within ranges of the shaded area. As the soil index test criteria showed suitable soil, it is necessary to check it by further test to know the point at which soil got its maximum shear resistance and high bearing capacity. So the further test to be performed by the researcher was the compaction test. The general meaning of soil compaction in soil mechanics is to press soil particles tightly together by Mechanical method to remove a void space occupied by air. It is cheap and an effective way of increasing soil strength.

The amount of compaction in a laboratory test is measured by maximum dry density at which soil gains a maximum strength within a fixed corresponding amount of water. The standard proctor compaction test is carried out to classify soil of the Adama area using ASTM D 698 Method A, and the result is plotted in Figure 4.6 and detailed measurements and raw data are given in Appendix-1. The compaction effort is the primary factor affecting the maximum dry density and optimum moisture content for a given soil type. In this compaction of the soil sample, the researcher was conducted by using a 6MPa rammer.

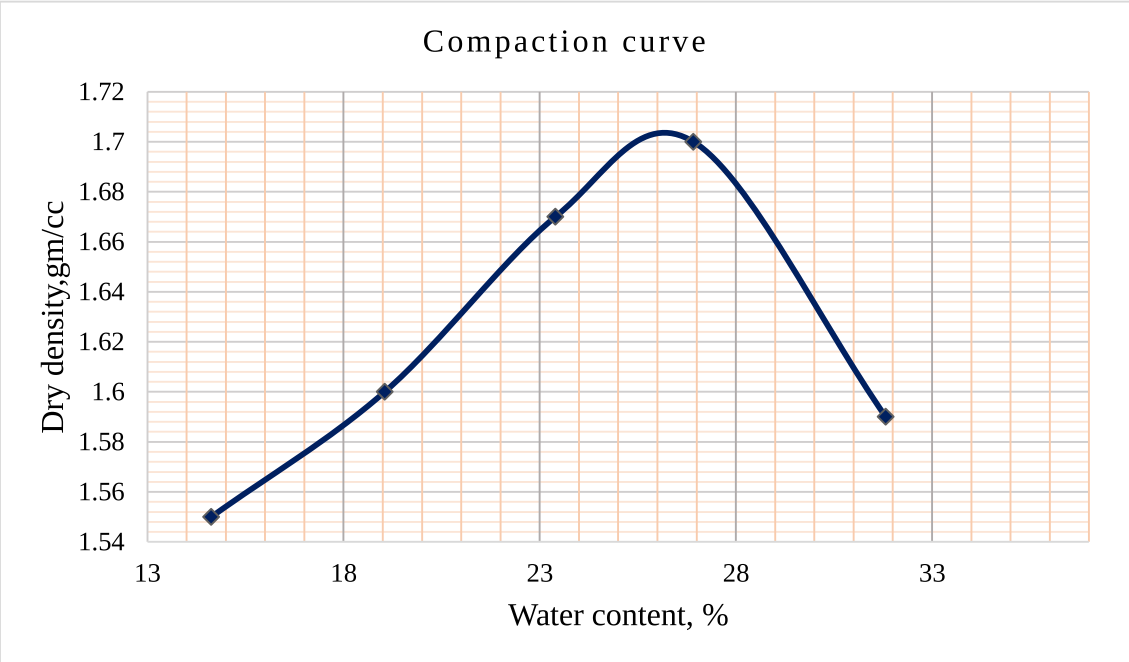


Figure 4.6: Proctor compaction curve of the soil from Adama town

According to the above curve, the maximum dry density (MDD) and optimum moisture content (OMC) of the Adama soil are 1702 kg/m3 and 26.92% respectively. This result is within the range of soil compactibility set by (Houben & Guillaud, 1994) for soil block production. The amount of moisture content used to produce soil block is initially used on ideal block length using optimum moisture content. The ideal block length was nearly 29 cm and the amount of water required to get this length was 25%.

4.3 Chemical Analysis

The materials used for the production of the compressed stabilized soil block have different chemical oxides, PH levels, and compositions. From the literature chemical properties of the soil are one of the areas of interest when chemical additives are used during the production of compressed stabilized soil blocks. In this research work, different additives are used for block production. These additives include ordinary Portland cement, marble dust, and filter cake.

The hydration reaction that proceeds when water is added to unreacted OPC particles follows two distinct phases: setting, followed by hardening, to form a cement paste. The mechanism of the reaction involving the main phases in unreacted cement (C_3S, C_2S, C_3A, and C_4AF), occurs at different rates for each phase. When water is added to the OPC particles, the reaction begins from the surface of the particles, then progresses inwards. This results in the formation of gels and ettringite. The C_3S and C_2S form gels, while the C_3A form ettringite (Kerali & Masce, 2001). The chemical reactions proceed in OPC hydration to give strength to cement constituent construction materials has four phases. These are summarized as follows.

For C_3S:- $2C_3S + 7H_2O \rightarrow C_3S_2H_8 + 3Ca\,(OH)_2$

For C_2S:- $2C_2S + 5H_2O \rightarrow C_3SH_8 + Ca\,(OH)_2$

For C_3A:- $C_3A + 3C_5SH_2 + 26H_2O \rightarrow C_6AS_2H_{32}$ (Ettringite)

$2C_6AS_2H_{32} + 2C_3A + 4H_2O \rightarrow 3C_4ASH_{12}$ (Monosulphoaluminate)

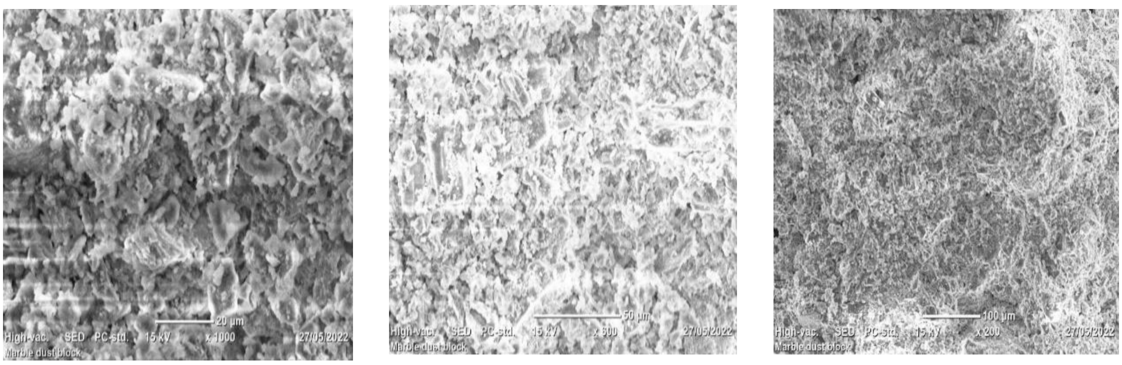
For C_4AF:- $C_4AF + 2Ca\,(OH)_2 + 14H_2O \rightarrow C_4\,(A, F)\,H_{13} + (A, F)H_3$

Since ordinary Portland cement, marble dust, and the filter cake is used as a stabilizer there is a chemical reaction carried out with soil to give strength to the block. So, to know the chemical oxides of all this material chemical analysis was conducted at the Geological Survey of Ethiopia, Geochemical laboratory. The main goal of chemical analysis is to get chemical oxide found in constituent materials used for soil block and to gain insight into the reaction occurring in compressed stabilized soil block mixture. The chemical oxide of soil has the most dominant oxide of SiO_2 around 64.66% and Al_2O_3 of 16.84%. Soil silica and alumina react with a stabilizer to form a cementing agent. SiO_2 and Al_2O_3 from soil react with CaO from cement, marble dust, filter cake, and water. This implies that given sufficient cement, marble dust and filter cake control the right strength is obtained by the block. The higher the silica contents in the soil the more active the soil and better reactive with CaO exist in marble dust and filter cake. Even though the low PH of the soil does not in themselves constitute a definite indication of poorly reacting soil, 7.34 PH level soil helps to consider the soil as good reacting soil.

4.4 Scanning electron microscope (SEM) images of the soil block

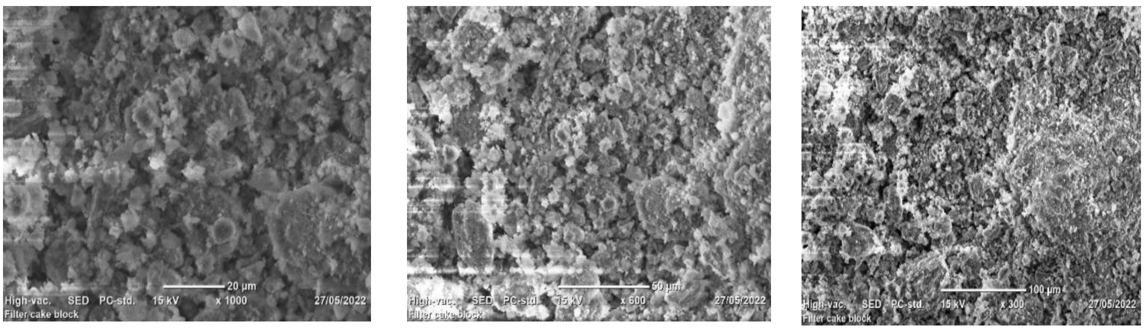
A scanning electron microscope (SEM) scans a focused electron beam over the surface of a compressed soil block sample to produce an image. The electrons in the beam interact with the sample, creating differing signals that can be employed to gain information about the surface topography and composition of the block sample that enters the scanner.

Scanning electron microscope (SEM) images of different compressed soil blocks were taken and used to clarify the difference between blocks produced with marble dust, filter cake, and cement. SEM images, taken at both a 20 μm and 50 μm scale, as shown in Figure 4.7, clearly show the angular particle shape of the cement, marble dust, and filter cake blocks.



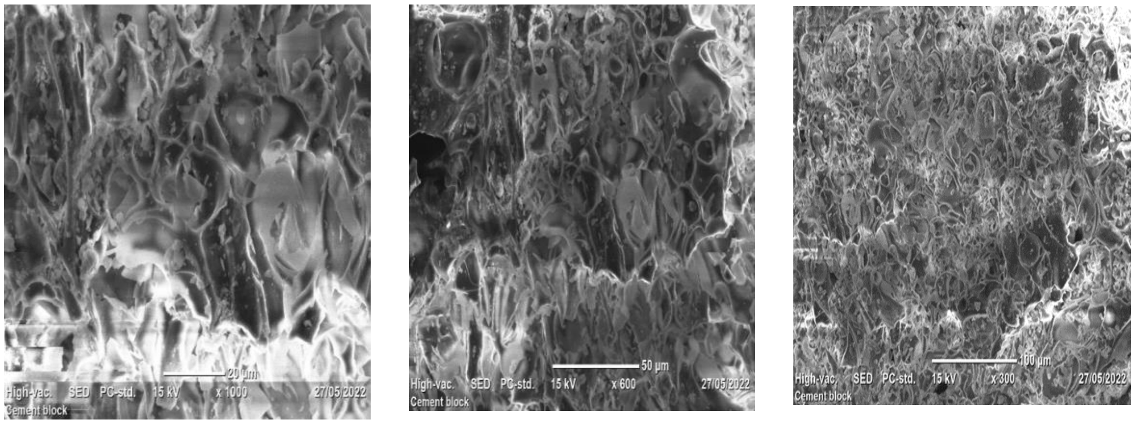
(a) 20 μm (b) 50 μm (c) 100 μm

Figure 4.7: SEM images of marble dust stabilized soil block taken at a different scale



(a) 20 μm (b) 50 μm (c) 100 μm

Figure 4.8: SEM images of Filter Cake stabilized soil block at a different scale



(a) 20 μm (b) 50 μm (c) 100 μm

Figure 4.9: SEM images of cement stabilized soil block at a different scale

As the chemical oxide of stabilizers is different the morphological structure of the block shows different shapes as shown in Figures 4.7, 4.8, and 4.9. the dark black area that is seen on the surface of the SEM images shows the void space that occupies the inner surface of the block. The marble dust has less void space than others as shown in Figure 4.7 and also there is a connected line that looks dark white line on the whole figure. These lines are the needle-like structure which is called ettringite that formed during the hydration process of filter cake, marble dust, and cement. This morphological structure has a deep relation with the strength of the block because as the void space in the block is very tiny in size the structure can resist the high load. However, when the size of the void space is big the block becomes shrink to each other and resist only a small amount of load.

4.5 Performance evaluation of Stabilized Soil Block

The performance of soil block can be influenced by the constituent material that forms a block and processing systems like an applied load to compact the soil, the amount of water used for mixing, curing system, and environmental factors during the production of the block that has a great effect on the depletion of water from the block at high speed which causes the random cracking and shrinkage. CSBs is a composite material that is brittle and able to resist load like compression and have less tension load resistance. Unreinforced masonry units behave like that of plain concrete when subjected to compression forces and tensile forces. Axial compressive loads applied normally to the bending plane are effectively resisted by masonry units, therefore it is possible to design load-bearing walls.

These properties of soil block change with the composition of soil and the percentage change of stabilizers added during production. So, to know these properties researchers are carrying out laboratory tests like compression tests, water absorption, and dry density. This chapter presents the block's properties that influence the bond strength obtainable between the block and the stabilizers, which in turn influences the structural integrity of construction with these blocks. Detailed investigations of the block's properties are thus required to be able to predict the performance of the CSBs block for construction material.

4.6 Mechanical properties of CSBs

Different tests can be classified under mechanical and physical properties among these the compressive strength of CSBs is regarded as the value by which the block's quality can be established, therefore it can be regarded as one of the key characteristics of the block itself. The compressive strength along with some of the most fundamental properties of the blocks are discussed in the subsequent sections.

4.7 Compressive strength

The compressive strength investigation for soil block is governing criteria that briefly show the strength of manufactured block as a load-bearing structural material. In this research, the compressive strength of soil blocks for different days was analyzed. This compressive strength for the block was carried out after 7, 14, and 28 days. This test proceeds at Adama Science and Technology University in the construction laboratory.

The block produced has different stabilizers that are added starting from 5 percent by an increment of 5 up to 15%. Then, the produced block is tested to measure stength in a laboratory. The compressive strength proceeded until the maximum crushing load was obtained for each sample. And the compression machine gives the maximum compressive strength by calculating the ratio of the maximum load and the cross-sectional area of the block in N/mm^2. In this research work, three types of stabilizers from different sources are used, the one bought from the local market is national cement of OPC type having a grade of 42 N.

4.7.1 Effect of cement content on the compressive strength of soil blocks

The results of the compressive strengths of CSBs at a curing age of 7, 14, and 28 days, are shown in Figure 4.10. This figure indicates that strength was gained over time as the compressive strengths were measured at a testing age of 7 days, 14 days, and 28 days. The block has higher strength at 28 days than that measured at a testing age of 7 days. Each data point in the figure represents the mean compressive strength values of compressed soil blocks stabilized with cement contents of 5%, 10%, and 15%. The average value of compressive strength (fc,d) was measured for each group. All the raw data of mean compressive strength test results are presented in a tabulated form in Appendix-3. The mean compressive strength of cement stabilized block is expressed in table 4.2 and it is summarized in a graphical form in Figure 4.10 on this page for blocks having OPC cement stabilizers.

Table 4.2: Compressive strength of cement stabilized soil blocks

mix	Mean Compressive Strength (MPa)		
	7th	14th	28th
CSB1 (5% Cement)	1.50	2.18	2.86
CSB2 (10% Cement)	2.47	3.23	4.54
CSB3 (15% Cement)	2.95	3.87	5.02

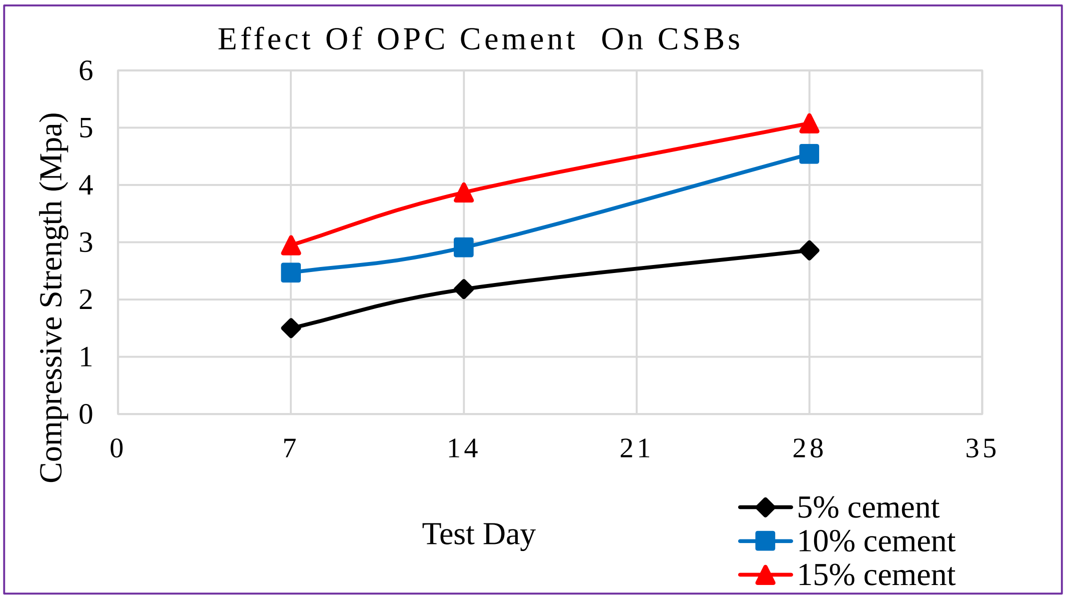


Figure 4.10: Effect of cement content on CSBs

From these results, the strength-gaining process of cement-stabilized soil masonry units is based on the degree of hydration of cement. This implies that sufficient moisture is needed within the soil mixture to allow adequate and complete hydration since inadequate moisture conditions will disrupt the strength-gaining process. Curing the block is very important until the recommended date of sufficient strength is obtained by the masonry unit. Different duration of curing is dictated by the specification based on the type of stabilizer used; 28 days when OPC is used and 56 days when hydrated lime is used (BS 890, 1972). Therefore, the increment in cement with age results in the deposition of cement gel between soil and creates high strength by interlocking the soil particles together.

From the graphical presentation of the results shown in Figures 4.10 and 4.11, the result shows that the block produced at varying cement contents from 5% in increments of 5% up to 15% at a constant compaction pressure of compressing machine. The researcher has recognized that the quantity and type of stabilizer added to a soil mixture have a great effect on the strength with the age of the block, stabilizers such as Portland cement have a significant influence on the compressive strength of CSBs.

The addition of cement stabilizers to the soil ensures the formation of calcium silicate hydrate (CSH) upon exposure to water. Because the chemical composition of soil attached to appendix-2 show that the soil is most abundant with silicon dioxide and Portland cement has a high percentage of calcium oxide, therefore, creation of CSH assists in the formation of strong bonds among soil particles, which effectively enhances the rigidity of the soil structure and leads to higher compressive strengths. An increase in cement content increases both the volume of CSH produced and the resulting compressive strength. The 28-day compressive strengths (*fc,d*) exhibited by mix CSB1, CSB2, CSB3, indicated this notion and are shown in Figure 4.11. The compressed soil block that has 15% blended cement has high compressive strength than others. This result shows as a higher percentage of cement added to the block gets high strength with curing age.

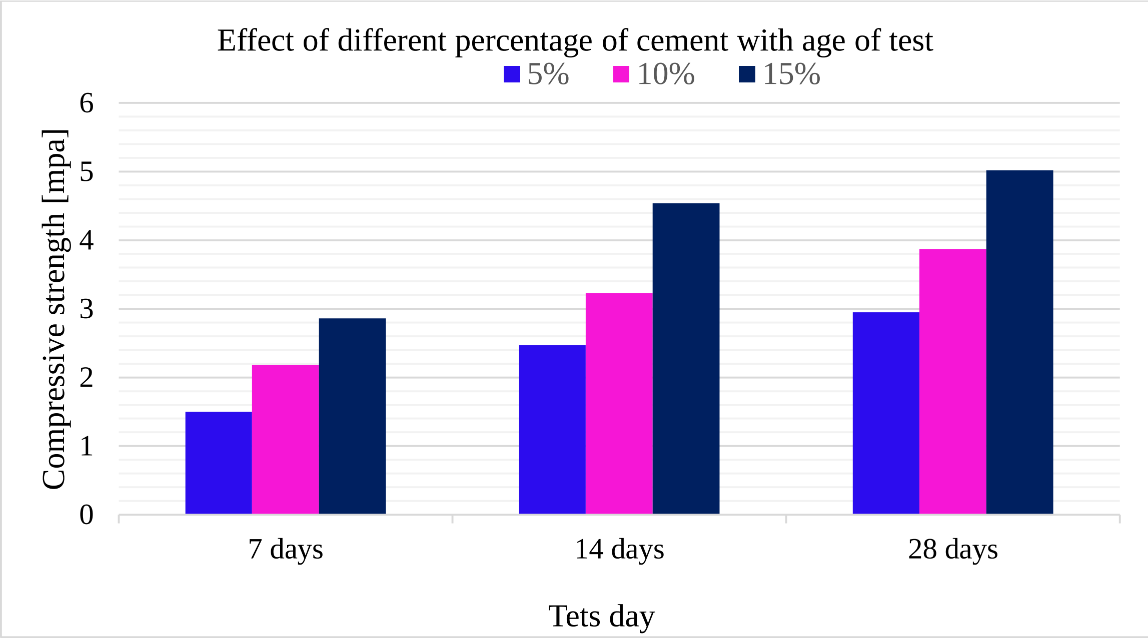


Figure 4.11: A comparison of the CSB dry compressive strengths of mix CSB1, CSB2, and CSB3, at a 7, 14, and 28-day testing age.

A similar trend is seen for the compressive strength (*fc,d*) measured and reported on the above bar chart the percentage increment to optimize the right amount of cement is calculated from the variation created from one mix design to the next. An increase in cement content from 5 to 10% resulted in a strength increase of 45% by 7 days and 31% by 28 days. However, the incorporation of a further 5% cement into the soil mixture, amounting to a total cement content of 15%, yielded a strength increase of 31% by 7 days and 30% by 28 days.

The strength gain variations observed for an increase in cement content from 5 to 10% were more significant than the strength gain observed when increasing the cement content from 10 to 15%. The occurrence of such a phenomenon highlights the significant influence of the correct amount of stabilizer on the compressive strength of CSBs. An increased tendency of soil mixtures to agglomerate was noted for higher cement contents, which negatively influenced the mixture's particle packing efficiency. The agglomeration of soil mixtures containing cement could be reduced by adjusting the amount of water added. To ensure that adding water that corresponds to the optimum moisture content of such a soil mixture. This optimum moisture content is obtained by experimental investigation of compaction tests at which soil achieved its high dry density. It should be kept in mind that the effect of additional water on the strengths obtained should be explained because the amount of water used in the mixture affects the block.

4.7.2 Effect of adding filter cake on the compressive strength of stabilized soil blocks

The 7th, 14th, and 28th days' mean compressive strength values of compressed soil blocks stabilized with total stabilizer content of 5%, 10%, and 15% with varying filter cake content are shown below and all the raw data of block compressive strength test results are presented in tabulated form in the Appendix-3. the filter cake used for this stabilized soil block is a by-product of Awash Melkassa aluminum sulfate and Sulfuric Acid Share Company.

Table 4.3: Compressive strength of filter cake stabilized soil blocks

mix	Mean Compressive Strength (MPa)		
	7th	14th	28th
CSB4 (5% Filter Cake)	1.12	1.72	2.33
CSB5 (10% Filter Cake)	2.29	2.98	3.51
CSB6 (15% Filter Cake)	2.04	2.59	3.18

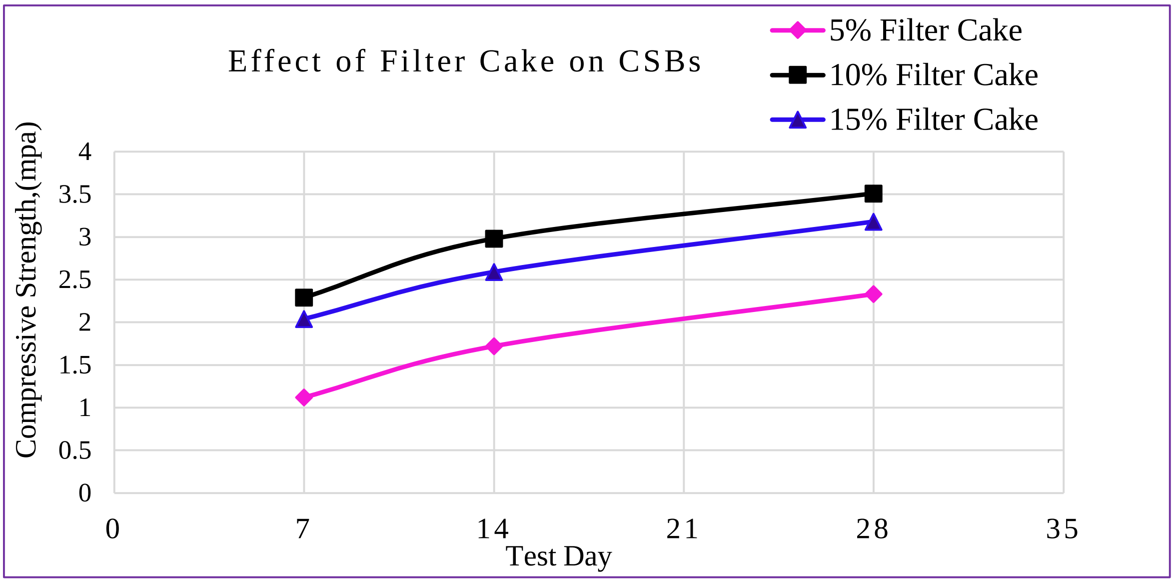


Figure 4.12: Effect of Filter Cake content on CSBs

From this result, there is declining in compressive strength after the addition of 10% of filter cake to the soil mixture. This strength reduction shows that the hydration of Filter Cake is secondary to that of cement. Because during curing with the age of cement stabilized block there is increasing of strength as more amount of stabilizers added to the mixture. This show that the optimum amount of Filter Cake stabilizers used in the production of soil block cannot be above 10%. The usage of the right amount of stabilizer has a great advantage on the increment of CSBs compressive strength and increases the life expectancy of soil block. An increase in Filter Cake from 5% to 10% resulted in a strength increase of 105% by 7 days and 51% by 28 days. This show that there is a double-fold increase of strength as the filter cake amount added from 5% is rise to 10% on the 7^{th} day and above 51% increment on the 28^{th} day. However, the incorporation of a further 5% Filter Cake into the soil mixture, amounting to a total filter cake content of 15%, did not show a good result as it yielded a strength decrease of 11% by 7 days and 9% by 28 days. Therefore the addition of 5% more filter cake from 10% to 15% cause a reduction in strength.

4.7.3 Effect of adding marble dust on the compressive strength of stabilized soil blocks

The 7^{th}, $14^{th,}$ and 28^{th} days' mean compressive strength values of compressed soil blocks stabilized with varying marble dust content of 5%, 10%, and 15% were added to a different mix in soil block production. The increasing percentage of marble dust has a positive effect on the compressive strength of the soil block. The tabulated result of mean compressive strength on the following page shows that as the quantity of marble dust used in the samples goes up there is an increase in the compressive strength. This shows that the marble dust chemical oxide has a good chemical reaction with the soil mixture to give strength with the increasing amount of marble dust.

Table 4.4: Compressive strength of marble dust stabilized soil blocks

mix	Mean Compressive Strength (MPa)		
	7^{th}	14^{th}	28^{th}
CSB7 (5% Marble Dust)	1.18	1.87	2.39
CSB8 (10% Marble Dust)	2.34	2.76	3.82
CSB9 (15 Marble Dust)	2.75	3.42	4.45

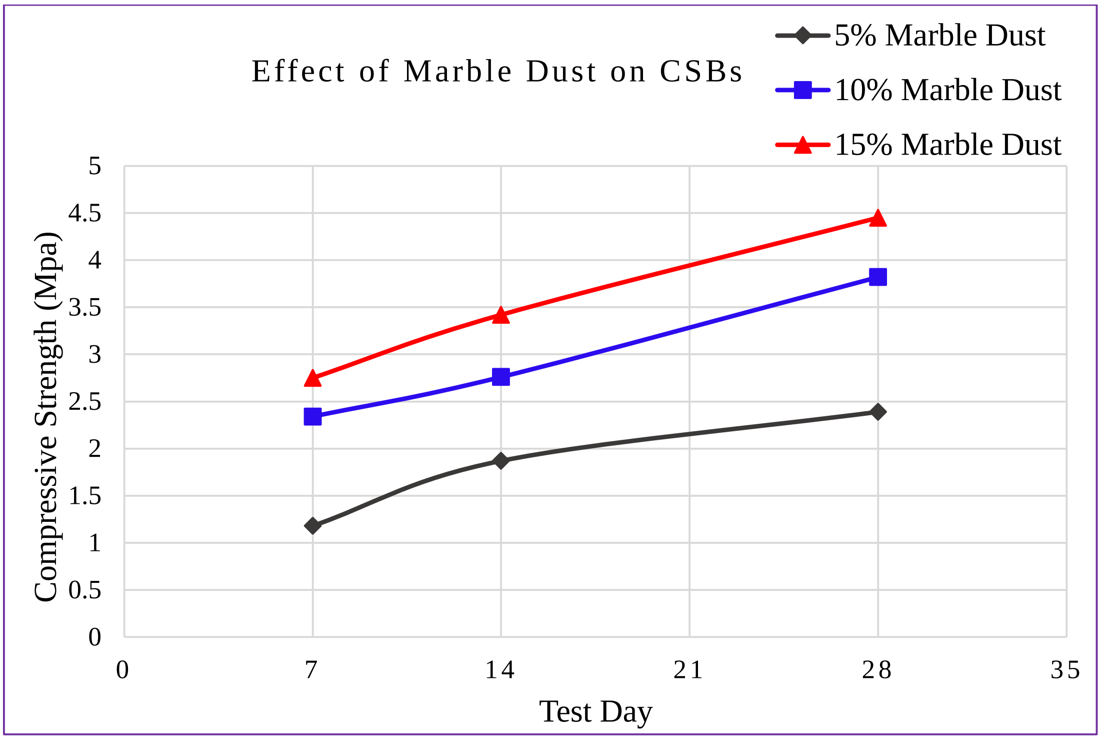


Figure 4.13: Effect of Marble Dust content on CSBs

The marked increase in strength was witnessed in all marble dust blocks with testing age. However, the block with 15% marble dust showed the greatest strength as opposed to filter cake stabilizers. In this case, the improvement can solely be attributed to the inclusion of Marble dust in the mix with soil particles. An increase in the amount of marble dust added to the soil results in enhanced bond strength between soil particles along with a reduction in the average pore size of the specimen, which in turn yields a reduction in the amount of water used for mixing during block production and increase in compressive strength as shown in Table 4.4.

The general pattern of improvement in strength and other properties of the block are undeniable. The upturn in strength is a consequence of its CaO reaction with the freed SiO2 in the soil mixture as the soil has a great amount of silica. An increase in marble dust from 5% to 10% resulted in a strength increase of 98% by 7 days and 18% by 28 days. However, the incorporation of a further 5% marble dust into the soil mixture, amounting to a total marble dust content of 15% showed a good result as it yielded a strength increase of 17.5% by 7 days and 16.5% by 28 days. This experiment test result verifies that the optimum amount of marble dust for soil block production is above 15%.

4.7.4 Comparison of cement with different amounts of filter cake and marble dust

The influence of Filter Cake on the packing of a soil mixture differs from the influence of marble dust due to a variation in both the shape and size of the particles. And also the chemical composition of the stabilizers have a great effect on the influence created in a mixture of soil for block manufacturing purpose. The particle size range of Filter cake is greater than that of marble dust therefore the ability of the marble dust particles to fill the voids within the soil matrix is superior to that of filter cake. The finer marble dust particles also provide more phase transition sites for the deposition of hydration reaction products, which positively contributes to the strength gained over time. Filter cake also has a high percentage of SiO_2 that make it similar properties to the soil as the soil is most abundant in silicon dioxide. The reactivity of the silica (SiO_2) in soil within marble dust enables an enhanced pozzolanic reactivity compared to that of Filter Cake.

The hydration of cement is more effective than the hydration of a supplementary cementitious material (SCM) as shown in Figure 4.5. As supplementary cementitious material is increased in proportion it influences the hydration kinetics of the clinker phases and the products formed. The reaction of SCMs is slower than that of the main clinker phase. This results in a decrease in early strength development when the SCM replacement level is increased (Skibsted & Snellings, 2019).

Table 4.5: Compressive strength of different stabilizers

Percentage of stabilizers	28^{th} day mean compressive strength		
	Filter Cake	Marble Dust	Cement
5%	2.33	2.39	2.86
10%	3.51	3.82	4.54
15%	3.18	4.45	5.08

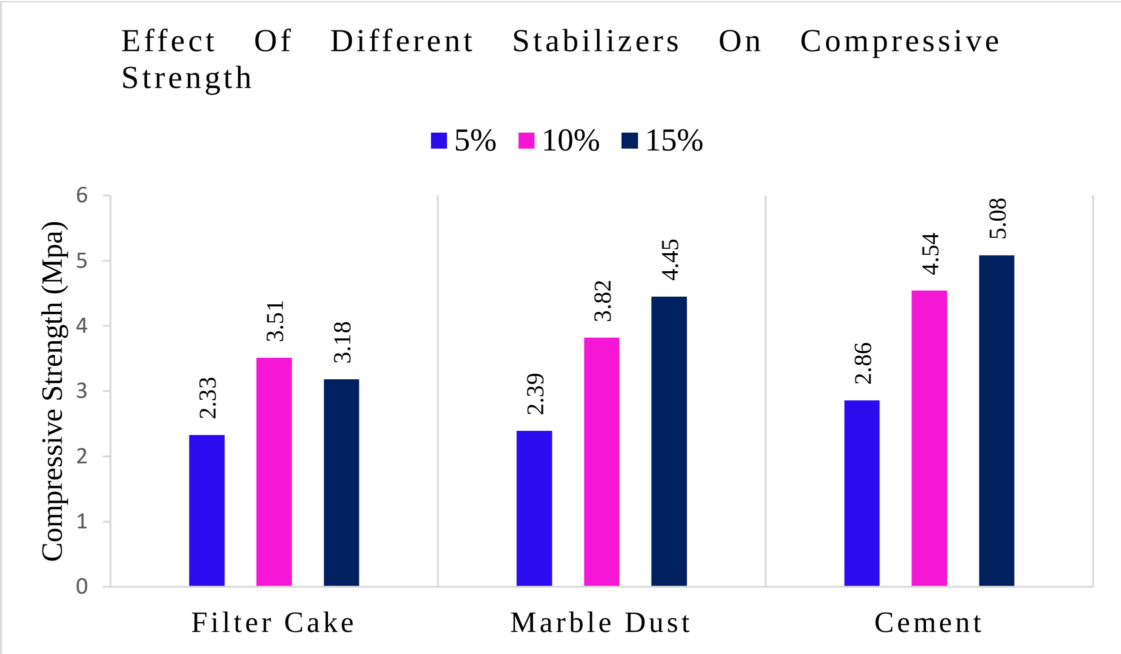


Figure 4.14: The 28-day compressive strength of CSBs manufactured with the binder content as the comparative factor.

From this result, the compressive strength gaining of cement stabilized soil block at different testing ages were sped up than other stabilizers used in soil block production. This happened due to the chemical composition of cement that gave early strength. As (BS 12, 1971; BS 890, 1972) stated that ordinary Portland cement has gained its maximum strength before the 28th day. The maximum compressive strength resulted from the block produced from the cement stabilizer. The strength of the marble dust block shows a good result with an increasing amount of stabilizers but the addition of filter cake of more than 10% is not a good result. This showed that the optimum mix of filter cake stabilizer is 5% to 10%.

4.7.5 Effect of adding filter cake and marble dust on the compressive strength of cement stabilized soil blocks

The 7th, 14^{th,} and 28th days' mean compressive strength values of compressed soil blocks stabilized with total stabilizer content of 5%, 10%, and 15% with varying amounts of cement partial replacement with either filter cake or marble dust content are shown in Figure 4.15 and Figure 4.16 below and all the raw data of block compressive strength test results are presented in tabulated form in the Appendix-3. All comparisons are made for each mixture group.

A. Filter cake Replacement

According to the tabulated results on the following page, the compressive strength of the masonry units that have both cement and filter cake rises up greater than the soil block produced with only cement. This briefly indicated that the chemical oxides existing in filter cake are more active in the early gaining of compressive strength when it is mixed with cement as shown in Table 4.6. The chemical oxide of filter cake has Cao that actively reacts with silica (SiO2) and forms CSH that gives high strength in the early stage of the masonry units. However, as much amount of filter cake is mixed with cement the mixture of soil plus cement and the filter cake is agglomerate and forms a small ball that needs more water than the designed amount of water. This formation of the agglomerated mixture causes the decrease in strength of the block that has 7.5% cement plus 7.5% filter cake.

Table 4.6: Compressive strength of cement blended with filter cake CSB

Testing age	Mean Compressive Strength (MPa)		
	7^{th}	14^{th}	28^{th}
	2.5 % C + 2.5% F	5% C+5% F	7.5% C+7.5% F
7th	2.46	3.41	3.25
14th	2.96	3.95	3.78
28th	3.49	5.53	4.73

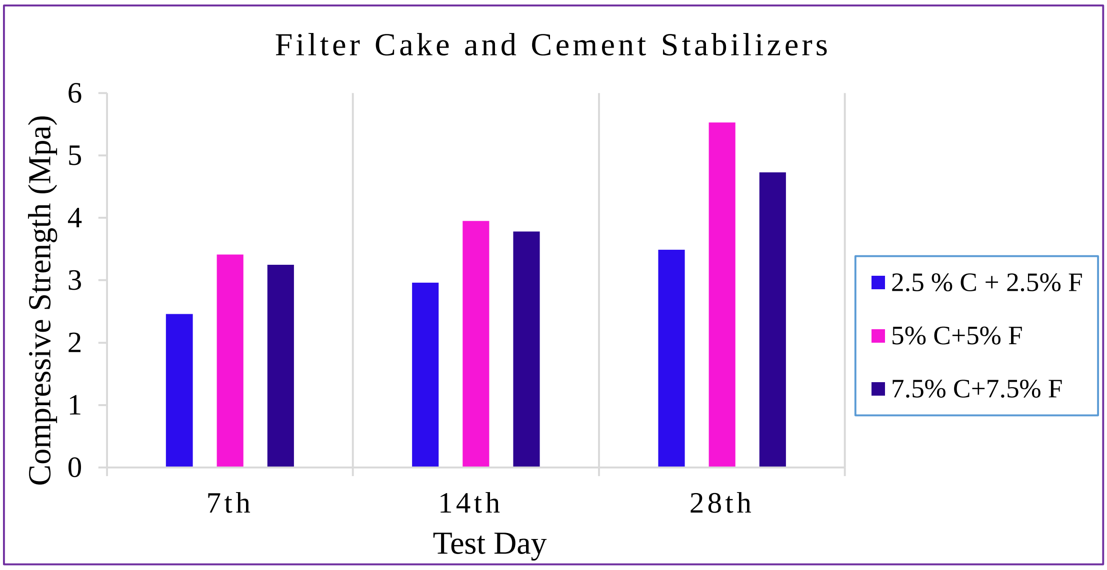


Figure 4.15: Compressive strength development of filter cake and cement replacement in soil blocks

The results of this test proved that the early compressive strength of the mixes containing filter cake and cement is greater at 5% cement plus 5% filter cake. Even if 7.5% of filter cake plus 7.5% of cement increases strength with the age of the test it has lower strength than 5% cement plus 5% filter cake. As filter cake and cement increase from 2.5% to 5%, the compressive strength by 7 days is increase by 39% and 59% by 28 days. When 2.5% more filter cake and cement are added and making a total stabilizer of 15% cement plus filter cake the compressive strength by 7 days is decreasing by 5% and 15% decrease by 28 days. Therefore, the optimum amount of filter cake used in soil block production as a partially replaced cement is around 5%. This show that the actual result obtained from 5% cement plus filter cake gives the right amount of filter cake usage as partially replaced material with cement in soil block.

B. Marble Dust Replacement

Soils stabilized with an adequate amount of marble dust, generally exhibit a higher increase in strength upon testing date than soils containing insufficient amounts of marble dust. The larger difference shown by 5% marble dust replaced cement, is attributed to the existence of a sufficient amount of marble dust required to stabilize the large volume of fines present within the soil. According to the tabulated results on the following page, the compressive strength of the masonry units that have both cement and marble dust rises greater than the soil block produced with only cement. This briefly notify that the fines of marble dust and chemical oxide composition are more reactive with soil and cement to yield a high-strength block. But, when the amount of marble dust added to soil has become increased there is a small reduction in strength. This is due to the CaO oxide in the marble dust becoming excessive and left unreactive with soil SiO_2.

Table 4.7: Compressive strength of cement blended with marble dust CSB

Testing age	Mean Compressive Strength (MPa)		
	7th	14th	28th
	2.5 % C + 2.5% MD	5% C+5% MD	7.5% C+7.5% MD
7th	2.81	4	3.73
14th	3.35	4.72	4.25
28th	4.22	5.6	4.84

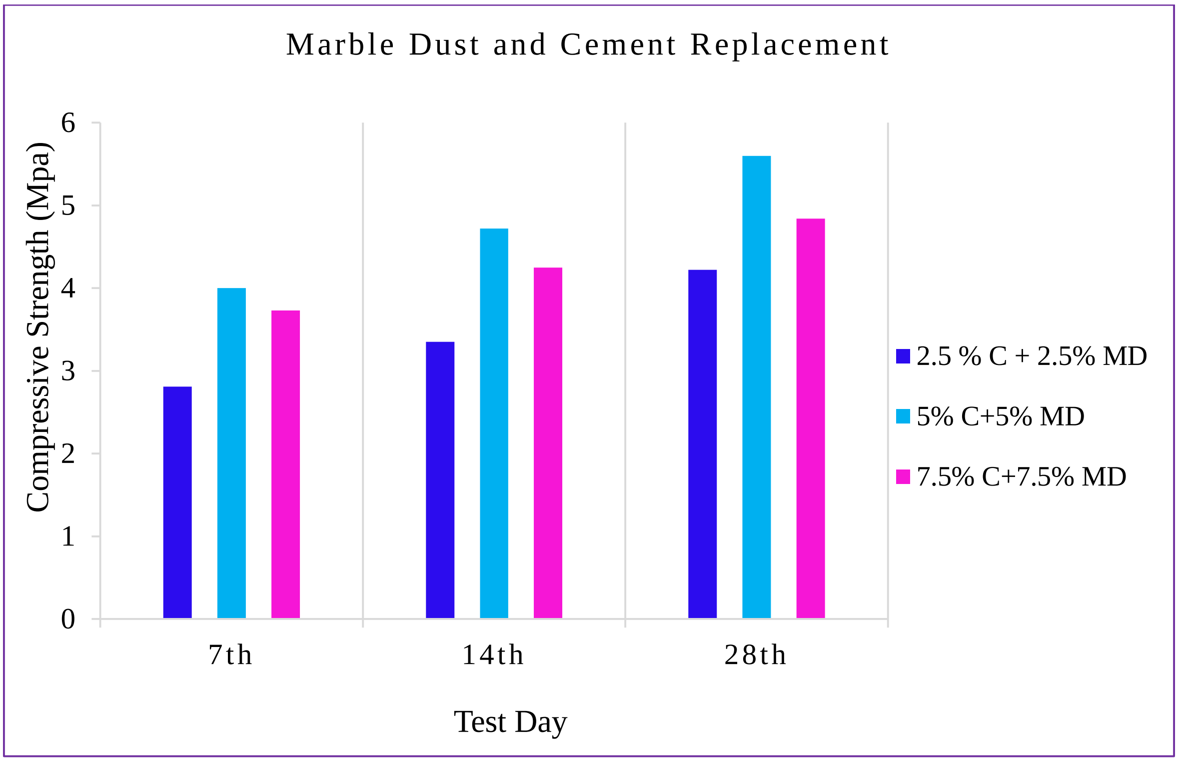


Figure 4.16: Compressive strength development of marble dust and cement replacement in soil blocks

The results of this test verified that the early compressive strength of the mixes containing marble dust and cement is higher at 5% cement plus 5% marble dust. These properties of marble dust make it similar to filter cake as filter cake is also gaining its optimum strength at 5% filter cake plus 5% cement. The chemical oxide of marble dust and filter cake has most abundant by CaO as shown in appendix-2. So, this oxide is the cause for their similarity in creating similar properties as it is added to the soil mixture. 5% Marble dust plus 5% cement was also shown that the highest compressive strength among other mixes of cement plus marble therefore this point is an optimum point for marble dust plus cement. As marble dust and cement increased from 2.5% to 5%, the compressive strength by 7 days is increase by 42% and 33% by 28 days. When 2.5% more marble dust and cement are added and making a total stabilizer of 15% cement plus marble dust the compressive strength by 7 days is decreasing by 7% and 14% decrease by 28 days. Therefore, the optimum amount of marble dust used in soil block production as a partial replacement for cement is around 5%.

4.7.6 Comparison between the control mix and mix containing a 5% stabilizer

When 5% cement is used as a control mix and evaluated with other stabilizers packed into the soil mixture. The mixture of soil and each stabilizer were less than cement compressive strength because According to Malherbe, (2016), strength gain in mixtures containing stabilizers other than cement, occurs at a slower rate than in Portland cement mixtures. This statement was verified by the inability of CSBs containing additions other than cement, to reach the same final strength shown by CSBs stabilized solely with cement. However, when cement is partially replaced with either marble dust or filter cake soil block gained a maximum strength than the controlling mix (cement replacement).

Table 4.8: compressive strength of samples with 5% stabilizers and 2.5% cement replacement

stabilizers	Mean Compressive Strength (MPa)		
	7	14	28
Cement	1.5	2.18	2.86
Filter Cake	1.12	1.72	2.33
Marble Dust	1.18	1.87	2.39
Cement + Filter Cake	2.46	2.96	3.49
Cement + marble Dust	2.81	3.36	4.22

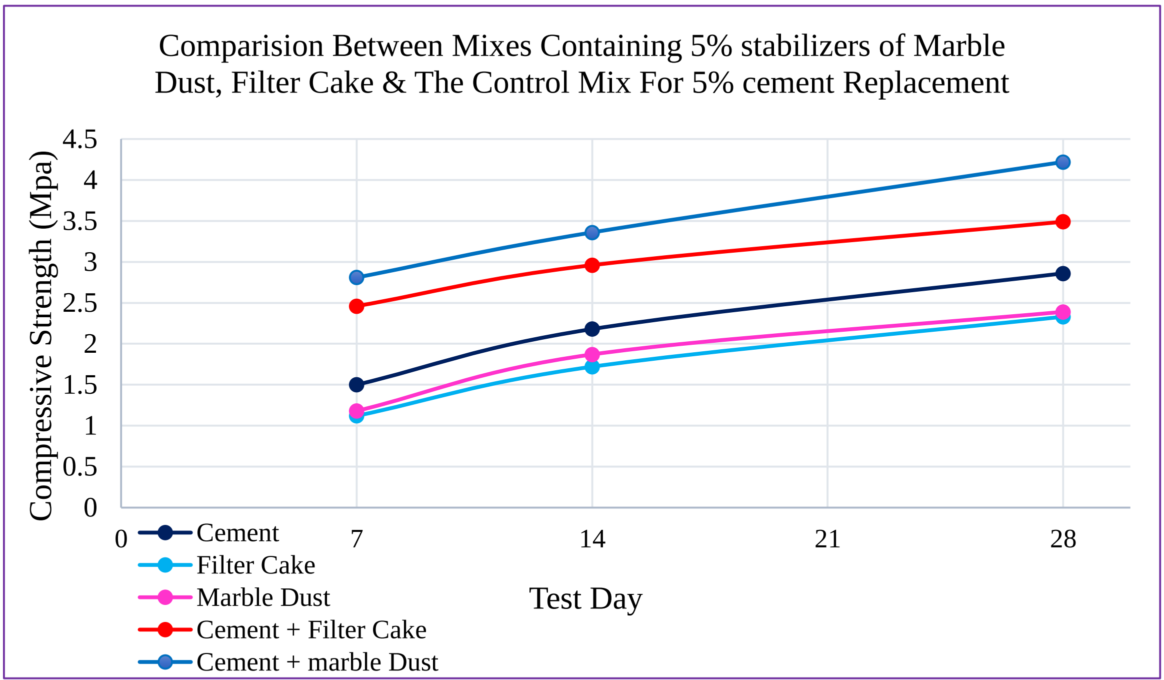


Figure 4.17: Compressive strength comparison- mixes containing a stabilizer of 5% replacement

The results of this test proved that the 7th, 14^{th,} and 28th-day compressive strength of the mixes containing filter cake is lower than the corresponding compressive strength of the mix containing marble dust and cement. But the 7th-day compressive strength of the mix containing 2.5% cement plus 2.5% filter cake is 64% higher than the mix containing 5% cement and the mix containing 2.5% cement plus 2.5% marble dust is 87% higher than the control mix which contains 5% cement. This showed that marble dust is the best fit stabilizer with cement because the strength obtained by cement plus marble dust is higher than any other stabilizers. The graphical presentation in the figure above also showed that the high-strength masonry units are obtained when the cement and either filter cake or marble dust are used as a partial cement replacement.

4.7.7 Comparison between the control mix and mix containing 10% stabilizer

As the amount of stabilizers percentage rises it has a different effect for different stabilizers. This showed that the more the stabilizer added to the soil mixture cause the strength increment until it reaches its optimum point. The compressive strength of compressed stabilized soil blocks (CSBs) is tested for five mixes, two mixes with no cement (10% filter cake and 10% marble dust), three mixes with cement (10% cement), (5% cement plus 5% filter cake), and (5%% cement plus 5% marble dust). The values of the mean compressive strength for the blocks ranged between 2.29 MPa and 5.60 MPa.

Table 4.9: Compressive strength of samples with 10% stabilizers and 5% cement replacement

stabilizers	Mean Compressive Strength (MPa)		
	7	14	28
Cement	2.47	2.91	4.54
Filter Cake	2.29	2.98	3.51
Marble Dust	2.34	2.76	3.82
Cement + Filter Cake	3.41	3.95	5.53
Cement + marble Dust	4	4.72	5.6

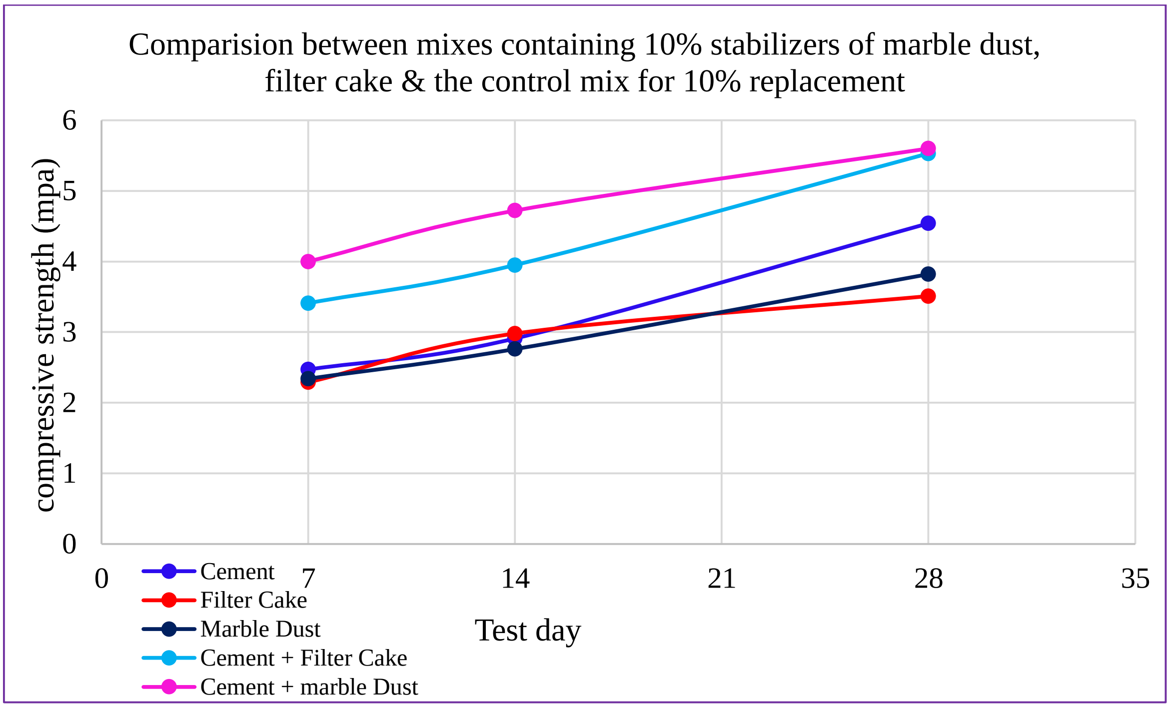


Figure 4.18: Compressive strength comparison- mixes containing a stabilizer of 10% replacement.

A similar trend emerged with results obtained for the blocks. As Figure 5.3 on the above graph indicates, the compressive strength test result of the mixes containing filter cake is increased in small value. It has a lower compressive strength than other stabilizers on the 7th day and increases by 30% by the 14th day. The mix containing no cement showed a maximum increase of mean compressive strength of 18% and 38% for filter cake and marble dust respectively on the 28th day. But the 28th-day compressive strength of the mix containing (5% cement & 5% filter cake) is 22% higher than the mix containing 10% cement and the 28th-day compressive strength of the mix of (5% cement & 5% marble dust) is 23.3% higher than Mix of containing 10% cement.

4.7.8 Comparison between the control mix and mix containing 15% stabilizer

The compressive strengths measured for the various CSBs, under dry conditions, showed that strength gain occurs with time as the strengths measured on the 28th day were higher than that measured on the 7th day. An increase in strength was observed among specimens with higher cement contents showing that increasing the cement content within a soil mixture yields higher strengths. All CSBs remained increased on cement stabilizer and marble dust.

However, a significant strength reduction was observed when specimens were tested for more addition of filter cake. The percentage reduction in strength shown by filter cake was the least, indicating that the addition of 10% filter cake to the blended soil, is the most sufficient for stabilization. The partial replacement of cement with either filter cake or marble dust, resulted in a strength increasing showed that the hydration of marble dust and the filter cake is higher when mixed with cement.

Table 4.10: Compressive strength of samples with 15% stabilizers and 7.5% cement replacement

stabilizers	Mean Compressive Strength (MPa)		
	7	14	28
Cement	2.95	3.87	5.08
Filter Cake	2.04	2.59	3.18
Marble Dust	2.75	3.42	4.45
Cement + Filter Cake	3.25	3.78	4.73
Cement + marble Dust	3.73	4.25	4.84

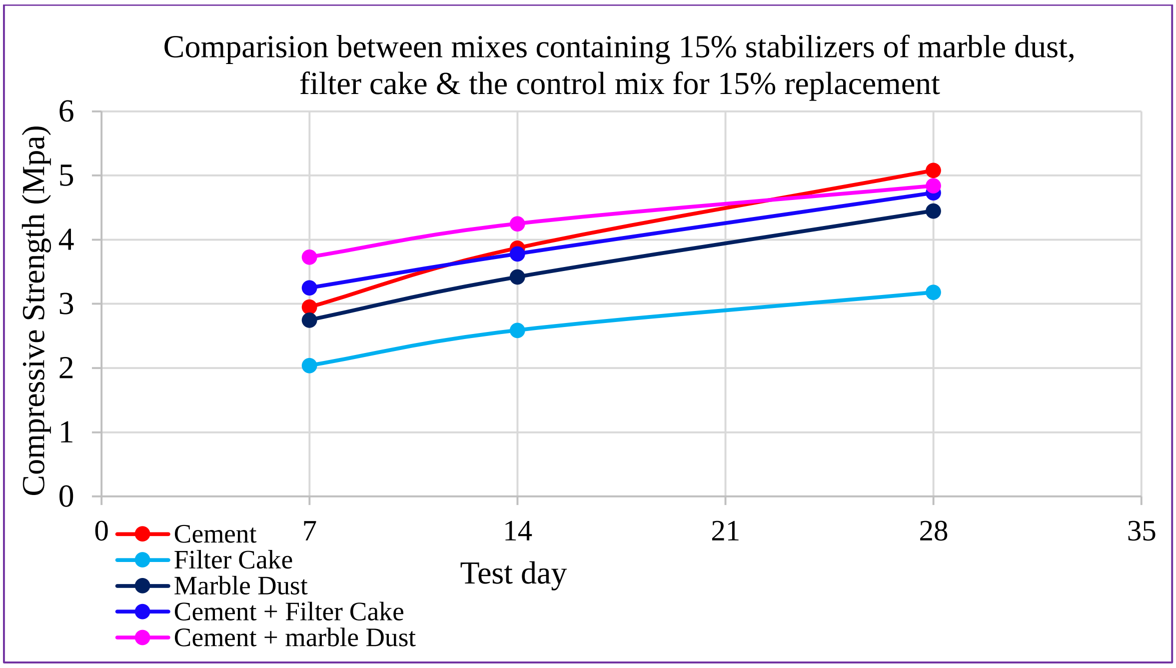


Figure 4.19: Compressive strength comparison- mixes containing a stabilizer of 15% replacement

The results obtained from a partial cement replacement revealed that marble dust and filter cake possesses higher strength-gaining properties superior to that of block produced merely with either filter cake or marble dust. But the cement shows a unique result than other stabilizers. When more amount of cement has been added the strength of the block linearly increases than other stabilizers. The cement increase yields the different outcomes shown in the above figure on the 28th day. It means that as we are adding more cement stabilizers to the block the block yields more strength than other stabilizers. When replacing cement with either marble dust or filter cake, is attributed to the difference from the mixture containing only cement. The strength on day 7th of marble dust and filter cake block also shows high strength than cement stabilized block. But after day 14 cement block strength increases linearly than other stabilizers.

4.7.9 Comparison of a partial cement replacement with filter cake and marble dust on compressive strength

A comparison of CSBs manufactured with soil mixtures containing a binder of filter cake and marble dust that is partially replaced with cement increased the strength. The chemical composition of filter cake shows that it has a high percentage of SiO_2 and CaO. It can be seen clearly in the Figure below that the compressive strength of the CSB increased as the percentage of stabilizers increased. Filter cake stabilized CSB gained the peak compressive strength at the proportion of 5% and 10%. This is due to the effectiveness of the reaction between CaO and silicates that are available in clay. As a result, a calcium silicate compound would be formed. Such the calcium silicate compound plays a major role in binding the soil particles together and ultimately increases the compressive strength of the CSB (Hwang et al., 2018).

According to the tabulated results in Table 4.11 and Figure 4.20 on the following page, the compressive strength of CSB is tested for sixteen mixes, this includes blocks containing 2.5% Cement plus 2.5% filter cake and 2.5% Cement plus 2.5% marble dust. The other contains 5% Cement plus 5% filter cake and 5% cement plus 5% marble dust and the block contains 7.5% Cement plus 7.5% filter cake and 7.5% cement plus 7.5 % marble dust, and the soil block without stabilizers (0%). The partially replaced cement by both filter cake and marble dust attained a compressive strength greater than that achieved by cement only at 28th days.

Table 4.11: Compressive strength of CSB at 28 days.

stabilizers	Mean Compressive Strength (MPa)			
	0% (soil)	5%	10%	15%
Cement	0.99	2.86	4.54	5.08
Filter Cake	0.99	2.33	3.51	3.18
Marble Dust	0.99	2.39	3.82	4.45
Cement + Filter Cake	0.99	3.49	5.53	4.73
Cement + marble Dust	0.99	4.22	5.6	4.84

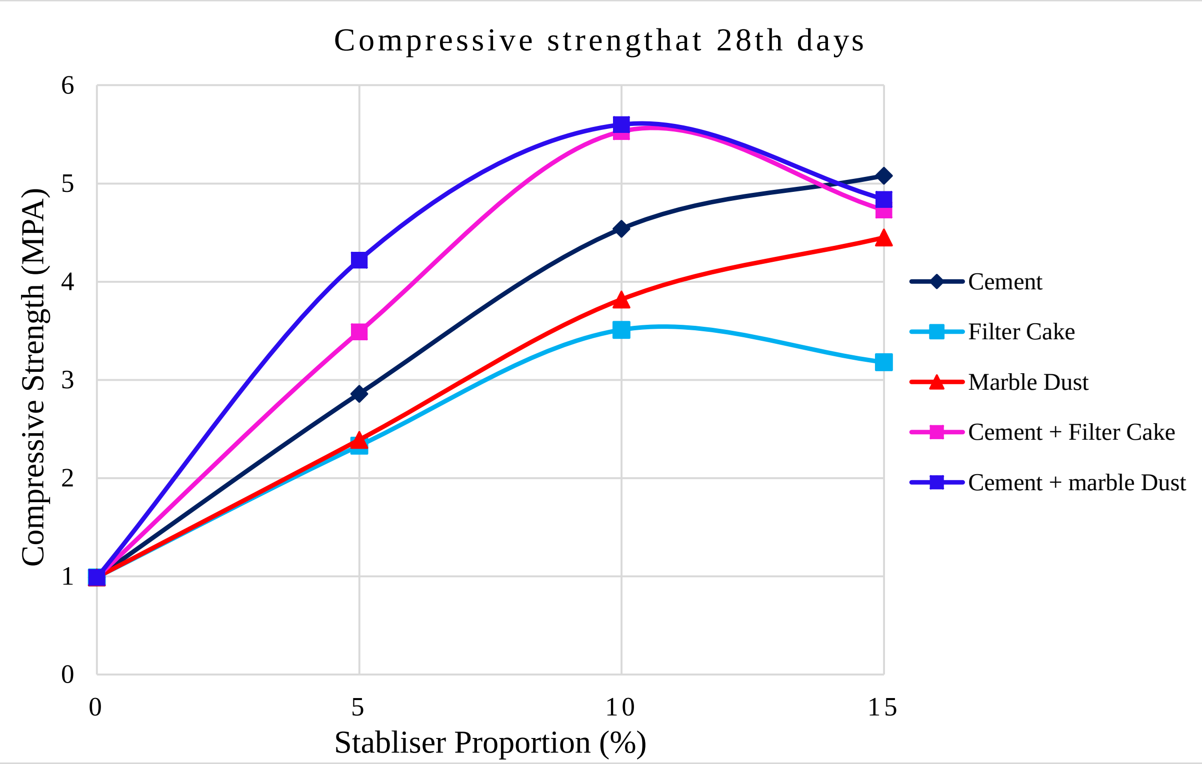


Figure 4.20: Compressive strength of CSB at 28 days

The results of this test proved that the early compressive strength of the mixes containing marble dust and the filter cake is lower than the compressive strength of the mix containing cement. The compressive of block produced from cement blended with marble dust rises by 23.34% more than cement block and rises by 21.81% for cement blended with filter cake more than cement block. The compressive strength of all stabilized blocks increased slightly after 10% of stabilizers since there will be free Cao and silicate, which would not generate C-S-H gel to improve the strength. In cement-replaced stabilizers the strength of the block decrease after a 5% replacement of each stabilizer. Because filter cake and marble dust have high CaO and in addition, filter cake has high silica which will be left free in the block as the amount of stabilizers increases.

The cement stabilized blocks had the best compressive strength values at all different proportions since cement can undergoes self-hydration with water. Filter cake stabilized block produced much lower compressive strength than other blocks, but the strength significantly improved when filter cake was mixed with cement. This may be due to the calcium and silicate reaction. However, there was no significant difference in the increased strength after 10% because silicate content might be over the optimum amount. The results of this study recommend that the optimum combinations of stabilizers for either filter cake or marble dust be (5% filter cake plus 5% cement) and (5% marble dust plus 5% cement).

4.8 Effects of compaction pressure on compressive strength of soil blocks

Compaction pressure applied on the soil block increase the density of the soil as the soil has different phase system like air, water, and solid soil. When this compaction load is applied to the stabilized block the space occupied by air and water is removed to make it densified by reducing the void space occupied by water and air. The stabilizer increases with compaction pressure yielding a high compressive strength and impact resistance of the block, as well as reducing its tendency to swell and shrink; by sealing all voids and pores and providing a waterproofing film. The effect of stabilization is greatly increased when the soil is compacted.

According to Table 4.12, the compaction pressure is revealed for a test that was carried out for 15% stabilizer replacement with different compaction pressure of 6mpa, 10mpa, and 14mpa. From the literature, increasing levels of compaction have a significant effect on the compressive strength of the sample and on the effectiveness of the stabilizer added. The researcher proved this fact in the laboratory by using different compaction pressure for different mixes. Table 4.12 and Figure 4.21 below indicate test results of the relationship between compaction pressure and 28-day compressive strength of blocks containing 15% stabilizers.

Table 4.12: Effect of compaction pressure on the 28th day compressive strength of blocks stabilized with 15% of different stabilizers.

Code	stabilizers	Compaction Pressure	Mean Compressive strength (MPa)
A	cement	6	2.87
B		10	4.17
C		14	5.25
D	Filter cake	6	2.07
E		10	2.91
F		14	4.09
G	Marble dust	6	2.88
H		10	4.18
I		14	5.37
J	Filter cake and cement	6	3.0
K		10	4.32
L		14	5.56
M	Marble dust and cement	6	3.04
N		10	4.48
O		14	5.63

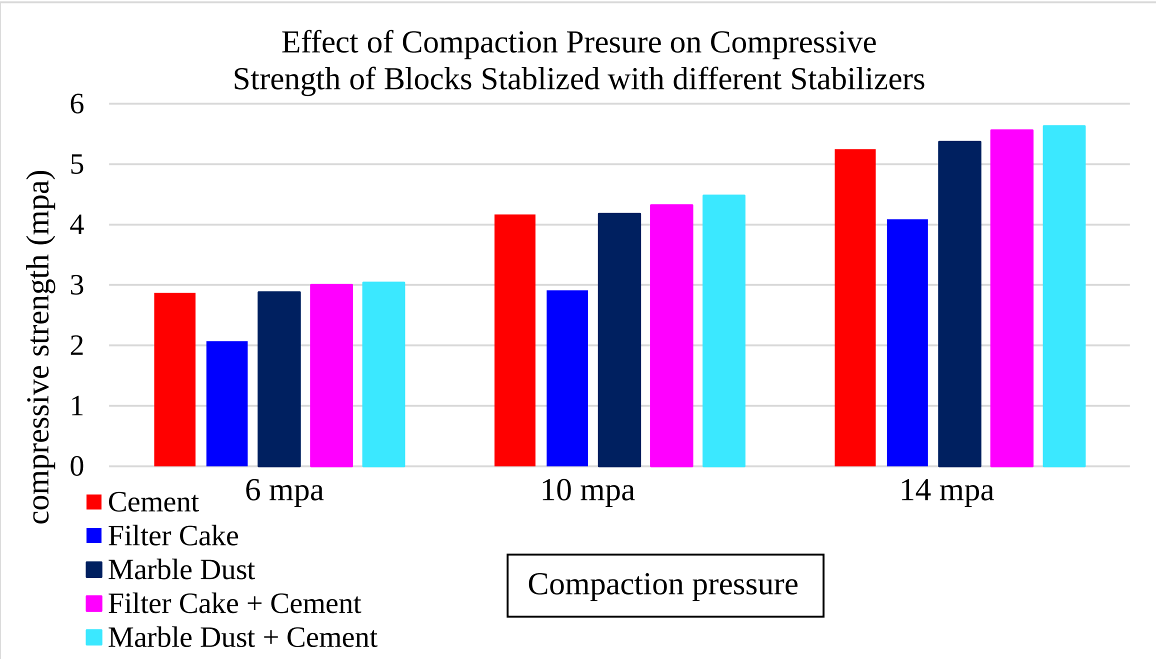


Figure 4.21: Effect of compaction pressure on the 28th day compressive strength of blocks stabilized with 15% different stabilizers.

The values of the average 28-day compressive strength for different stabilizers were satisfactory. The values ranged between 2.07 MPa and 5.63 MPa. The lower values in all compaction pressure correspond to the filter cake content of 15%, while the higher ones are to marble dust plus cement stabilizer. As can be seen, the graph values for marble dust and cement were found to be considerably higher than all other blocks made in the same manner. On average the addition of marble dust and cement resulted in a higher strength in blocks. These results also confirm the earlier theoretical assumptions that the higher the compaction pressure the higher the compressive strength. When the compaction pressure is increased from 6MPa to 14MPa at constant stabilizer content of 15%, compressive strength is increased by 82.9% for cement, 97.58% for filter cake, 86.45% for marble dust, and 85.33% for filter cake plus cement, and 85.19% for marble dust plus cement stabilizer. This approach represents a new way forward in terms of strengthening CSB fabrics for wider engineering applications. It is also likely to be particularly useful for blocks exposed to severe environmental conditions.

4.9. Water Absorption

To carry out a water absorption test the same type of sample that is used for dry compressive strength is used. The manufactured soil block was weighed before starting the experiment. The sample was then immersed in water to a height of 5 mm. The height of the water was constantly maintained to ensure that it remained at a depth of 5mm, and spacers were used to support the samples. During the weighing, the sample was dabbed to remove any dripping water. Then by using pre-test weight and post-test weight water absorption of soil block is calculated. Damp spots appeared on the top surfaces of all CSBs within a period of an hour, which is indicative of rapid moisture absorption. The moisture spread through the entire specimen within around four hours as all surfaces of the CSBs were damp.

4.9.1 Water Absorption Test Result for Cement Stabilized Blocks

The influence of an increase in the quantity of cement on the rate of water absorption was measured for different mixes of cement by varying the percentage of cement. The experimental results of the water absorption test are tabulated in Appendix-3. The tabulated water absorption result of the blocks with cement is shown in Table 4.13 below. Result of the Figure 4.22 below, shows the effect of cement content increase on the water absorption capacity of the blocks.

Table 4.13: The effect of cement content on water absorption of the soil blocks

mixes	Cement content	Mean water absorption
V	5%	13.95
V	10%	9.55
V	15%	11.96

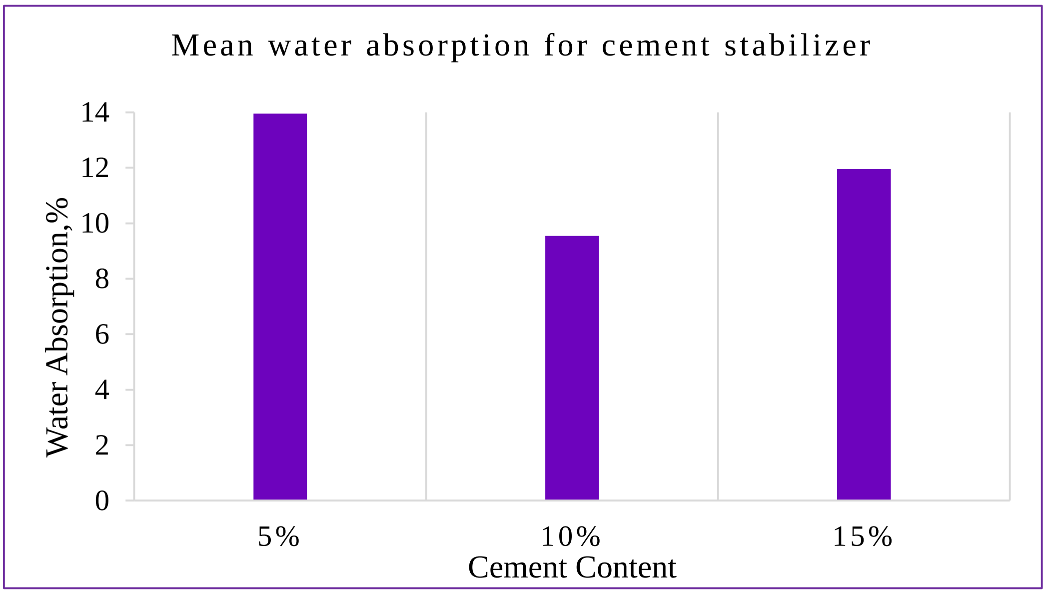


Figure 4.22: The effect of cement content on water absorption of the soil blocks

According to the results in Table 4.13 and Figure 4.22 above, the mean water absorption values for the various sample of blocks stabilized with cement range from 13.95% for the 5% cement content samples to 11.96% for the 15% cement content samples. The graph shows that as the amount of the cement stabilizer increases there is a reduction in water absorption. However, after 10% of cement content, there is more water absorption. This shows the optimum percentage that fit a right stabilizer amount with soil is 10% cement. The block shows a 31.54% percent reduction in capillary absorption as the cement increase from 5% to 10% and increases by 25.23 as 5% more cement is added up.

4.9.2 Water absorption test result for filter cake stabilizer

According to the results in table 4.14 and Figure 4.23 below, the mean water absorption values of the three samples containing 5%, 10%, and 15% filter cake are 15.84%, 13.24%, and 14.02% respectively. From the literature, the recommended maximum water absorption value for blocks is 15% (Tekle & Dinku, 2018). Therefore the amount used at 5% is not good for the stabilization of soil block. The block that has 10% filter cake showed a 16.41% reduction in water absorption. Conversely, the block water absorption of 15% filter cake rises than 10% filter cake replacement by 5.89% and 11.49% lower than 5% filter cake replacement.

Table 4.14: The effect of Filter Cake content on water absorption of the soil blocks

mixes	Filter cake content	Mean water absorption
W	5%	15.84
W	10%	13.24
W	15%	14.02

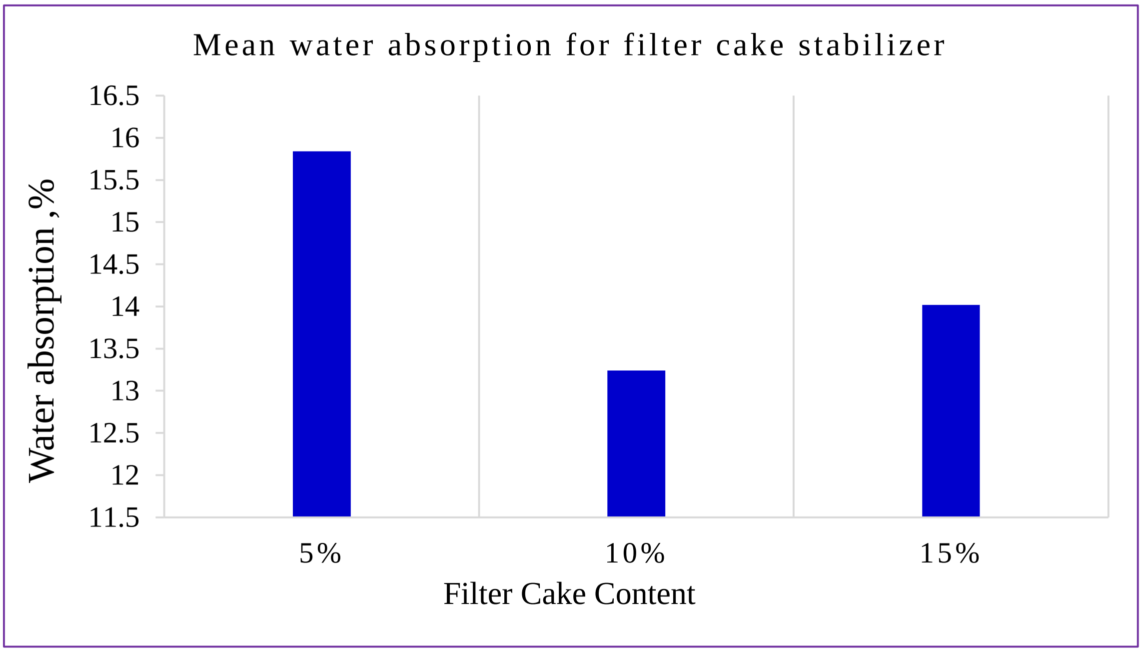


Figure 4.23: The effect of Filter Cake content on water absorption of the soil blocks

4.9.3 Water Absorption Test Result for marble dust stabilizer

According to the results in table 4.15 and figure 4.24 below, the mean water absorption values of the three samples of the block containing marble dust of 5%, 10%, and 15% are 11.96%, 10.72%, and 9.03%, respectively. This water absorption result of marble dust is very low as compared to other stabilizers and as the percentage of marble dust added to the block is rise up the water absorption is decreased. As shown below as the marble dust rises up from 5% to 10% there is a 10.37% decrease in water absorption and a 15.76% decrease in water absorption as 5% more marble dust is added and makes a total of 15% of marble dust stabilizers.

Table 4.15: The effect of marble dust content on water absorption of the soil blocks

mixes	Marble dust content	Mean water absorption
X	5%	11.96
X	10%	10.72
X	15%	9.03

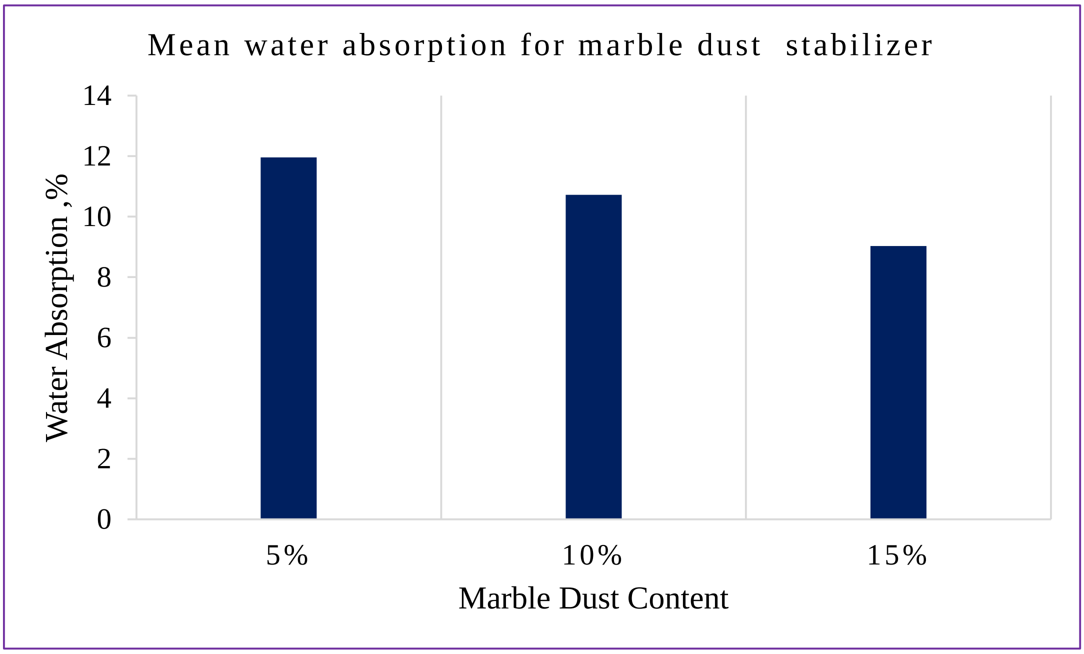


Figure 4.24: The effect of marble dust content on water absorption of the soil blocks

4.9.4 The effect of cement replacement with other stabilizers on water absorption of the soil blocks

The water absorption rates estimated from CSB masses recorded after six hours showed less variation among the different CSBs used. The results also verify that different stabilizers have a different effect on soil block production. This variation for partial replacement of cement by other stabilizers shows less water absorption than the block solely produced by one stabilizer. As shown in table 4.16 and figure 4.25 the water absorption for cement and marble dust is better than the block produced by cement and filter cake. The replacement of both filter cake and marble dust has shown less water absorption than cement for different percentage replacements.

Table 4.16: Water absorption of cement and cement replaced CSB

Percentage of stabilizers	Cement	Cement + Filter Cake	Cement + Marble Dust
5%	13.95	12.51	11.66
10%	9.55	9.30	8.47
15%	11.96	11.429	9.06

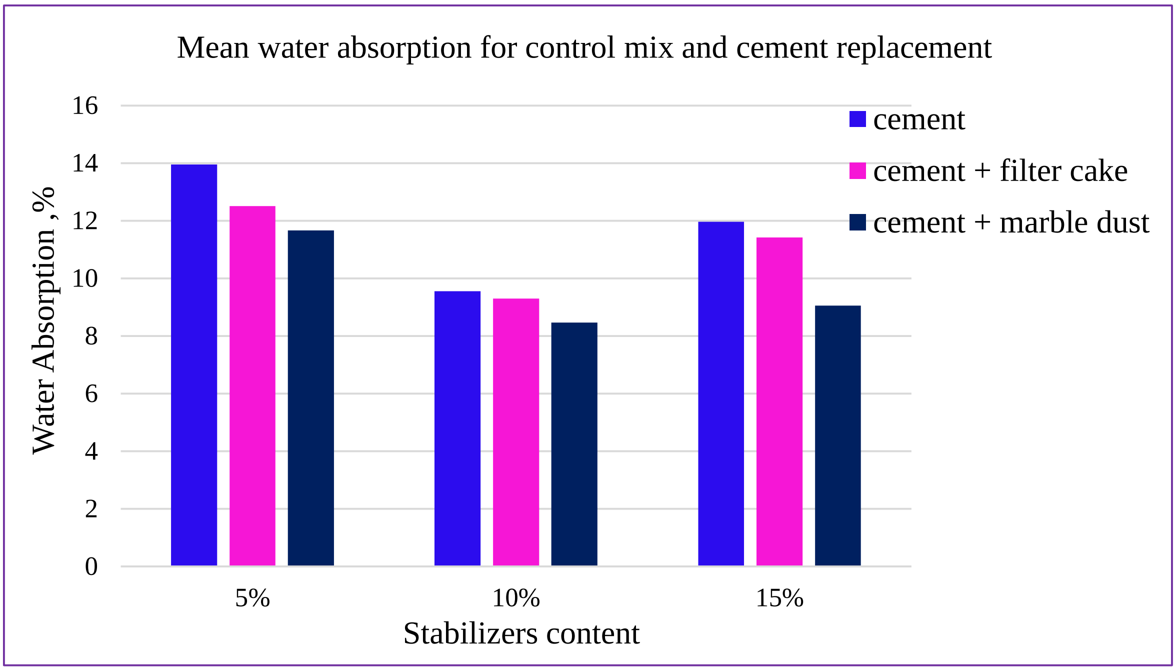


Figure 4.25: The effect of cement replacement with other stabilizers on water absorption of the soil blocks.

The block water absorption of marble dust has a lower value at 10% replacement. It shows a 9.8% reduction from the block produced with filter cake and a 12.75% reduction from the control mix that contains only cement. However, the amount of water absorption at 15% stabilizers with cement replacement is rise by a high percentage relative to 10% replacement.

4.9.5 Water Absorption Test Result for different stabilizer and cement replacement

As stated earlier, filter cake would have had a high water absorption value; block produced with only cement would also have experienced a high absorption value. On the other hand, when cement is partially replaced with either filter cake or marble dust there is a reduction in the amount of water absorption. As seen in the table and figure below filter cake absorb more amount of water.

Table 4.17: The effect of different stabilizers and cement replacement on water absorption

Stabilizers content	Cement	Filter cake	Marble dust	Filter cake + cement	Marble dust + cement
5%	13.95	15.84	11.96	12.51	11.66
10%	9.55	13.24	10.72	9.30	8.47
15%	11.96	14.02	9.03	11.42	9.06

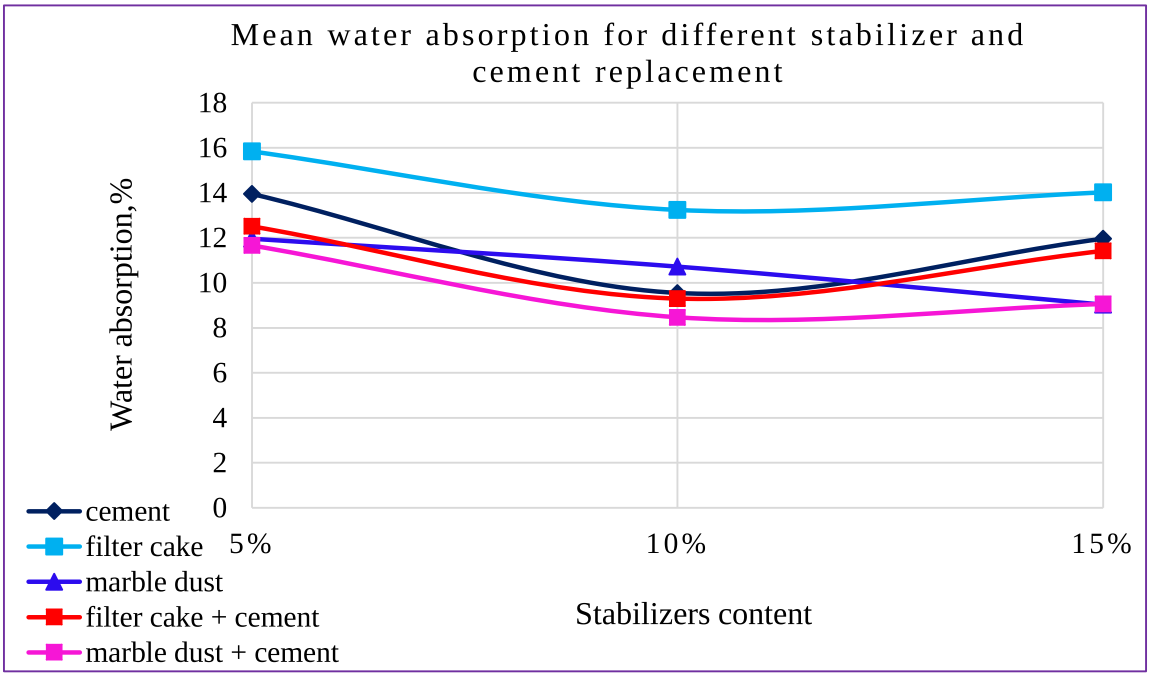


Figure 4.26: The effect of different stabilizers and cement replacement on water absorption

The result showed that the water absorption of the CSB block was significantly improved across different types and proportions of stabilizers. According to the result of table 4.17 and figure 4.26 the highest water absorption level of 15.84% was recorded on the filter cake soil blocks, while the lowest water absorption rate of 8.47% was obtained on the cement plus marble dust stabilized blocks. Marble dust stabilized blocks had a lower water absorption rate relative to cement stabilized blocks. The presence of CaO and silica inside the cement blocks may cause high water absorption to carry out hydro silicate reaction in the cement block and thus increase the water absorption rate of the blocks.

Among all of the blocks, the water absorption rate of the filter cake stabilized blocks was highest because of a high content of CaO and silica and also it proceed low pozzolanic reaction, which provided a limited hydration rate to form calcium-silicate for binding soil particles together and form solid water expelling substance. Hence, filter cake stabilized blocks would absorb more water, which will be exposed to shrinkage when the blocks got dry. This may reduce the strength and durability of the CSB blocks. However, water absorption of both filter cake and marble dust stabilized blocks was improved significantly by combining with cement. In this study, the optimum combination was found to be 5% filter cake and 5% cement or 5% marble dust and 5% cement. Because at this percentage the compressive strength of blocks is also good.

4.10 Dry Density of Soil Block

The densities of various blocks varied slightly due to the variation in constituent particle densities. A density comparison of different stabilizers, reveals that a partial replacement of cement with filter cake results in a density reduction, and marble dust replacement results in an increase in density. This reduction or increase is attributed to the particle properties of these materials and the effect thereof on the particle packing arrangement of the soil mixture. The particle densities of the filter cake are less than that of cement and marble dust is greater than that of cement, therefore a unit volume of a soil mixture containing marble dust as the sole stabilizer would have a higher mass. As a result, CSBs containing marble dust and cement as a stabilizer have higher densities than the equivalent CSBs containing a combination of stabilizing materials.

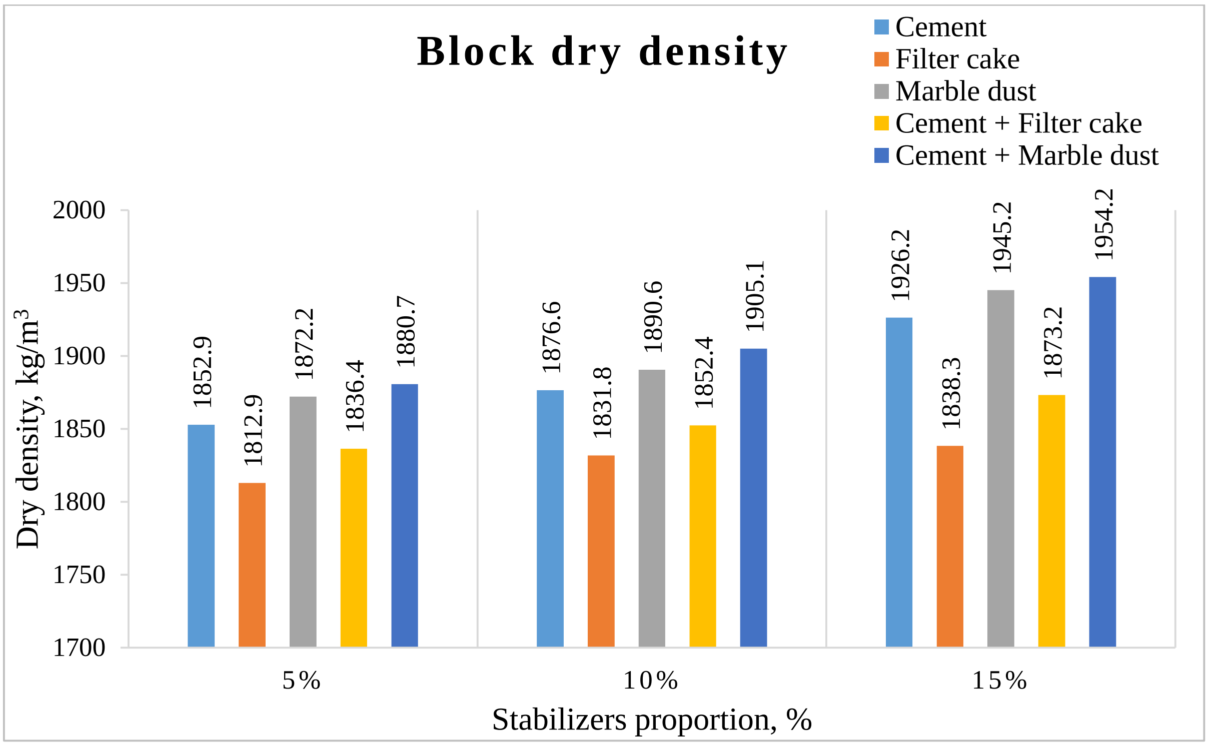


Figure 4.27: Dry density of stabilized soil block

The marble dust particles are finer than both the cement and filter cake particles, therefore the soil mixture having a stabilizer content comprised of merely marble dust has an enhanced particle packing efficiency. The specific surface area of the filter cake is much higher than that of cement, indicating that the addition of filter cake to a soil mixture would require additional water if the same mixture workability is sought. The moisture content added to the various soil mixtures was kept constant during this study, to prevent the effect of additional water on the compressive strengths obtained. Consequently, adequate moisture was not provided, which resulted in a reduction in the workability of the soil mixture. Poor workability reduces the particle packing efficiency of a soil mixture

4.11 Cost analysis of compressed stabilized soil blocks

4.11.1 Production cost of the compressed stabilized soil block

In this research work to analyze the production cost of compressed stabilized soil block, the relevant data were collected from the building construction laboratory of Adama Science and Technology University. These raw data are the initial cost of the compressed block-making machine, cost of installation, maintenance cost and necessary spare parts, and grease cost of the machine for effective workability of the machine. The price of raw materials used in the production of soil block was taken from the current market price of construction materials from construction retailers in Adama town.

The block production process of this research work was focused crucial on the use of stabilizers for creating efficient use of the waste product with expensive construction materials like cement. So to fix the optimum stabilizer content for cost analysis the mechanical properties are mandatory. The result of mechanical strength of stabilized soil block also showed that the optimum amount for cement is 10% as the water absorption of the block produced by 15% cement is above 10% cement block and the same is true for filter cake. The optimum amount of filter cake is 10% because the compressive strength of the block containing 15% filter cake is less than the block containing 10% filter cake. The optimum amount for marble dust is also 10% as mixed cement and marble dust give good value at 10% cement and marble dust So further increasing the stabilizer content will increase the cost of the blocks production and the optimum amount for compressive strength of CSBs at the 28th day is also higher than the recommended 28th compressive strength which is 1MPa- 2MPa (Tekle & Dinku, 2018).

4.11.2 Parameters that influence the production cost of CSB

A) Machine Life Span and Equipment Cost

Aurum press 3000 machines used for this research work used to manufacture about 500000 compressed blocks without much maintenance. This compressed stabilized soil makes the machine work effectively over a period of 5 years with good efficiency. The main equipment and machinery used for the production of compressed stabilized earth blocks are Aura press 3000 blocks making machine, soil mixer, soil sieve, wheelbarrow, water can, and plastic sheet. Based on the current price the cost of the Aura press 3000 block-making machine with all the accessories is around 200,000 ETB. Equipment depreciation is calculated on the lifespan of the press on average it serves for 5 years. Therefore, the depreciation can be estimated as 20% per year. Straight-line depreciation method was used for calculation.

B) Daily production and Annual production

The daily production of the block that has a size of 290×140×90 mm by using Aura press 3000 machine is range from 400 to 500 blocks per day. In this research work, 400 blocks per day are taken as daily production. It is the monthly production (26 days) over a period of 11 months. Every year, one month is deducted for the maintenance of the equipment. In this research work, 114400 blocks per year are taken as yearly production.

C) Buildings & Infrastructure

Building and infrastructure cost was taken as 100,000 ETB. And its building depreciation is taken as 5% per year by taking the life span of the building 20 years.

D) Maintenance

The maintenance cost of the machine includes the daily maintenance and the yearly repairs, once a year. In this research work, the yearly maintenance cost of the machine is taken as 5% of the initial cost of the compressed soil block-making machine.

E) Cost of Labor

It was found that a crew of four workers consisting of unskilled laborers can produce 400 blocks of size 290mm x 140mm x 100mm per day. This information was taken from Selam Technical and Vocational center where soil block and hydra form is produced. This number is not much affected by the size of the block for Aura press 3000. Thus, a total of 400 blocks per day was used as the rate of production of 290mm x 140mm x 100mm blocks as well. Based on the current market, the perdiem cost of daily laborers is taken as 250ETB/day.

F) Cost of stabilizers content

The optimum amount of all stabilizers is 10% as it gave more than allowable compressive strength on the 28th day and further increasing the stabilizer content will increase the cost of the blocks. The cost of each stabilizer depends on the percentage usage in each 290mm x 140mm x 90mm. the cost of a bag of cement is considered as 425 ETB/bag. Where the market price varies from 425 to 500 ETB. The cost of waste products used as stabilizers is 50ETB/bag of filter cake and 50 ETB/bag of marble dust.

Table 4.18: Number of Blocks per Bag of stabilizers and Cost of stabilizers per Block

Percentage of stabilizers	290mm x 140mm x 90mm blocks	
	Numbers of blocks per bag	Cost in ETB
10% cement	60	7ETB cement per block
10% Filter Cake	60	1ETB Filter cake per block
10% Marble Dust	60	1ETB Marble dust per block

G) Soil

Based on the current market if the soil exists at the site of construction the cost will be only the labor cost for preparing the soil which is considered as 150ETB/m^3 and the cost of the soil obtained from the supplier taken as 250 ETB/m^3 which includes the excavation cost of the soil from the source, loading-unloading and transportation costs. It was found during the experimental program that it is possible to produce 120 blocks/m^3 of soil that has a size of 290mm x 140mm x 100mm.

soil	Cost of 290mm x 140mm x 100mm blocks
Soil is available at the site	1.25
Soil is transported to the site	2.08

H) Profit Margin

The profit margin of 15% (of the direct cost) is taken in this research work for cost analysis.

4.11.3 Unit Cost of Block

The unit cost calculation for the production of CSBs with cement, filter cake, and marble dust, are shown in Tables 4.20 and 4.21 respectively. Information used for the unit cost calculations is summarized in Table 4.19 below.

Table 4.19: Factors affecting the Unit Cost Calculations

Number of blocks produced	**Units**	**Production/cost**
Daily production	Blocks	400
Annually production	Blocks	1,14400
Material cost		
Soil cost for transported soil	ETB/m^3	250
Soil costs available at the site	ETB/m^3	150
Cement price excluding VAT	ETB/ quintal	850
Filter cake price excluding VAT	ETB/quintal	100
Marble dust price excluding VAT	ETB/quintal	100
Labor cost		
Daily Laborers	ETB/day/person	250
Forman Salary	ETB/month	10,000
Equipment and Building cost		
Equipment cost (with Accessories)	ETB	200,000 (initial cost)
Buildings and infrastructure cost	ETB	100,000 (initial cost)
Maintenance cost per year	ETB/year	10,000

Table 4.20: Unit cost calculation table for (290mm x 140mm x 100mm) block using 10% stabilizer

Variable Cost	**Required Amount**	**Cost**	**Cost/Block (ETB)**
Daily Laborer	3 laborer/day	250ETB/day/person	1.88
Forman salary	1	10,000ETB/month	0.83
Soil	4 m^3/day	150 ETB/m^3	1.50
Cement (10%)	3.4 quintal/ day	850ETB/quintal	7.23
Filter cake (10%)	3.4 quintal/ day	100ETB/quintal	0.85

Marble dust (10%)	3.4 quintal/ day	100ETB/quintal	0.85
Maintenance cost			0.09
Fixed Costs	**Amount**	**Initial cost (ETB)**	**Cost/Block (ETB)**
Investment cost	7% per year (interest)	350,000	0.21
Equipment depreciation (lifespan)	20% per year	200,000	0.35
Building depreciation (site duration)	5% per year	100,000	0.04
Miscellaneous	2%		0.11
Profit margin	5%		0.28
Overhead	5%		0.28
Total fixed cost (ETB)			**1.27**

From the above table, the Variable cost per block is calculated for 400 blocks/day and the fixed cost is calculated for 114400 blocks/year. If the compressed stabilized soil block is manufactured for sale a suitable markup is added to a given cost. Thus, in the above table Miscellaneous, Profit margin, and Over Head are added to calculate the block for sale. And the cost of each block for cement, filter cake, and marble dust is shown in the below table.

Table 4.21: Cost of unit block produced with different stabilizers for a Soil available at the site

Block type	Cost per unit
Cement compressed block	12.8ETB/ block
Filter cake compressed block	6.42ETB/ block
Marble dust compressed block	6.42ETB/ block
Cement plus filter cake compressed block	9.57ETB/ block
Cement plus marble dust compressed block	9.57ETB/ block

According to the result of cost analysis, there is a reduction in cost for blocks produced without cement and by partial replacement of cement. Specifically block produced with partial replacement of cement is most attractive as it has high strength than others.

4.12 Unit cost calculation for production of Hollow Concrete Blocks (HCBs) Class B

The amount of material used for a unit of HCBs is 2.5kg cement, 0.004m^3 sand, 0.004m^3 crushed stone, and 0.004m^3 red ash as a mix design for the unit cost calculation of the wall made with class B HCB.

Table 4.22: Factors affecting the unit cost calculations of HCBS

Factors Affecting Unit cost of HCB	**Unit**	**Production or Cost**
Daily production	Blocks	1000
Annual production	Blocks	286000
Equipment cost with accessories	ETB	150,000
Buildings and infrastructure cost	ETB	100000
Cost of sand	ETB/m^3	450
Cost of cement excluding VAT	ETB/quintal	850
Cost of Red sand	ETB/m^3	200
Cost of Crushed stone 01	ETB/m^3	200
Maintenance	ETB/year	15000

Table 4.23: Unit Cost calculation for (200x200x400) mm HCB "Class B"

Variable Cost	**Required Amount**	**Cost**	**Cost/Block (ETB)**
Daily Laborer	10 laborer/day	250ETB/day/person	2.5
Sand cost per day	4 m^3/day	450 ETB/m3	1.8
Red sand per day	4 m^3/day	200 ETB/m3	0.8
Crushed stone 01 per day	4 m^3/day	200 ETB/m3	0.8
Cement per day	25 Quintal/day	850 ETB/Quintal	21.25

Maintenance cost block			0.05
Total variable Costs (ETB)			**27.2**
Fixed Costs	**Amount**	**Initial cost (ETB)**	**Cost/Block (ETB)**
Investment cost	7% per year (interest)	200,000	0.05
Equipment depreciation (lifespan)	20% per year	150,000	0.10
Building depreciation (site duration)	5% per year	100,000	0.04
Miscellaneous	2%		0.03
Profit margin	5%		0.08
Overhead	5%		0.08
Total fixed cost (ETB)			**0.38**
Total cost (ETB)			**27.58**

The total cost of the block in the current market with the right usage of cement is 27.58 ETB. This has become an accurate cost when low-cost materials to save cement are not mixed with the block ingredient.

4.12.1 Comparison of compressed stabilized soil block with hollow concrete blocks per m^2 area of the wall

The first question potential users will arise is whether a building built with compressed stabilized earth block is more economical than one built with any other material. To answer this question, first of all, one must consider the type of building. In the luxury villa, the cost of the wall building materials accounts for very little of the total cost. But in the case of low-cost houses, such as those social housing programs, the cost of walls is a major component of the total cost (Tekle & Dinku, 2018). This implies that the choice of building materials and wall-building techniques are more critical.

The use of hollow concrete blocks is widespread all over the world as its production is simple and safe for construction purposes. The ingredient for the production of this hollow concrete block usually has low-cost material that partially replaced either cement or sand. This method is used especially in developing countries to save the cost of either cement or sand used in hollow concrete block production. Therefore, the cost of most HCB replaced with other materials in production is very small compared to the hollow concrete block produced with the right amount usage of cement.

However, replacing cement in block production with soil is environmentally safe and simple as the raw materials are readily available everywhere. This usage of soil as a replacement of cement causes a great reduction in cost compared to concrete blocks and also CSBs act naturally to regulate the internal temperature of a building. In colder climates, CSBs use passive solar energy to heat a building by absorbing heat during the day and releasing it at night. Allowing thermal mass to control the building’s temperature decreases the need for air conditioning or heating (Tekle & Dinku, 2018).

The construction of CSBs most of the time can be left unplastered since the surface of CSBs is smooth and aesthetically pleasing. But HCB needs plastering to control thermal conductivity and make a smooth internal surface of the wall. Conversely, Walls constructed with interlocking compressed earth blocks are laid without mortar thereby leading to considerable savings in cost associated with mortar and also saving a considerable time of construction than that of HCB walls.

To make an accurate comparison, it was important to consider a complete section of the wall including the cost of plastering and structural elements. In this research, a wall made of HCB was plastered on both sides compared with compressed stabilized soil blocks (with stabilizers). Cost comparisons are prepared and tabulated in Tables 4.24 and 4.25 below.

A) Cost of mortar for 290mm x 140mm x 100mm blocks

The effective size blocks with a 10mm mortar joint are 300mm x 140mm x 100mm. the number of blocks required for 1m^2 of the wall is around 34 blocks (1000mm/290mm * 1000mm/100mm). The volume of mortar per 1m^2 is 0.0182m^3 and the water-cement ratio used is 1.2. The bulk density and solid density of cement are 1450 and 3150 kg/m^3

respectively. The bulk density of sand is 1700kg/m^3 and its solid volume is 2600kg/m^3. The following table calculated for 1:6 cement sand mortar and per bag of cement

	Bulk volume (m^3)	Solid volume (m^3)
Cement	50/1450 = 0.035	50/1350 = 0.016
Sand	0.035*6 = 0.21	0.21*1700/2600 = 0.137
Water		1.2*50/1000 = 0.06

Total solid volume = 0.016 + 0.137 + 0.06 = 0.213 m^3.

Total cost per 0.0182m^3 of cement sand mortar, assuming water 2ETB/ m^3. Total cost = (425 + 0.21*450 + 0.06 *2)*0.0182/0.213 = 44.39ETB and an allowance of 10% is made for wastage and variation of density. 44.39*1.1 =48.84ETB

B) Cost of labor for the construction of compressed stabilized soil block

To construct compressed stabilized soil block one skilled labor and one unskilled labor is necessary. As data from Selam Technical and Vocational center shows one skilled and unskilled labor construct around 7m^2 per day. The cost of skilled labor is 350ETB and unskilled labor is 250ETB per day. So, the cost to construct 1m^2 is CSBs 85.71ETB.

From above data the cost of cement sand mortar and labor to construct 1m^2 compressed stabilized soil block is 48.84ETB + 85.71ETB = 134.55ETB/m^2.

C) Total cost to construct 1m^2 area of 290mm x 140mm x 100mm block

The overall cost to construct 1m^2 of 290mm x 140mm x 100mm is given in table 4.24 below

Table 4.24: Cost per 1m^2 area of 290mm x 140mm x 100mm block for soil available at the site

Block type	Cost of blocks in ETB	Cost of labor and mortar	The total cost of a 1m^2 wall
Cement compressed block	435.2ETB	134.55ETB/m^2	569.75 ETB/m^2
Filter cake compressed block	218.28ETB	134.55ETB/m^2	352.83 ETB/m^2
Marble dust compressed block	218.28ETB	134.55ETB/m^2	352.83 ETB/m^2
Cement plus filter cake block	325.38ETB	134.55ETB/m^2	459.93 ETB/m^2
Cement plus marble dust block	325.38ETB	134.55ETB/m^2	459.93 ETB/m^2

D) Total cost to construct 1m^2 area of 400mm x 200mm x 200mm HCB block

The hollow cement sand block required for 1m^2 of the wall is obtained from the building schedule of rates (BSR). Since this block is standard size. When this HCB is used for the external wall it needs a plaster to achieve a wall thickness of 125mm as required by building regulations.

Table 4.25: Cost to construct HCB

The total cost of 400mm x 200mm x 200mm HCB block and mortar				
Type of material	Unit	Quantity	rate	Cost per unit
HCB	Pcs	13	27.58	358.54
Cement	Qt.	0.08	92.39	7.39
Sand	M^3	0.02	450	6
water	M^3	0.004	2	0.008
Total cost				371.94
Labor cost for building 1m^2 wall				
Labor by grade	No.	UF	Indexed hourly	Cost per unit
Foreman	1	0.25	48.08	12.02
mason	1	1	46.88	46.88
Daily labor	2	1	25	50
Total cost				108.9

Table 4.26: Cost of plastering

Cost of two coats plastering wall surface				
Type of material	Unit	Quantity	rate	Cost per unit
Cement	Qt.	0.076	850	64.6
Sand	M^3	0.0186	450	8.37
water	M^3	0.001	2	0.002

Total cost				72.97
Labor cost for plastering wall surface				
Labor by grade	No.	UF	Indexed hourly	Cost per unit
Foreman	1	0.2	48.08	9.62
plasterer	1	1	40	40
chilser	1	1	30	30
Daily labor	1	1	25	25
Total cost				104.62

Cost of constructing 1m^2 HCB = 371.94 + 108.9 + 72.97 + 104.62 = 658.43 ETB/m^2

As per the analysis in table 4.24 of different stabilizers wall of soil block, the maximum cost of stabilized soil block is 569.72ETB/m^2 for cement stabilized soil block. But the cost of constructing HCB per square meter is around 658.43ETB/m^2 which is 15.57% more expensive than a wall made from compressed stabilized soil block. And the lowest cost of stabilized soil block is the block fabricated by using either filter cake or marble dust. It cost 352.83 ETB/m^2 and this cost is very low compared to a wall constructed with HCB. HCB wall is 86.61% more expensive than either filter cake or marble dust block. And also block produced with cement blended with either filter cake or marble dust is constructed for 459.93 ETB/m$^{2.}$which is 43.15% less expensive than the HCB block. Therefore soil block is one of the alternative materials that have effective cost for construction purposes.

4.13 Environmental impacts and embodied energy assessment of stabilized soil blocks

The term embodied energy is used in the construction industry as a way to identify the overall environmental impact of construction methods and systems. It is the way of selecting an energy-efficient construction method. This embodied energy is used to calculate the total energy required for the raw material extraction, processing, manufacturing, and delivery to the building site. The estimation of embodied energy showed that most conventional material used in the construction industry has high embedded energy. So, Minimizing the consumption of convectional material in the construction industry is also a way of considerable energy saving and as well as reduction of CO_2 emissions. One of the main ways of minimizing conventional materials is using alternative materials like stabilized soil blocks that have low embedded energy (P et al., 2018).

The alternative material used for construction purposes in this study is stabilized soil blocks. Stabilized soil blocks can have various sizes depending on the mold. The block manufactured for this study has a size of 290 mm x 140mm x 100mm. A commonly used size of 290 mm x 140 mm x 90 mm block was selected to determine the embodied energy (Jayasinghe, 2011).

The energy is not allocated for soil considering manual excavation for this research work. However, transportation energy is included for a transportation distance of 20km. Since the soil is readily available in most of the locations in the Adama area. Cement is transported over a distance of 354 km. The weight of cement needed for a unit compressed soil block making is 850 gm. for 10% replacements. Marble dust and filter cake are the byproducts of the industry used as stabilizers and are transported to the site by lorry. Using this data, the embodied energy Analysis of the compressed stabilized soil block is carried out as below:

The process of stabilized soil block making involves the following steps:-

- Extraction of soil, and transporting the soil to the site.
- Placing the soil at the site where the compression machine was installed
- Proportioning of the soil required for a single soil block using necessary stabilizers as mentioned in the methodology of this study.
- Fabricating stabilized soil blocks for construction with the right proportion of water, cement, filter cake, and marble dust.

Energy calculation for a unit of compressed soil block produced in this study

Materials Requirements for 1 Stabilized Soil Block of 10% Replacement		
Soil	stabilizers	Water
7.650 kg.	0.85kg. (cement)	1.2 liter
7.650kg	0..85kg (filter cake)	1.5 liter
7.650kg	0..85kg (marble dust)	1.1 liter

A list of assumptions made for the below calculation is:-

1. Soil extraction is made using human labor and the labor is available at the site. And also the material is transported to the site by lorry and truck.
2. The transportation distance for filter cake and marble dust is assumed as 30 km.
3. Soil is transported to the site from a distance of 20km.
4. Marble dust or filter cake is transported by lorry to the site. One lorry can load $11.33m^3$ of either marble dust or filter cake.

Transport: 1 lorry load of soil = $11.33m^3$ in volume = 11.33 x 1.3 tones = 14.729 tones (1 m^3 of topsoil weights is equal to minimum = 1.2 tons (for compacted topsoil) Average = 1.6 tons.)

The assumption made while calculating energy due to transportation of soil from a distance of 20km

- Up trip: 5km/liter of diesel.
- Down trip: 4km/liter of diesel.
- Total diesel 20/5 + 20/4 = 9 Liters

Energy due to transportation of soil to the site where the compression machine was installed = 9 x 38.7 MJ = 348.3MJ.

Number of stabilized soil blocks from this soil = 13361.93 /7.650 = 1746 soil block/ lorry for 10% replacement.

Soil transport energy for stabilized soil blocks production =348.3/1746 = 0.199 MJ/ block

Cement was transported from Dire Dawa national cement to Adama town. The distance between Adama and Dire Dawa is around 354km. to calculate transportation the same method for an up trip and down trip of soil were used.

Total diesel = 354/5 + 354/4 = 159.3 liters of diesel

Energy due to transportation of cement = 159.3 x 38.7MJ = 6164.91MJ and a truck can carry 475 bags of cement. Energy due to transportation = 6164.91MJ/475bags = 12.98 MJ/bag. It is around 0.2596 MJ of transportation energy per kg of cement.

Marble dust and filter cake are transported from Awash Melkassa and Gelan respectively. The average distance for both by-products used in this calculation is 30km and the same method of the trip for soil. Total diesel = 30/5 + 30/4 = 13.5 liters. The Energy due to transportation of either filter cake or marble dust = 13.5 x 38.7 MJ = 522.45MJ.

Calculating the energy of transportation for each block based on the lorry used and the volume of the lorry. From local data, the lorry is used for transportation in this study. The loaded material converted to tons as Crushed stone can weigh anything from 1.5 to 2.2 tons per m^3, so 1.6 x 11.33m^2 = 18.128 tons of filter cake or marble dust transported to the site. Around 850 grams of either filter cake or marble dust is used in a unit soil block for block stabilized with 10% replacement of stabilizers.

Transportation energy of either filter cake or marble dust per kilogram = 522.45/18128 = 0.0288MJ/kg. Thus, the energy required to produce a unit compressed stabilized soil block is calculated as Embodied energy of either marble dust or filter cake soil block = 0.199MJ/block + 0.02449MJ = **0.224MJ/block**

Embodied energy for Cement block = 0.199MJ/block + 0.221MJ = 0.41966 MJ/block. But, here in the calculation, the production energy of cement is not included. According to ((Surekha et al., 2016) total embodied energy per Kg of Cement is 3.6 MJ. However, in an earlier paper, (Venkatarama Reddy & Jagadish, 2003) used a value of 5.85 MJ per Kg since many cement production plants were using an inefficient wet process. In this research, 3.6MJ is used for calculation. Embodied energy per gram of cement during production = 3.6/50000 = 0.000072MJ/gram of cement. Embodied energy for Cement soil block = 0.199MJ/block + 0.221MJ + 0.0612MJ = **0.48086MJ/block.**

Generally, Embodied energy consists of all the greenhouse gas emissions associated with building construction, including those that arise from extracting, transporting, manufacturing, and installing building materials on-site, as well as the operational and end-of-life emissions associated with those materials. Therefore as stabilized soil block has low embodied energy than HCB it emits low CO_2 to the environment. Hence it is a very sustainable material for construction.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

One of the essential preconditions for improving the standard of living of people is providing sustainable building materials and Selecting energy-efficient construction materials for reasonably good housing. In this context, it is appropriate to explore the way of using available locally material while optimizing the usage of traditional material.

In this thesis, compressed stabilized soil blocks have been introduced as one of the alternative construction materials to reduce environmental degradation caused by conventional materials. This showed that it is possible to manufacture CSBs from regional materials that do not cause environmental pollution like that of conventional materials. These regional materials include a locally available byproduct of the industry to produce long-lasting construction materials. The compressed stabilized soil block produced in this research work is used by-product of industry. And a carefully designed experimental framework was used for testing CSBs manufactured from these byproducts. The study evaluated the performance of the CSB by using compressive strength, material density, water absorption, and compaction pressure.

5.1 Conclusions

Based on the test results and investigation reported in the previous chapters, the following conclusions are drawn: The soil mixture produced with filter cake is low compressive strength and high water absorption. On the contrary to that, the cement blended with either filter cake or marble dust has high strength and low to medium water absorption. Both filter cake and marble dust were good stabilizers for the production of CSB. They were more effective when they were combined with cement. Cement and Marble dust stabilized blocks had the higher compressive strength and density and lower water absorption rate in comparison with the other blocks. Filter cake stabilized blocks exhibited poor strength and density and high water absorption. The mixture of (5% marble dust and 5% cement) and (5% filter cake and 5% cement) were the optimum mixtures to produce good quality CSB.

The study proved that the soil from the Adama area has acceptable properties regarding physical and chemical composition for the production of compressed stabilized soil blocks as alternative materials. In terms of energy, the CSB fabricated in this research work is an energy-efficient construction material that has very small embodied energy compared to that of HCB. The soil block produced is preferable to other wall-making materials due to the low cost of materials, local skills, and simplicity of manufacturing and construction.

Generally, the results obtained from the structural and non-structural tests performed showed that suitable optimum quantities of byproducts incorporated into CSB soil mixture is 10% and the stabilizers blended with cement also give a good result when 5% of each stabilizer mixed into the soil together. Thus 10% replacement of stabilizers used in this gives a good CSB for structural material.

5.2 Recommendations

Based on the findings of this research the following recommendations are drawn;

1. The research results revealed that the compressed stabilized soil block produced can be used as an alternative material for town housing. And also it is can be used for one-story load-bearing houses as compressive strength is high. Cost analysis also showed that significant cost cuts can be achieved in the production of this CSB. So, any concerned body can use this material as an alternative wall-making material with proper quality control.

2. Using industrial byproducts as stabilizers in combination with cement would help in reducing the use of cement. This has serious consequences in terms of the reduction of energy consumed in the manufacture of blocks when done on large scale. This would also help in the sustainable growth of the society by optimizing the resources used, reduction in energy consumed, and lesser pollution of the environment.

3. Lower-income families facing a lack of reasonable and quality housing stock able to construct a good house using compressed stabilized soil block and the difficulty of obtaining housing finance solved.

Recommendations for further study

Below are topics which, doing further research would be advantageous**.**

- The study of Durability and cause of deterioration in stabilized soil block produced with filter cake and marble dust.
- The performance of alternative surface coatings and plasters that can be used with stabilized soil block. A successful development of such water repellent coatings enables the use of compressed stabilized blocks with more confidence even at a location where there is a risk of floods. So, it is better to study CSB using water-repellent liquids like bitumen and other low-cost material like oil engines for future research.

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APPENDIX- 1

LABORATORY TEST RESULTS OF SOIL INDEX PROPERTIES

Table A1: Natural Moisture Content Determination

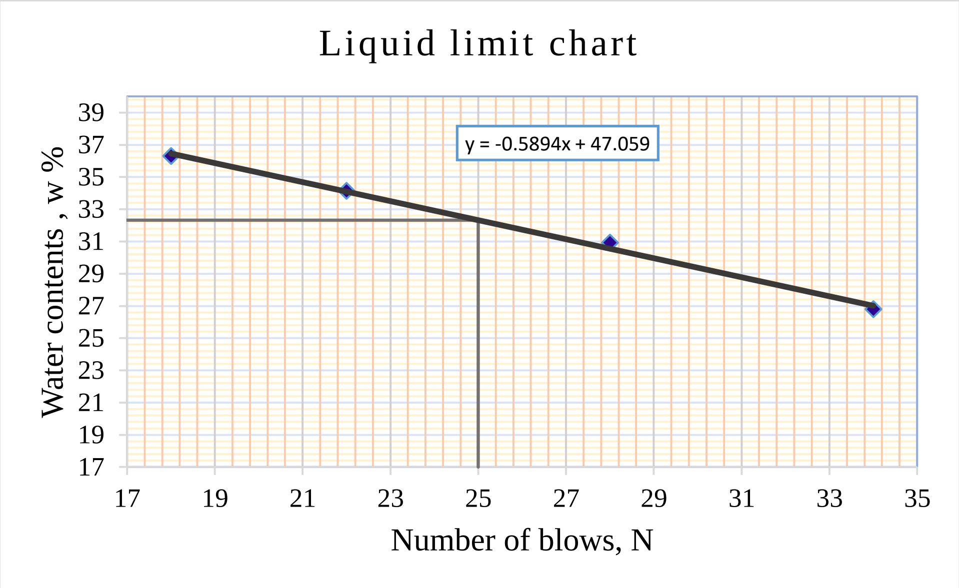
Location: Adama town	Job ref.		Thesis research
The moisture content of the soil	Tested by:		Yosef F.
Soil description: sandy soil	Date		3-4/3/2022
Test method: ASTM D 2216	Investigated in Adama science and technology university		
Specimen number	1	2	3
Can number	O_1	O_2	O_3
Weight of can, Wc(gm)	19.56	19.59	19.54
Weight of can + Wet Soil, W_1(gm.)	82.10	86.06	76.43
Weight of can + Dry Soil, W_2(gm.)	77.67	82.48	73.48
Weight of Water, Ww(gm.)	4.43	3.58	2.95
Moisture contents of the soil	7.62%	5.69%	5.47%
	6.23%		

Table A2: Specific Gravity Test

Location: Adama town	Job ref.		Thesis research
The specific gravity of soil	Weight of oven-dry Sample		10 gm.
Soil description: sandy soil	Date		3-4/3/2022
Test method: ASTM D 854	Investigated in Adama science and technology university		
Specimen number	1	2	3
Density bottle number	A0	A1	A2
Weight of Density bottle, M1	46.81	46.81	46.81
Weight of Density bottle + Soil, M2	56.77	56.79	56.80
Weight of Density bottle + Soil +Water, M3	151.96	152.02	152.03
Weight of Density bottle + Water, M4	145.88	145.87	145.85
The specific gravity of distilled water, GT	1	1	1
The specific gravity of the Soil, Gs	2.58	2.61	2.62
Average specific gravity	**2.60**		

Table A3: Plastic Limit and Liquid Limit Determination

Location; Adama town	Job ref.			Thesis research
Soil description: sandy soil	Date			7/3/2022
Test method: Atterberg limit, ASTM D 4318	Investigated in Adama science and technology university			
Plastic limit test				
Sample No.	1	2	3	4
Can number	2A	2B	2C	2D
Weight of can(gm.)	19.37	19.57	19.38	19.46
Weight of Can + wet soil (gm.)	31.61	29.43	32.32	33.24
Weight of Can + dry soil (gm.)	29.38	27.58	30.11	30.78
Weight of water (gm.)	2.23	1.85	2.21	2.46
Water content w%	22.28	23.09	20.59	21.73
Plastic limit of soil	**21.93**			
Liquid limit test				
Sample No.	1	2	3	4
Can number	1P	1Q	1R	1S
Weight of can(gm.)	19.38	19.46	19.59	19.39
Weight of Can + wet soil (gm.)	32.30	32.98	33.44	30.89
Weight of Can + dry soil (gm.)	28.86	29.54	30.17	28.46
Weight of water (gm.)	3.35	3.44	3.27	2.43
Water content w%	36.29	34.13	30.91	26.79
Number of drop	18	22	28	34



Liquid Limit	**32.324**	**Plastic limit**	**21.93**

Table A4: Sieve Analysis

Location: Adama town	Job ref.	Thesis research
Types of test: sieve analysis	Weight of air dry Sample	200 gm.
Soil description: sandy soil	Date	27-29/2/2022
Test method: ASTM D 422-63	Investigated in Adama science and technology university	

ASTM Sieve number	Sieve opening (mm)	Weight of sieve (g)	Weight of sieve + soil retained (g)	Weight of soil retained (g)	%Retained on each sieve	Cumulative of %Retained	%Passing (finer)
4	4.75	440	440	0	0.00%	0.00%	100.00%
8	2.36	406	410	4	2.00%	2.00%	98.00%
10	2.0	384	391	7	3.50%	5.50%	94.50%
16	1.18	359	378	19	9.50%	15.00%	85.00%
30	0.6	330	372	42	21.00%	36.00%	64.00%
40	0.425	367	390	23	11.50%	47.50%	52.50%
50	0.3	295	312	17	8.50%	56.00%	44.00%
100	0.150	278	292	14	7.00%	63.00%	37.00%
200	0.075	273	284	11	5.50%	68.50%	31.50%
pan		252	315	63	31.50%	100.00%	0.00%
				200gm.			

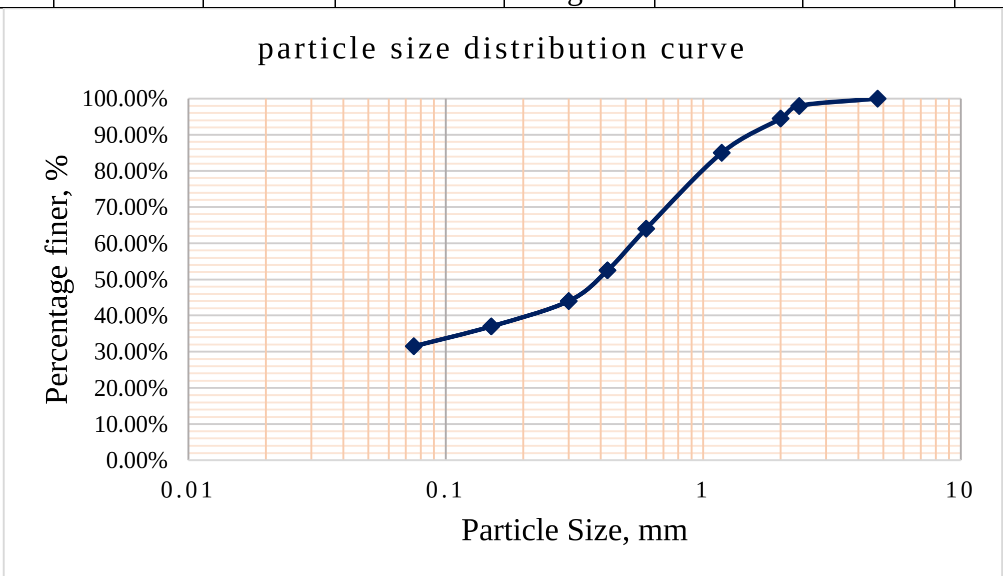


Table A5: Hydrometer Analysis

Location: Adama town	Job ref.	Thesis research
Types of Hydrometer analysis used 152H	Weight of oven-dry Sample	50 gm.
Soil description: sandy soil	Date	3-4/3/2022
Amount of Dispersing agent used 40gm/Liter	Value of **a** for GS of 2.60	1.01
F_{200} (% finer of #200 sieve as a percent)=31.50%	Zero correction	+2
Test method: ASTM D 422	Investigated in Adama science and technology university	

date	Elapsed Time, t (min)	Actual Reading (Ra)	R = Ra + Meniscus correction	Corrected Reading, RC= Ra-Zero correction + CT	T c^0	L = (16.29 – 0.1641R)	$\sqrt{\frac{L}{t}}$	K	Particle size, D = $K\sqrt{L/t}$	% of Finer, P = $\frac{Rc*a*100}{Ms}$	% adjusted finer, PA
3/3/2022	0.5	45.00	46.00	44.00	20	8.74	4.18	0.01386	0.058	88.88	28.00
	1	44.00	45.00	43.00	20	8.91	2.98	0.01386	0.041	86.86	27.36
	2	43.00	44.00	42.00	20	9.07	2.13	0.01386	0.030	84.84	26.72
	4	41.00	42.00	40.20	21	9.40	1.53	0.01369	0.021	81.20	25.58
	8	40.00	41.00	39.20	21	9.56	1.09	0.01369	0.015	79.18	24.94
	15	39.00	40.00	38.20	21	9.73	0.81	0.01369	0.011	77.16	24.31
	30	38.00	39.00	37.40	22	9.89	0.57	0.01353	0.008	75.55	23.80
	60	37.00	38.00	36.40	22	10.05	0.41	0.01353	0.006	73.53	23.16
	120	37.00	38.00	36.40	22	10.05	0.29	0.01353	0.004	73.53	23.16
	240	36.00	37.00	35.40	22	10.22	0.21	0.01353	0.003	71.51	22.53
	480	35.00	36.00	34.40	21	10.38	0.15	0.01369	0.002	69.49	21.89
	960	34.00	35.00	33.00	20	10.55	0.11	0.01386	0.0015	66.66	21.00
4/3/2022	1440	33.00	34.00	32.00	20	10.71	0.09	0.01386	0.001	64.64	20.36

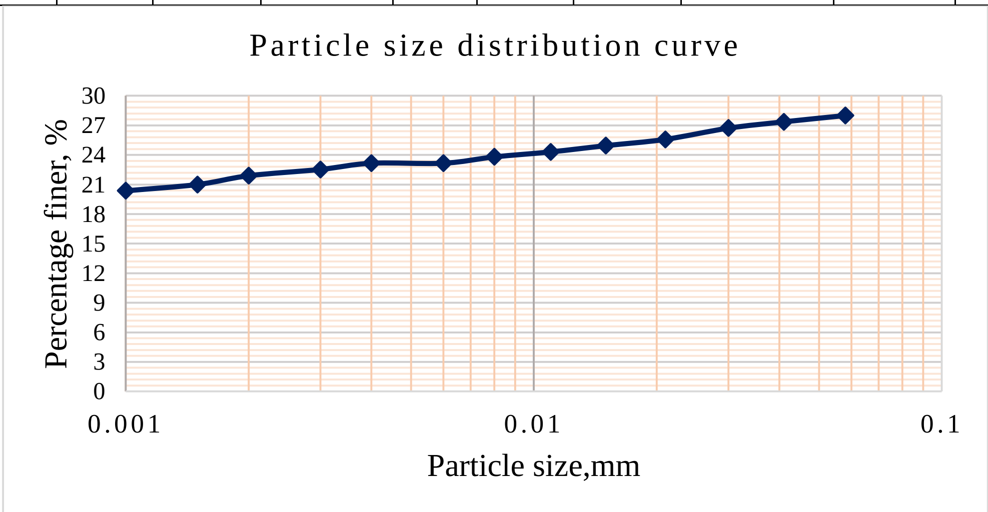
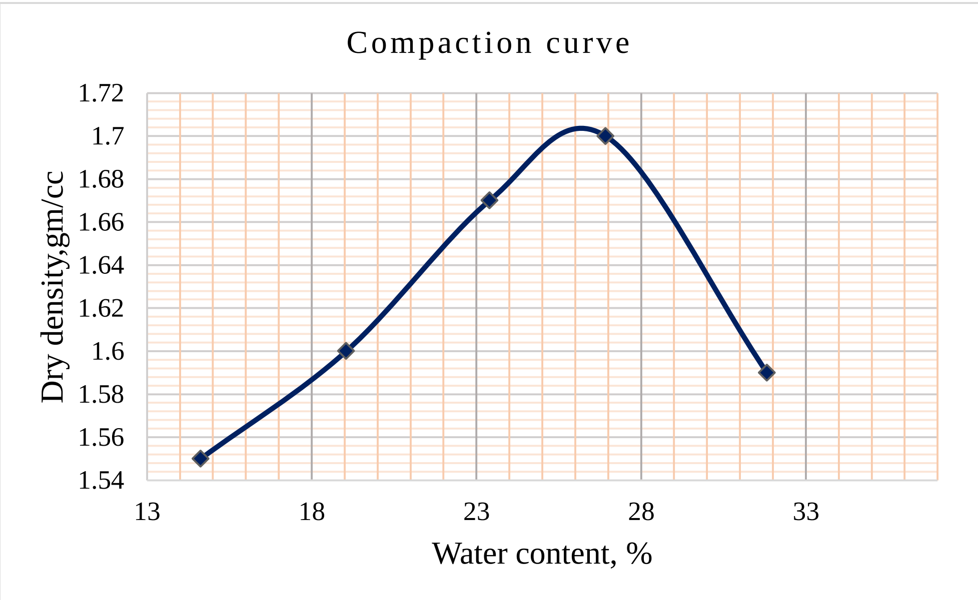


Table A6: Compaction test

Location; Adama town	Job ref.			Thesis research		
Soil description: silt sand	Date					
Test method: Standard Compaction, ASTM D 698-91	Investigated in Adama science and technology university					
Blows/layer	25	No. of layers	3	Wt of hammer, Kg	2.5	
Mold diameter, cm	10	Mold Height, cm	12	Volume, CC	944	
Water Content Determination						
Determination No						
Container No	A0	A1	A2	A3	A4	
Mass of Container, M1 ,g	19	20	19	19	19	
Mass of Container + Wet Soil, M2 ,g	66	70	77	85	77	
Mass of Container + Dry Soil, M3 ,g	60	62	66	71	63	
Mass of Water, M2-M3 ,g	6	8	11	14	14	
Mass of Dry Soil, M3-M1 ,g	41	42	47	52	44	
Moisture Content, W=(M2-M3)/(M3-M1)*100, %	14.63	19.05	23.4	26.92	31.82	
Density Determination						
Water content. Wo, %	14.63	19.05	23.4	26.92	31.82	
Wt of soil + mold, g	5439	5551	5700	5799	5732	
Wt of mold, g	3757	3757	3757	3757	3757	
Wt of soil in mold, g	1682	1794	1943	2042	1975	
Wet density, g/cc	1.78	1.9	2.06	2.16	2.09	
Dry density, g/cc	1.55	1.6	1.67	1.7	1.59	



APPENDIX- 2

CHEMICAL ANALYSIS OF SOIL, FILTER CAKE, AND MARBLE DUST

Geological Survey of Ethiopia: Geochemical Laboratory Directorate

Geochemical Laboratory Complete Silicate Analysis Report Format Form G0004

FILE ID; 0110/21 Pvt Originator; Yosef Fanta

Sample Type: Soil Date Submitted; 03/02/2022

Preparation; 200 MESH

Number of Samples: 1 **Element to be determined Major Oxides and Minor Oxides**

Analytical Method: LIBO2 FUSION, HF attack, GRAVIMETRIC, COLORIMETRIC, and AAS

Analytical results in PERCENT

FIELD NO	Lab No	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	H_2O	SO_3	LOI	Cl^-	PH
Soil-Y	0110/21	64.66	16.84	6.95	1.03	0.36	1.68	3.82	0.18	0.42	<0.01	0.22	0.09	4.27	<0.01	7.34

Analysts	Checked by	Approved by	Quality Control	Date Reported
Tizita Zemene				
Yirgalem Abreham	Gosa Haile	Demisew Lemma	Awash Yirga	17/4/2022
Yohannes Getachew				
Elsa Fisseha				
Bethelehem Tefera				

Geological Survey of Ethiopia: Geochemical Laboratory Directorate

Geochemical Laboratory Complete Silicate Analysis Report Format Form G0004

FILE ID; 0109/21 Pvt Originator; Yosef Fanta

Sample Type: Marble Dust Date Submitted; 03/02/2022

Preparation; 200 MESH

Number of Samples: 1 **Element to be determined Major Oxides and Minor Oxides**

Analytical Method: LIBO2 FUSION, HF attack, GRAVIMETRIC, COLORIMETRIC, and AAS

Analytical results in PERCENT

FIELD No	Lab No	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	H_2O	LOI
Marble-P	0109/21	17.86	<0.01	<0.01	44.68	2.36	<0.01	<0.01	<0.01	0.02	0.03	0.04	35.29

Analysts	Checked by	Approved by	Quality Control	Date Reported
Tizita Zemene				
Yirgalem Abreham	Gosa Haile	Demisew Lemma	Awash Yirga	17/4/2022
Yohannes Getachew				
Elsa Fisseha				
Bethelehem Tefera				

Geological Survey of Ethiopia: Geochemical Laboratory Directorate

Geochemical Laboratory Complete Silicate Analysis Report Format Form G0004

FILE ID; 0116/21 Pvt Originator; Yosef Fanta

Sample Type: Filter Cake Date Submitted; 03/02/2022

Preparation; 200 MESH

Number of Samples: 1 **Element to be determined Major Oxides and Minor Oxides**

Analytical Method: LIBO2 FUSION, HF attack, GRAVIMETRIC, COLORIMETRIC, and AAS

Analytical results in PERCENT

FIELD NO	Lab No	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	P_2O_5	H_2O	SO_3
Cake-A	0116/21	51.65	1.04	<0.01	39.43	0.08	0.07	0.05	<0.01	0.42	1.03	5.26	0.51

Analysts	Checked by	Approved by	Quality Control	Date Reported
Tizita Zemene				
Yirgalem Abreham	Gosa Haile	Demisew Lemma	Awash Yirga	22/4/2022
Yohannes Getachew				
Elsa Fisseha				
Bethelehem Tefera				

APPENDIX- 3

COMPRESSIVE STRENGTH TEST RESULT

Table 1: 7th Day Compressive Strength Test Result

Mix 1 (Block Produced With Soil Only)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								0.71
CSB0	24/3/2022	1/4/2022	7	7.12	287	138.5	96..5	29	0.71	
CSB0	24/3/2022	1/4/2022	7	7.14	288.6	139.5	98	27	0.66	
CSB0	24/3/2022	1/4/2022	7	7.05	289	138	96.5	31	0.76	

Mix 2 (Block Produced With Soil plus 5 % of cement)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								1.50
CSB1	1/4/2022	8/4/2022	7	7.09	288	137	97	63	1.55	
CSB1	1/4/2022	8/4/2022	7	7.06	289	139	97	59	1.45	
CSB1	1/4/2022	8/4/2022	7	7.13	289	137.5	96	61	1.50	

Mix 3 (Block Produced With Soil plus 10% of cement)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.47
CSB2	1/4/2022	8/4/2022	7	7.21	287.5	139.5	98	107	2.63	
CSB2	1/4/2022	8/4/2022	7	7.35	288.5	138.5	94	96	2.36	
CSB2	1/4/2022	8/4/2022	7	7.19	289	138	92.5	99	2.43	

Mix 4 (Block Produced With Soil plus 15% of cement)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.95
CSB3	1/4/2022	8/4/2022	7	7.44	288	137	97	115	2.83	
CSB3	1/4/2022	8/4/2022	7	7.56	289	139	97.5	127	3.12	

CSB3	1/4/2022	8/4/2022	7	7.39	287.5	138	95	118	2.90	

Mix 5 (Block Produced With Soil plus 5 % of Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								1.12
CSB4	1/4/2022	8/4/2022	7	7.24	289	137.5	93.5	46	1.13	
CSB4	1/4/2022	8/4/2022	7	7.17	287	138.5	97	42	1.03	
CSB4	1/4/2022	8/4/2022	7	7.19	288.5	139.5	98	49	1.21	

Mix 6 (Block Produced With Soil plus 10% of Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.29
CSB5	1/4/2022	8/4/2022	7	7.22	288.5	137.5	98	94	2.31	
CSB5	1/4/2022	8/4/2022	7	7.23	288.5	138.5	97	99	2.43	
CSB5	1/4/2022	8/4/2022	7	7.17	289.5	138	98	87	2.14	

Mix 7 (Block Produced With Soil plus 15% of Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.04
CSB6	1/4/2022	8/4/2022	7	7.11	287	138	94.5	78	1.92	
CSB6	1/4/2022	8/4/2022	7	7.16	287	137	96	90	2.22	
CSB6	1/4/2022	8/4/2022	7	7.15	289.5	139	98.5	81	1.99	

Mix 8 (Block Produced With Soil plus 5 % of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								1.18
CSB7	1/4/2022	8/4/2022	7	7.27	289	139.5	93.5	49	1.21	
CSB7	1/4/2022	8/4/2022	7	7.22	289	137.5	96.5	51	1.26	
CSB7	1/4/2022	8/4/2022	7	7.21	287.5	138.5	93.5	44	1.08	

Mix 9 (Block Produced With Soil plus 10% of Marble Dust)									
Specimen Notation	Date	Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)

	Casting	Testing								2.34
CSB8	1/4/2022	8/4/2022	7	7.51	288.5	139	95.5	104	2.56	
CSB8	1/4/2022	8/4/2022	7	7.69	289.5	139	97	86	2.12	
CSB8	1/4/2022	8/4/2022	7	7.24	287.5	137.5	98	95	2.33	

Mix 10 (Block Produced With Soil plus 15% of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.75
CSB9	1/4/2022	8/4/2022	7	7.37	288	139	97	109	2.68	
CSB9	1/4/2022	8/4/2022	7	7.37	289	137	95	116	2.85	
CSB9	1/4/2022	8/4/2022	7	7.52	289.5	138	96.5	111	2.73	

Mix 11 (Block Produced With Soil plus 2.5 % of cement and 2.5 % Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.46
CSB10	3/4/2022	10/4/2022	7	7.12	289	139	94.5	96	2.36	
CSB10	3/4/2022	10/4/2022	7	7.13	288	137	95	101	2.48	
CSB10	3/4/2022	10/4/2022	7	7.21	287.5	139.5	98	104	2.56	

Mix 12 (Block Produced With Soil plus 5 % of cement and 5 % Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.41
CSB11	3/4/2022	10/4/2022	7	7.23	289	139	98.5	138	3.40	
CSB11	3/4/2022	10/4/2022	7	7.19	289.5	138.5	92.5	142	3.50	
CSB11	3/4/2022	10/4/2022	7	7.20	287	139	94	136	3.34	

Mix 13 (Block Produced With Soil plus 7.5 % of cement and 7.5% Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.25
CSB12	3/4/2022	10/4/2022	7	7.17	289	139	97	129	3.17	
CSB12	3/4/2022	10/4/2022	7	7.16	288	137	95.5	133	3.27	
CSB12	3/4/2022	10/4/2022	7	7.21	289	137	97.5	135	3.32	

Mix 14 (Block Produced With Soil plus 2.5 % of Cement and 2.5% Of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.81
CSB13	3/4/2022	10/4/2022	7	7.26	286.5	138.5	98	115	2.83	
CSB13	3/4/2022	10/4/2022	7	7.37	289	139.5	97.5	118	2.90	
CSB13	3/4/2022	10/4/2022	7	7.49	287.5	137.5	98	110	2.70	

Mix 15 (Block Produced With Soil plus 5 % of Cement and 5% Of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								4.0
CSB14	3/4/2022	10/4/2022	7	7.48	289.5	139.5	96	163	4.01	
CSB14	3/4/2022	10/4/2022	7	7.48	287.5	139.5	96.5	155	3.81	
CSB14	3/4/2022	10/4/2022	7	7.37	289.5	137	96	170	4.18	

Mix 16 (Block Produced With Soil plus 7.5 % of Cement and 7.5% Of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.73
CSB15	3/4/2022	10/4/2022	7	7.57	289	139	97	156	3.84	
CSB15	3/4/2022	10/4/2022	7	7.66	288.5	138	96.5	148	3.64	
CSB15	3/4/2022	10/4/2022	7	7.53	288.5	139	98	151	3.71	

Table 2: 14th Day Compressive Strength Test Result

Mix 1 (Block Produced With Soil Only)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								0.84
CSB0	23/3/2022	7/4/2022	14	7.13	288.5	139.5	94.5	32	0.79	
CSB0	23/3/2022	7/4/2022	14	7.19	287.5	138.5	96.5	38	0.93	
CSB0	23/3/2022	7/4/2022	14	7.17	289	139	97.5	33	0.81	

Mix 2 (Block Produced With Soil plus 5 % of cement)									
Specimen Notation	Date	Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)

	Casting	Testing								2.18
CSB1	23/3/2022	7/4/2022	14	7.41	287.5	137	98	88	2.17	
CSB1	23/3/2022	7/4/2022	14	7.41	289	138.5	97.5	92	2.26	
CSB1	23/3/2022	7/4/2022	14	7.23	289	138	96.5	86	2.11	

Mix 3 (Block Produced With Soil plus 10% of cement)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.91
CSB2	23/3/2022	7/4/2022	14	7.25	287.5	139.5	98	126	3.10	
CSB2	23/3/2022	7/4/2022	14	7.59	286.5	138.5	94	114	2.80	
CSB2	23/3/2022	7/4/2022	14	7.34	289	139	92.5	115	2.83	

Mix 4 (Block Produced With Soil plus 15% of cement)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.87
CSB3	23/3/2022	7/4/2022	14	7.65	287	138.5	94.5	148	3.64	
CSB3	23/3/2022	7/4/2022	14	7.49	287	139	95	166	4.08	
CSB3	23/3/2022	7/4/2022	14	7.23	289.5	139	97	159	3.91	

Mix 5 (Block Produced With Soil plus 5 % of Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								1.72
CSB4	23/3/2022	7/4/2022	14	7.22	288	139	96	74	1.82	
CSB4	23/3/2022	7/4/2022	14	7.21	289	138	97.5	69	1.69	
CSB4	23/3/2022	7/4/2022	14	7.20	287.5	138	98	67	1.65	

Mix 6 (Block Produced With Soil plus 10% of Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.98
CSB5	23/3/2022	7/4/2022	14	7.20	287.5	139.5	96	121	2.98	
CSB5	23/3/2022	7/4/2022	14	7.20	289	139.5	95	128	3.15	
CSB5	23/3/2022	7/4/2022	14	7.18	289.5	139	95	115	2.83	

Mix 7 (Block Produced With Soil plus 15% of Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.59
CSB6	23/3/2022	7/4/2022	14	7.08	289	139	95.5	113	2.78	
CSB6	23/3/2022	7/4/2022	14	7.13	288	137.5	97	98	2.41	
CSB6	23/3/2022	7/4/2022	14	7.11	289	139	96	105	2.58	

Mix 8 (Block Produced With Soil plus 5 % of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								1.87
CSB7	23/3/2022	7/4/2022	14	7.27	289	138.5	93	79	1.94	
CSB7	23/3/2022	7/4/2022	14	7.22	287	139.5	96	77	1.89	
CSB7	23/3/2022	7/4/2022	14	7.51	289.5	138.5	93.5	73	1.79	

Mix 9 (Block Produced With Soil plus 10% of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.76
CSB8	23/3/2022	7/4/2022	14	7.31	287.5	138	95	104	2.56	
CSB8	23/3/2022	7/4/2022	14	7.39	287.5	138	97	119	2.93	
CSB8	23/3/2022	7/4/2022	14	7.54	289.5	138.5	98.5	114	2.80	

Mix 10 (Block Produced With Soil plus 15% of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.42
CSB9	23/3/2022	7/4/2022	14	7.47	289	139	97	154	3.79	
CSB9	23/3/2022	7/4/2022	14	7.47	287	138	95	129	3.17	
CSB9	23/3/2022	7/4/2022	14	7.42	287.5	139	96	135	3.32	

Mix 11 (Block Produced With Soil plus 2.5 % of cement and 2.5 % Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.96
CSB10	27/3/2022	11/4/2022	14	7.27	289.5	139	95	116	2.85	
CSB10	27/3/2022	11/4/2022	14	7.25	289	139	97	121	2.98	

CSB10	27/3/2022	11/4/2022	14	7.31	288.5	139.5	98	124	3.05	

Mix 12 (Block Produced With Soil plus 5 % of cement and 5 % Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.95
CSB11	27/3/2022	11/4/2022	14	7.31	288	139	98	160	3.94	
CSB11	27/3/2022	11/4/2022	14	7.28	289.5	139.5	96.5	165	4.06	
CSB11	27/3/2022	11/4/2022	14	7.30	289	138.5	95	156	3.84	

Mix 13 (Block Produced With Soil plus 7.5 % of cement and 7.5% Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.78
CSB12	27/3/2022	11/4/2022	14	7.21	289	139.5	97	149	3.67	
CSB12	27/3/2022	11/4/2022	14	7.16	289	139	96	152	3.74	
CSB12	27/3/2022	11/4/2022	14	7.20	289	139	97	160	3.94	

Mix 14 (Block Produced With Soil plus 2.5 % of Cement and 2.5% Of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.35
CSB13	27/3/2022	11/4/2022	14	7.19	289.5	139.5	95	137	3.37	
CSB13	27/3/2022	11/4/2022	14	7.26	289	139	97	138	3.39	
CSB13	27/3/2022	11/4/2022	14	7.38	289.5	138.5	95	134	3.30	

Mix 15 (Block Produced With Soil plus 5 % of Cement and 5% Of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								4.72
CSB14	27/3/2022	11/4/2022	14	7.27	287.5	139	96	191	4.70	
CSB14	27/3/2022	11/4/2022	14	7.59	289.5	139.5	94.5	195	4.80	
CSB14	27/3/2022	11/4/2022	14	7.62	289.5	137	96	189	4.65	

Mix 16 (Block Produced With Soil plus 7.5 % of Cement and 7.5% Of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)

	Casting	Testing								4.25
CSB15	27/3/2022	11/4/2022	14	7.25	287	137.5	93	179	4.40	
CSB15	27/3/2022	11/4/2022	14	7.46	289.5	139	97	170	4.18	
CSB15	27/3/2022	11/4/2022	14	7.25	289.5	137	98	170	4.17	

Table 3: 28th Day Compressive Strength Test Result

Mix 1 (Block Produced With Soil Only)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								0.99
CSB0	21/3/2022	19/4/2022	28	7.32	288	139.5	97.5	43	1.05	
CSB0	21/3/2022	19/4/2022	28	7.32	289.5	139	96	37	0.91	
CSB0	21/3/2022	19/4/2022	28	7.31	289	139	95	41	1.0	

Mix 2 (Block Produced With Soil plus 5 % of cement)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.86
CSB1	21/3/2022	19/4/2022	28	7.49	289	139	96.5	117	2.88	
CSB1	21/3/2022	19/4/2022	28	7.33	289	137	98.5	117	2.88	
CSB1	21/3/2022	19/4/2022	28	7.51	286.5	137	96	115	2.83	

Mix 3 (Block Produced With Soil plus 10% of cement)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								4.54
CSB2	21/3/2022	19/4/2022	28	7.26	289.5	138.5	98	188	4.63	
CSB2	21/3/2022	19/4/2022	28	7.39	287	139	95.5	181	4.45	
CSB2	21/3/2022	19/4/2022	28	7.47	288	139	94	185	4.55	

Mix 4 (Block Produced With Soil plus 15% of cement)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								5.08
CSB3	21/3/2022	19/4/2022	28	7.47	289	138	96.5	204	5.0	
CSB3	21/3/2022	19/4/2022	28	7.20	287.5	138	97.5	211	5.19	
CSB3	21/3/2022	19/4/2022	28	7.23	289.5	139	95.5	206	5.07	

Mix 5 (Block Produced With Soil plus 5 % of Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.33
CSB4	21/3/2022	19/4/2022	28	7.20	289	139	95.5	100	2.46	
CSB4	21/3/2022	19/4/2022	28	7.23	287.5	139	98	89	2.19	
CSB4	21/3/2022	19/4/2022	28	7.20	289	139	97.5	96	2.36	

Mix 6 (Block Produced With Soil plus 10% of Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.51
CSB5	21/3/2022	19/4/2022	28	7.22	289	139	97.5	141	3.47	
CSB5	21/3/2022	19/4/2022	28	7.19	288	137.5	98	137	3.37	
CSB5	21/3/2022	19/4/2022	28	7.18	289.5	138	94	150	3.69	

Mix 7 (Block Produced With Soil plus 15% of Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.18
CSB6	21/3/2022	19/4/2022	28	7.08	289	139	95.5	129	3.17	
CSB6	21/3/2022	19/4/2022	28	7.13	287	138.5	97.5	124	3.05	
CSB6	21/3/2022	19/4/2022	28	7.11	287	139	96	136	3.34	

Mix 8 (Block Produced With Soil plus 5 % of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.39
CSB7	21/3/2022	19/4/2022	28	7.24	289	139	97	96	2.36	
CSB7	21/3/2022	19/4/2022	28	7.22	287	137.5	96.5	91	2.24	
CSB7	21/3/2022	19/4/2022	28	7.22	289	139	93.5	105	2.58	

Mix 9 (Block Produced With Soil plus 10% of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.82
CSB8	21/3/2022	19/4/2022	28	7.21	288.5	137	95.5	165	4.06	
CSB8	21/3/2022	19/4/2022	28	7.19	288.5	138	97.5	148	3.64	

CSB8	21/3/2022	19/4/2022	28	7.24	289.5	139.5	98.5	153	3.76	

Mix 10 (Block Produced With Soil plus 15% of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								4.45
CSB9	21/3/2022	19/4/2022	28	7.39	289	139.5	97	181	4.45	
CSB9	21/3/2022	19/4/2022	28	7.27	289	137	94.5	185	4.55	
CSB9	21/3/2022	19/4/2022	28	7.36	287	139	96	177	4.36	

Mix 11 (Block Produced With Soil plus 2.5 % of cement and 2.5 % Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.49
CSB10	29/3/2022	27/4/2022	28	7.49	288	139	96	147	3.62	
CSB10	29/3/2022	27/4/2022	28	7.21	289	137	95	144	3.54	
CSB10	29/3/2022	27/4/2022	28	7.36	289.5	139	98.5	135	3.32	

Mix 12 (Block Produced With Soil plus 5 % of cement and 5 % Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								5.53
CSB11	29/3/2022	27/4/2022	28	7.41	289	137	98	225	5.54	
CSB11	29/3/2022	27/4/2022	28	7.22	288	139.5	96.5	219	5.39	
CSB11	29/3/2022	27/4/2022	28	7.29	289	139.5	94	231	5.68	

Mix 13 (Block Produced With Soil plus 7.5 % of cement and 7.5% Filter Cake)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								4.73
CSB12	29/3/2022	27/4/2022	28	7.17	289	137.5	98	197	4.85	
CSB12	29/3/2022	27/4/2022	28	7.19	289	139	96.5	189	4.65	
CSB12	29/3/2022	27/4/2022	28	7.20	287.5	139	97.5	191	4.70	

Mix 14 (Block Produced With Soil plus 2.5 % of Cement and 2.5% Of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								4.22
CSB13	29/3/2022	27/4/2022	28	7.17	288.5	139.5	98	171	4.21	
CSB13	29/3/2022	27/4/2022	28	7.21	289	137.5	96	176	4.33	
CSB13	29/3/2022	27/4/2022	28	7.19	289.5	139.5	95	168	4.13	

Mix 15 (Block Produced With Soil plus 5 % of Cement and 5% Of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								5.60
CSB14	29/3/2022	27/4/2022	28	7.20	289.5	139	97	229	5.64	
CSB14	29/3/2022	27/4/2022	28	7.20	288.5	138	96.5	230	5.66	
CSB14	29/3/2022	27/4/2022	28	7.17	289	139	93	224	5.51	

Mix 16 (Block Produced With Soil plus 7.5 % of Cement and 7.5% Of Marble Dust)										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								4.84
CSB15	29/3/2022	27/4/2022	28	7.19	287	139.5	96	204	5.02	
CSB15	29/3/2022	27/4/2022	28	7.23	287	138	94.5	197	4.85	
CSB15	29/3/2022	27/4/2022	28	7.45	289.5	138	98.5	190	4.67	

Effect of Compaction Pressure on 28th day Compressive Strength Test Result

Mix A (15% cement) With compaction pressure 6 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.87
A1	7/3/2022	5/4/2022	28	7.35	288.5	139.5	99	114	2.81	
A1	7/3/2022	5/4/2022	28	7.37	289.5	137.5	98.5	117	2.88	
A1	7/3/2022	5/4/2022	28	7.37	289.5	137.5	97	119	2.93	

Mix B (15% cement) With compaction pressure 10 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								4.17
B2	7/3/2022	5/4/2022	28	7.29	289.5	137.5	97	166	4.09	
B2	7/3/2022	5/4/2022	28	7.32	287.5	139	98	173	4.26	
B2	7/3/2022	5/4/2022	28	7.34	289	139	96	169	4.16	

Mix C (15% cement) With compaction pressure 14 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								5.25
C3	7/3/2022	5/4/2022	28	7.34	289	139.5	98.5	214	5.27	
C3	7/3/2022	5/4/2022	28	7.36	289.5	139	98	209	5.14	
C3	7/3/2022	5/4/2022	28	7.34	289	137.5	96.5	217	5.34	

Mix D (15% Filter Cake) With compaction pressure 6 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.07
D4	7/3/2022	5/4/2022	28	7.36	289.5	138	97	84	2.07	
D4	7/3/2022	5/4/2022	28	7.32	287	139.5	97.5	81	1.99	
D4	7/3/2022	5/4/2022	28	7.35	289.5	139	96	87	2.14	

Mix E (15% Filter Cake) With compaction pressure 10 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.91
E5	7/3/2022	5/4/2022	28	7.31	289.5	137	97.5	119	2.93	
E5	7/3/2022	5/4/2022	28	7.33	289.5	138	96	115	2.83	
E5	7/3/2022	5/4/2022	28	7.34	289.5	138	97	121	2.98	

Mix F (15% Filter Cake) With compaction pressure 14 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								4.09
F6	7/3/2022	5/4/2022	28	7.37	289	139.5	98	168	4.13	
F6	7/3/2022	5/4/2022	28	7.38	289	137.5	98	164	4.04	

F6	7/3/2022	5/4/2022	28	7.35	287.5	139	96.5	167	4.11	

Mix G (15% marble dust) With compaction pressure 6 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								2.88
G7	7/3/2022	5/4/2022	28	7.36	289	139.5	98	112	2.76	
G7	7/3/2022	5/4/2022	28	7.33	288	139.5	97.5	118	2.91	
G7	7/3/2022	5/4/2022	28	7.32	289.5	139.5	96	120	2.96	

Mix H (15% marble dust) With compaction pressure 10 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								4.18
H8	7/3/2022	5/4/2022	28	7.38	289	139	96.5	166	4.09	
H8	7/3/2022	5/4/2022	28	7.31	289	139.5	97.5	173	4.26	
H8	7/3/2022	5/4/2022	28	7.34	287.5	139	95.5	170	4.19	

Mix I (15% marble dust) With compaction pressure 14 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								5.37
I9	7/3/2022	5/4/2022	28	7.38	289.5	139.5	98	215	5.29	
I9	7/3/2022	5/4/2022	28	7.37	289	138.5	97.5	221	5.44	
I9	7/3/2022	5/4/2022	28	7.38	288.5	139	97	219	5.39	

Mix J (7.5% Filter Cake and 7.5% of cement) With compaction pressure 6 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.0
J10	8/3/2022	6/4/2022	28	7.29	289	139.5	97	122	3.0	
J10	8/3/2022	6/4/2022	28	7.33	289	139.5	97	125	3.08	
J10	8/3/2022	6/4/2022	28	7.33	288	139	98	119	2.93	

Mix K (7.5% Filter Cake and 7.5% of cement) With compaction pressure 10 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)

	Casting	Testing								4.32
K11	8/3/2022	6/4/2022	28	7.36	287.5	139.5	96	176	4.33	
K11	8/3/2022	6/4/2022	28	7.33	289	139	98	179	4.41	
K11	8/3/2022	6/4/2022	28	7.31	289.5	137.5	97	171	4.21	

Mix L (7.5% Filter Cake and 7.5% of cement) With compaction pressure 14 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								5.56
L12	8/3/2022	6/4/2022	28	7.37	289.5	139.5	98	227	5.59	
L12	8/3/2022	6/4/2022	28	7.37	289.5	139	98	221	5.44	
L12	8/3/2022	6/4/2022	28	7.38	288.5	139.5	97	229	5.64	

Mix M (7.5% marble dust and 7.5% of cement) With compaction pressure 6 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								3.04
M13	8/3/2022	6/4/2022	28	7.35	289.5	139.5	98	122	3.0	
M13	8/3/2022	6/4/2022	28	7.30	289	138	96.5	126	3.10	
M13	8/3/2022	6/4/2022	28	7.34	289	139	97	123	3.03	

Mix N (7.5% marble dust and 7.5% of cement) With compaction pressure 10 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								4.48
N14	8/3/2022	6/4/2022	28	7.31	288.5	139	95	181	4.46	
N14	8/3/2022	6/4/2022	28	7.35	289	137	96.5	185	4.56	
N14	8/3/2022	6/4/2022	28	7.32	289	137	98	180	4.43	

Mix O (7.5% marble dust and 7.5% of cement) With compaction pressure 14 MPa										
Specimen Notation	Date		Age (Days)	Mass (Kg)	L (mm)	W (mm)	H (mm)	Failure Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (MPa)
	Casting	Testing								5.63
O15	8/3/2022	6/4/2022	28	7.34	289.5	139.5	98	229	5.64	
O15	8/3/2022	6/4/2022	28	7.35	287.5	138	96	231	5.69	
O15	8/3/2022	6/4/2022	28	7.37	289.5	139.5	97	226	5.57	

Water Absorption Test Result

Mix V (Block produced with Cement)						
Percentage of stabilizers	5%		10%		15%	
Sample number	1	2	1	2	1	2
Pre-test dry mass (kg)	8.19	8.21	8.23	8.20	8.17	8.22
Post-test wet mass (kg)	9.33	9.38	9.02	8.98	9.16	9.19
Total water absorption %	13.64	14.25	9.60	9.51	12.12	11.80
Mean water absorption %	13.95		9.55		11.96	

Mix W (Block produced with Filter Cake)						
Percentage of stabilizers	5%		10%		15%	
Sample number	1	2	1	2	1	2
Pre-test dry mass (kg)	8.22	8.19	8.21	8.17	8.25	8.22
Post-test wet mass (kg)	9.54	9.47	9.31	9.24	9.42	9.36
Total water absorption %	16.05	15.63	13.39	13.09	14.18	13.87
Mean water absorption %	15.84		13.24		14.02	

Mix X (Block produced with Marble dust						
Percentage of stabilizers	5%		10%		15%	
Sample number	1	2	1	2	1	2
Pre-test dry mass (kg)	8.22	8.25	8.19	8.23	8.21	8.17
Post-test wet mass (kg)	9.21	9.23	9.07	9.11	8.95	8.91
Total water absorption %	12.04	11.88	10.74	10.69	9.01	9.06
Mean water absorption %	11.96		10.72		9.03	

Mix Y (Block produced with filter cake and cement)						
Percentage of stabilizers	2.5% + 2.5 %		5 % + 5 %		7.5% + 7.5%	
Sample number	1	2	1	2	1	2
Pre-test dry mass (kg)	8.25	8.22	8.22	8.23	8.24	8.23
Post-test wet mass (kg)	9.27	9.26	8.98	9.0	9.19	9.16
Total water absorption %	12.36	12.65	9.25	9.36	11.53	11.30
Mean water absorption %	12.51		9.30		11.42	
Mix Z (Block produced with marble dust and Cement)						
Percentage of stabilizers	2.5% + 2.5 %		5 % + 5 %		7.5% + 7.5%	
Sample number	1	2	1	2	1	2

Pre-test dry mass (kg)	8.23	8.23	8.17	8.24	8.16	8.19
Post-test wet mass (kg)	9.18	9.20	8.88	8.92	8.90	8.93
Total water absorption %	11.54	11.79	8.69	8.25	9.07	9.04
Mean water absorption %	11.66		8.47		9.06	

APPENDIX-4

Block Dry density

Specimen notation	stabilizers		Dimensions				Oven dry mass	Block dry density	
	type	%	L (mm)	W (mm)	H (mm)	Gross volume (m^3), (10^{-3})	gm.	Gross, Kg/m^3	Mean, Kg/m^3
CSB_1	Cement	5	287.5	138	97.5	3.87	7132	1842.9	1852.9
CSB_1		5	286.5	139	96	3.82	7116	1862.8	
CSB_2		10	288	137	96.5	3.81	7145	1875.3	1876.6
CSB_2		10	289	137.5	95	3.78	7098	1877.8	
CSB_3		15	287	137	94.5	3.72	7206	1937.1	1926.2
CSB_3		15	286	139	98	3.89	7451	1915.4	
CSB_4	Filter cake	5	288.5	139	96.5	3.87	7016	1812.9	1812.9
CSB_4		5	289	138.5	97	3.88	7034	1812.9	
CSB_5		10	289	139.5	96	3.87	7093	1832.8	1831.8
CSB_5		10	287.5	138	97.5	3.87	7085	1830.7	
CSB_6		15	289	139	95.5	3.84	7019	1827.9	1838.3
CSB_6		15	288	137	96	3.79	7007	1848.8	
CSB_7	Marble dust	5	287.5	138	96	3.81	7176	1883.5	1872.2
CSB_7		5	289	137	97.5	3.86	7183	1860.9	
CSB_8		10	287	137	98	3.85	7189	1867.3	1890.6
CSB_8		10	288.5	137	95	3.75	7177	1913.9	
CSB_9		15	287.5	136.5	96	3.77	7293	1934.5	1945.2

CSB_9		15	289	138.5	97	3.88	7589	1955.9	

Specimen notation	stabilizers		Dimensions				Oven dry mass	Block dry density	
	type	%	L (mm)	W (mm)	H (mm)	Gross volume (m^3), (10^{-3})	gm.	Gross, Kg/m^3	Mean, Kg/m^3
CSB_{10}	Cement + filter cake	2.5+2.5	286.5	138.5	97.5	3.87	7064	1825.3	1836.4
CSB_{10}		2.5+2.5	287	137	96.5	3.79	7002	1847.5	
CSB_{11}		5+5	287	139	96.5	3.85	7110	1846.8	1852.4
CSB_{11}		5+5	289	138	94.5	3.77	7005	1858.1	
CSB_{12}		7.5+7.5	288.5	137	98	3.87	7252	1873.9	1873.2
CSB_{12}		7.5+7.5	289	138.5	97	3.88	7265	1872.4	
CSB_{13}	Cement + marble dust	2.5+2.5	289	138.5	96	3.84	7230	1882.8	1880.7
CSB_{13}		2.5+2.5	288	137	98	3.87	7270	1878.6	
CSB_{14}		5+5	287.5	138	95	3.77	7165	1900.5	1905.1
CSB_{14}		5+5	289	136.5	97	3.83	7314	1909.7	
CSB_{15}		7.5+7.5	287.5	137.5	94.5	3.74	7297	1951.1	1954.2
CSB_{15}		7.5+7.5	288	136	95	3.72	7281	1957.3	

APPENDIX-5

PICTURES

(a) Soil block production

(b) Compressive strength test

(c) Oven drying of sample & measuring for dry density test

(d) Block preparation and water absorption test and Sample for SEM test