ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

SCHOOL OF MULTI- DISCIPLINARY ENGINEERING

CENTER FOR MATERIALS ENGINEERING (CME)

STUDY ON THE EFFECT OF MARBLE WASTE POWDER AND FLY ASH IN COMPRESSED STABILIZED EARTH BLOCK MATERIALS

A thesis submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the requirement for the Degree of Master of Science in Materials Engineering

By: - Nigat Melak

Advisor: - Dr.Tesfaye Refera

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DECLARATION

I, declare that this thesis entitled "***Study on the Effect of Marble Waste Powder and Fly Ash in Compressed Stabilized Earth Block Materials***" is my original work with the guidance of my advisor **Dr.Tesfaye Refera,** School of Multi-Disciplinary Engineering Addis Ababa University as part of Masters of Science program in Center for Material Engineering. In Addition, I declare that this research has not been presented by any other person or any other university for an award of a degree. All sources of material used for this research have been appropriately acknowledged.

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List of Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AAR	Alkali-Silica Reaction
AASTU	Addis Ababa Science and Technology University
ACI	American Concrete Institute
ASR	Alkali-Silica Reactivity
ASTM	American Society for Testing Materials
ASTU	Adama Science and Technology University
BS	British Standard
CCIIDI	Chemical and Construction Inputs Industry Development Institute
CSEB	Compressed Stabilized Earthen Blocks
C-S-H	Calcium Silicate Hydrate
CTM	Compressive Testing Machine
EN	European Norm
FA	Fly Ash
FCB	Fired Clay Bricks
HCB	Hallo Concrete Block
IS	Indian Standard
ISO	International Organization for Standardization
Kg/cm^3	Kilogram per cubic centimeter

LOI	Loss on Ignition
MGR	Marble-Granite Residue
MM	Millimeter
MT	Million tons
MWP	Marble Waste Powder
N/mm^2	Newton per square millimeter
OPC	Ordinary Portland cement
OSP	Optical Surface Profile
PPC	Pozzolana Portland cement
SCM	Supplementary Cementations Material
SEM	Scanning Electron Microscope
SF	Silica Fume
STVC	Selam Technical and Vocational Center
TRAE	Tsehaye Rocili and Agricultural Industrial Engineering
WMD	Waste Marble Dust
WMS	Waste Marble Sludge
XRD	X-ray Diffraction

ABSRTACT

In this study, suitability of industrial wastes, fly ash (FA), and marble waste powder (MWP) are estimated along with cement as stabilizers for producing CSEBs with soil ingredients and water. The aim of this research is to manufacture and investigate alternative wall-making material that can be produced by locally available raw materials. Compressed Stabilized Earth Block (CSEB) has identified as low-cost, reducing environmental pollution and increasing energy efficiency building construction material. And also this study has analyzed the influence of these industrial wastes when used as certain percentage replacements of cement in provide adequate compressive strength and durability of the CSEB blocks. This experimental study on CSEB prepared using fly ash and marble waste as a replacement of cement in certain proportions has brought out the effectiveness of these binding materials with cement in improving the 28^{th} -day compressive strength and durability. This can be done by identifying the physical properties and chemical composition of the materials and the characteristics of the CSEBs. Different tests were conducted to determine the physical properties of the material like grain size distribution, water absorption, moisture content, specific gravity, silt content, compressive, and tensile strengths. Chemical composition and characterization of the CSEB blocks were investigated by XRD. The microstructural behavior of the CSEBs was analyzed by using SEM images to determine the anatomic changes and morphology that occurred at different marble waste and fly ash contents. Based on the test results, it has observed that fly ash 10% and marble waste powder 5% to achieve the maximum dry-and wet compressive strength values of the block which were 3.84 Mpa and 3.01Mpa respectively. It has also demonstrated water absorption (11.6%) after 28^{th} days curing. The cost of CSEB with only cement is higher than that of FA and MWP in combination with cement. The cost comparison of CSEB with the other conventional wall making construction material, like HCB, was preferred because it is a more economical construction material; the construction cost is low, and has to input less energy and environmental impacts including raw material use, waste generation, energy consumption and its associated air emissions (CO_2) and has simple building techniques. The results of this thesis work have shown that CSEB block can be used as an alternative wall making material and significant cost reduce can be achieved in low cost housing rural, semi-urban, and urban. Any concerned body can use this construction material as an alternative building material without compromise its quality.

Keywords: Compressed Stabilized Earth Blocks, Ordinary Portland cement, Fly Ash, Marble Waste Powder, Compressive Strength, Durability

CHAPTER ONE

INTRODUCTION

1.1 Background

Housing is a common problem in many parts of developing countries, like Ethiopia, where the population growth is disproportional to the number of houses constructed. Many societies in the world may have no access to affordable housing. A partial solution to this problem could though improvement of the locally available building materials, and the application of the appropriate technology in preparation and construction. Nowadays, cement-concrete based structures are constructed widely and extensively used for all types of residential buildings ranging from small independent rural houses to high-rise buildings in urban areas[1]. Conventional or common construction methods used construction materials like concrete, fired clay bricks, aluminum, steel and timber. The construction cost is high, and also needs high input energy to produce them and hence have environmental impacts[2].

Sustainable construction material is needed to address environmental and housing problems. As a measure of ensuring sustainability and reducing damages to the environment and climate, the construction of rural, semi-urban, urban housing buildings with earthen technology was a good viable solution. Compressed earth block (CEB) is made from compressing the soil at high pressure. When binding materials are added in certain proportions to prepare the mix for CEB, then it is changed into compressed stabilized earth block (CSEB). Addition of the proper type, and amount of stabilizer, the deficiencies of the soil should be overcome, and improving the strength, and durability of the material[3].

A CSB is a wall-making building material made from damp soil compressed at high pressure to form blocks. The hydraulic or mechanical press machine is used to produce compressed stabilized block stabilized with a chemical binder such as cement, marble waste powder, fly ash, and other stabilizers they are called CSEB[2].The use of CSEBs stabilized with waste marble powder and fly ash, can be considered as environment friendly it reduces CO_2 emission considerably compared to conventional materials (e.g. reinforced concrete) over the whole life cycle. Moreover, conventional materials have low recycling rate compared to earth blocks used for construction. Generally, the most advantages of this alternative material related to environmental, low energy-intensive production processes and lower embodied energy along with low CO_2 emission[4].

Soil is the main component of CSEB block production and the skeletal structure of the block. Soil has different qualities and dispositions, depending on its occurrences naturally. Soil is available in large quantities in most regions and cheap and affordable - in most parts of the world. It is easily accessible to low-income groups, and in some locations, it is the only material available[5].

The soil has the correct composition being mixed with cement and water. Before producing CSEB, the soil must be tested to determine if it is suitable for the CSSB-production or not. Suitability criteria are based on the gradation, plasticity, and chemical composition of the soil[6]. The marble waste was produced during the block cutting or the finishing process of stone materials. The use of waste materials was highly recommended to reduce landfilling and to reduce the abiotic problems as well as all the environmental impacts related to the production of energy-intensive binders. These concerns led to considered marble waste powder and fly ash as input materials for CSEB[7].

Marble was widely used as a building material in the civil engineering industry. The marble industry's disposal of marble waste in the form of powder material, and in the form of a fine powder has environmental problems in the world. Marble blocks are cut into smaller blocks to give them the desired smooth shape and it releases. During the cutting process about 30% of the original marble mass is lost in the form of dust in the Ethiopian context[8].

Marble dust was used to reduce the cost of cement-based material production partial substitution of marble dust in the production of construction materials has often been investigated by researchers. Its mechanical and durability properties were the main aspect of the analysis. Waste marble dust is used to accelerate the hydration rate of cement-based materials blended with. The effects of using waste marble powder as partial replacement of cement on the mechanical properties of CSEB were investigated. The optimum use of waste marble powder as replacement by weight of cement has the effects of CSEB block in compressive and tensile strengths[9].

Fly ash is, a by-product of coal-fired electric power plants, and its uses as a stabilizer including as easy availability, low cost, and sustainability. There were factors that influence the properties of CSEBs like the gradation of soil, clay content, suitable stabilizer for block preparation, a quantity of stabilizer, amount of water added for the preparation of blocks, compaction effort, etc. Stabilizer type, content and nature of soil were the two main factors which affect the performance of CSEBs in significantly [7].

Fly ash was very hard, durable and if finely ground, it can serve as a pozzolanic material thus making it suitable for use as partial substitution of cement Partial replacement also improved the flow properties of blocks, so it can be used to make high strength CSEB without using another super plasticizer. The utilization of finely fly ash powder as cement replacement has been yield positive results in CSEB batching. Fly ash has a high content of silica, thus making it a good Pozzolanic material when the size is reduced below 75 μm. Using supplementary cementing materials (SCM), such as blast furnace slag, fly ash, bottom ash, volcanic ash silica fume, burnt shale, limestone powder, sugarcane bag ash and natural pozzolanic can be used to partially replace cement in CSEB. The strength and durability requirements of CSEBs usually vary from code to code [9].

This research work objectives to fabricate CSEB block using fly ash and marble waste powder waste binding materials with replacements for cement. And also has analyzed study on the effect of these industrial wastes to enhanced Portland cement composites when used at a certain percentage replacement of cement. In this thesis compressed stabilized earth blocks are considered as an alternative wall-making material, and the main advantages of using stabilizers in compressed stabilized earth blocks are provided adequate compressive strength and durability[10].

1.2 Statement of the Problem

Recently, energy efficiency and sustainability of the buildings are important, radical growth of population combined with urbanization increased construction globally which led to significant environmental problems along with resource consumption. The most environmental advantages related to alternative materials are low energy-intensive production processes and lower embodied energy along with low CO_2 emission[7]. For conventional construction materials like concrete, Fired Clay Brick(FCB), aluminum, steel, and timber the construction cost was high and have to input more energy and environmental impacts including raw material use, energy consumption, waste generation, and its associated air emissions. The sustainability these cement concrete structures were leading to unsustainable conditions and damages due to the environment and enhance climatic change[11].

The use of concrete blocks and fired clay bricks have high carbon foot print, the materials has detrimental effects on the environment. Carbon dioxide(CO_2) emissions from concrete blocks and conventional and fired clay bricks are substantially high 143 kg/ton and 200 kg/ton respectively, which subsequently leads to high energy consumption and environmental pollution construction materials[7].

Cement is the most widely used binding and stabilizing material for construction. Cement production has a high contribution to global warming. The production of one ton of cement also produces approximately one ton of CO_2 and other greenhouse gases. To reduce this problem it is important to the search for more environmentally friendly materials as cement replacement[12]. The large amount of lime raw material for use in the cement production, which may result in running out of them, as it was predicted to happen in some places of the World. Recycled materials were commonly used as an alternative to non-renewable resources[13].

The optimization of wastes or recycled materials has been spelled out throughout the different researches. A lot of research efforts are made around the world to find an alternative material that will partially or fully replace cement in composite construction production. The results showed that using supplementary cementing materials (SCM), such as blast furnace slag, fly ash, bottom ash, volcanic ash silica fume, burnt shale, limestone powder, sugarcane bag ash, and natural pozzolan can be used to partially replace cement in CSEB.

Fly ash was one of the classes of natural pozzolans and marble waste powder was the focus of this research work in partially replacing ordinary Portland cement. Considering the construction industries of Ethiopia, to utilize and reuse these wastes can improve the mechanical properties and durability of CSEB within a certain amount. CSEB construction system is interlocking walling material that enables speedier construction of a high quality, aesthetic and affordable building. CSEB construction materials are made by using hydraulic block making machine or with other compressing manual machine [14].

Therefore, this study investigated the effect of industrial waste such as MWP, and FA were enhanced the binding nature of cement. The mechanical and durability parameters of CSEB material has analyzed [9]. The compressive strength test was performed at the age of 7, 14, 21, and 28 days according to ASTM C140 - Standard test methods [6]. The aim of this research is, to manufacture alternative wall-making material that can be produced by locally available raw materials. The need is to deliver more durable alternative construction material of lower cost.

1.3 Objectives

1.3.1 General Objectives

The general objective of this research is to produce CSEB alternative walling material by using waste marble powder and fly ash as a partial replacement for cement with respect to its strength and durability

1.3.2 Specific Objectives

The specific objectives are:

- To improve the mechanical properties, durability, and water permeability resistance of CSEBs materials
- To investigate the effects of marble waste powder and fly ash in CSEB production using density, water absorption, and compressive strength tests of blocks
- To determine the morphology of CSEBs and compare with the normal block using SEM to the enhancement of the block with WMP and FA incorporation after 28 days of curing
- To estimate the volume or percentages replacement or optimal utilization of wastes in the mixture of CSEBs.

1.4 Significance of the study

Recycling of industrial waste as supplementary cementations material (SCM) reduces cement consumption during CSEB production, by lowering CO_2 emission and finally makes waste management more efficient. Utilization FA and MWP materials used to reduce; cost of materials, energy consumptions and environmental pollutions. Using these composite stabilizers the work would have the following significances:

- Improve mechanical strength and durability of CSEBs
- Enhancing integrity and strength between stabilizer pastes and soils in CSEB microstructure
- Using waste stabilizers to produce efficient and durable CSEB materials
- Determine the effect and limitations of the cement with MWP and FA stabilizers
- The use of waste materials is highly recommended to reduce landfilling and to minimize abiotic depletion as well as all the environmental impacts related to the production of energy-intensive binders.
- The marble sludge or waste was the most interesting part of the waste because of its almost nil usage.
- Substituting of marble sludge and FA into the cement composites were improved the mechanical properties of CSEB.
- These concerns led to waste marble and fly ash were used for alternative, low cost, and affordable CSEB construction material production.

The research was to apply the waste material of coal and marble as constituent material or supplementary cementations material in the production of CSEB block. This study can be used as the discovery of optimum utilization of wastes in the process of block production with the same effect in the mechanical property as a standard block.

1.5 Scope of the Study

The research covers studying the physical and chemical properties of marble waste powder and fly ash blended Portland cement and studying compressive strength, tensile strength, and water absorption and water permeability of CSEB.

The microstructure of CSEB blocks (normal block using soil and cement only, replacing cement with components like flay ash and marble waste powder) were investigated by using SEM and materials are also characterized by XRD analysis.

1.6 Limitations of Study

This study is limited to the effect of wastes on mechanical properties of CSEB; such as Compressive strength, tensile strength and durability.

1.7 Structure of the Research

This thesis has five chapters and each chapter is also divided into main topics and further into subtopics or subsections. The first chapter contains a general introduction to the research work and the report. It is the relevance of the research. It discusses the background of the research, the objectives, the scope and limitation, the statements of the problem (Justification of the study), and the methodology of the thesis.

The second chapter contains review kinds of literature on the study area, which provides a general understanding of previous studies and theories related to this research. The third chapter has all the procedures and methods followed in this study to arrive at the research results. And also discusses the material properties used in the new investigation, sample preparations and methodology of the study that is experimental, and mix design program that was used in the research.

The fourth chapter is about the research results and discussion part obtained from the study. The last chapter that is chapter five draws the research conclusions and recommendations. All other important data are presented in the Appendices.

CHAPTER TWO

LITREATURE REVIEW

2.1 Introduction

The selection of construction materials is one of the basic criteria, which determines the mechanical strength, durability, quality, and economy of any construction. There are different types of building construction materials like stone, sand, earth, woods, etc. were used as building materials in their original form. Researchers have studied strong and durable alternative building construction materials. These alternative walling materials as compared to the modern hollow concrete block (HCB), Fired Brick, glass, and other recent technologies. But these materials have side effects related to cost, energy, and environment[14].

Earth or soil is an ancient construction material used for centuries. By using advanced technologies it was made to increase the performance of soil as a building material. Compressed stabilized earth block (CSEB) production is one of the advanced alternative forms of soil as a building material. CSEB is a composite construction material made by mixing soil, stabilizers, and water. CSEB blocks are effective in constructing and utilizing eco-friendly building systems with low embodied energy. These green systems are cost-effective, easy to construct, fast to use, and equally best for both rural areas and high-density urban areas. The capacity or the performance of CSEB depends on the compaction pressure, quality of the constituent materials as well as on their proportion, and the class of construction. Hence, to discuss the performance of CSEBs it is mandatory to learn the constituent materials and some other factors affecting its performance. [6]. This chapter is focusing on the main ingredient materials in compressed stabilized earth blocks and their properties.

2.2 Historical Background of Compressed Blocks

The history of earth block construction, the compressed stabilized earth block technique is a recent addition. It has been developed in 1950s in the frame of a research program concerning rural housing in Columbia. It is improved from the adobe production technique. In addition, molded by hand, the moistened soils are formed by applying pressure in steel press or mold. Compressed stabilized earth blocks are very popular in size, shape, and density. CSEB blocks are more used to making material two-three story recreational and residential buildings were built in the world. In Ethiopia, the applications of this material are limited[15]. In research centers of India, France, and South Africa Haydraform Company has made good progress on stabilized compressed stabilized earth blocks productions.

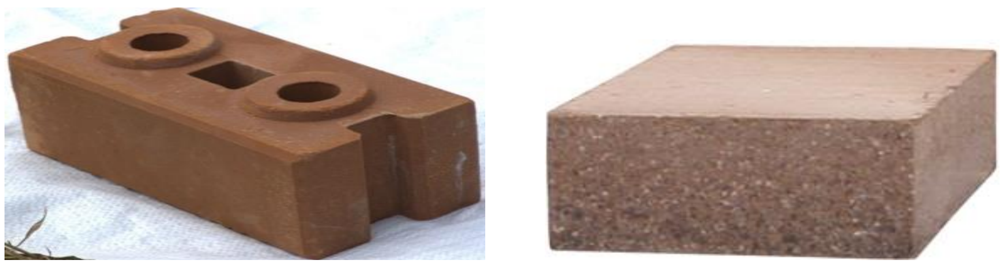


Figure2.1: Typical compressed earth block

2.3 Traditional Housing construction in Ethiopia

Soil construction material is not new building material in the world; however, it has limitations in disuse with the discovery of modern-day building materials like concrete, steel, and fired bricks. Earth as a material, has many advantages, such as cost, acoustic insulation and thermal, minimal impact on the environment, and its easy accessibility. The growing search for sustainable construction makes earth construction techniques important[16].

It is a well-known fact that the housing shortage in developing countries is a serious problem, especially in Ethiopia, where according to the United Nations housing classification system, eight percent of all dwellings are categorized as slums and low level of standards[17].

Most of the time, the soil is used extensively in the traditional construction of Chika or mud walls in all areas of Ethiopia. Mud or Chika is a mixture of clay, fine and short straw, and water. But traditional building techniques adopted for mud walls in Ethiopia have serious defects. The mud walls are poor or suffer from extended shrinkage cracks, which weaken the walls and can easily be eroded by rain. Buildings constructed by these materials have drawbacks and lead to soil is of inferior quality and should be avoided[6].

Based on altitude and climatic conditions traditional house construction in Ethiopia was divided into houses of low lands. Mud walls can be eroded by rain more in different building construction. Mud walls are needed surface maintenance every year. Sometimes to see houses that are constructed by worn-out clothes or other materials like plastics are used for the rain on the top of these clothes especially in the rural areas. These types of houses are common in the low-land region of Ethiopia[14].

Mud walls are easily eroded by rain more in low-land areas than in other areas. The protective surface needs continued maintenance and sometimes renewal almost every year. These drawbacks lead most to the misconception that buildings with soil are of inferior quality and should be avoided.

2.3.1 Adobe Blocks

Types of soil blocks made of soil and water in their simplest form are used as a building material, called traditional adobe blocks, and their usage can be traced back to 8000 BC; adobe construction has been found in Africa, the Americas, Europe, Asia, and Australia. It is an ancient building material and is still used today because construction does not require skilled laborers to build effective buildings. Relatively simple construction techniques, the soil is sustainable, recyclable, and abundantly available for brick-type construction[18].

Walls made from adobe blocks are the most common, popular, and one of the oldest forms of the earth housing system. Most of the time adobe blocks are made by mixing clay soil with water and fiber to a mud-like consistency and then placing the mixture in boxes called "forms"[19].

Most used for lightly loaded single and two-story residential buildings, adobes have also been used to construct ten-story high buildings in Yemen. The disadvantages of adobe blocks are usually not suited to climates that have high rainfall. Adobe block housed or Chika bet technique has been practiced for a long time in the traditional construction way of mud house construction in Ethiopia. Mud walls or buildings are constructed using this traditional building technique have many defects. Adobe blocks are the earth in a malleable state improved by the addition of straw or fibers and molded into a block form and dried in the sun[20].

2.3.2 Rammed Earth

The earth is massively duped into formworks and compacted with means of a rammer layer by layer in a rammed earth construction system [20]. Continuous walls are built by moist soil into position between different heavy wooden forms its construction method. The wall is constructed by like a rammed earth system when a short section of the wall is completed the forms are moved upwards or sideways and the process is repeated until the walls are completed. Most of the time it may be done by hand and a well-made rammed earth wall is one of the most durable earth walls that can be made. The disadvantage of these materials has, it is not easy to do well and the heavy wooden forms take time, money and some skill to build[2].

2.3.3 Cob

In this method of construction, straight mud is molded into balls and then piled up in thick layers to form the wall directly without the use of any kind of form. Each construction of the wall slowly so that each layer has a chance to harden before more mud is stacked on top of it[6]. The earth is often improved by the addition of straw or other fibers and shaped into big balls which are applied on top of one other and packed by hand or another tool, to erect shaped monolithic wall[20].

2.4 Compressed Earth Blocks

A compressed earth block is produced utilizing compression in hand-operated or pressing hydraulic machines. CEB block was first introduced in the 1950s in France and earth construction methods have a very long history. Compressed earth blocks were used for walling material and architectural purposes in 1952. A new little CINVA-RAM press machine was designed at the CINVA center in Bogota, Columbia. Today the development of standards and specifications related to earth construction methods and the generation of manual, mechanical, and motor-driven presses for the production and application of the compressed earth block[20].

In modern times, different researches have been undertaken to make the earth a sustainable construction material. The history of CSEBs was tried in the early 19th century in Europe. The CSBs became widely used around the world in more than 30 years in the last[6].

Figure2.2: The first original CINVA Ram Press Machine

During CSBs production use a mechanical press to form blocks out of an appropriate mix of fairly dry inorganic subsoil and soil stabilizers. If the blocks are stabilized with a chemical binder such as Portland cement, marble waste powder, fly ash, and other stabilizers are called compressed stabilized earth block (CSEB)[11].

The main use of compressed stabilized earth block to the utilization of local material and reducing the cost of transportation as the production is in situ, makes quality housing available to more people and used the local economy rather than spending for import materials. It is an and faster construction method resulting in the lesser requirement of skilled labor, good strength, insulation, and thermal properties, In the production phase, less carbon emission, and embodied energy create an extremely low level of waste and cause no direct environmental pollution during the whole life cycle[15].

The exact difference between compressed stabilized earth blocks and common brick blocks is the energy consumed during the production process and carbon emission. CSEB block creates only 22 kg CO_2 per ton compared to that of concrete blocks (143 kg CO_2 per ton, conventional fired clay bricks 200 kg CO_2 per ton, and aerated concrete blocks (280 – 375 kg CO_2/ton) during production[21].

Figure2.3: Typical Interlocking CSEB Blocks Produced in STVC

2.4.1 Classifications of CSEB Bricks

Based on ASTM standards bricks construction materials can be classified as building brick (ASTM62), facing brick (ASTM216), hollow brick (ASTM 652), and thin veneer brick (ASTM1088).The differences between stabilized soils block and brick block are the energy consumed during the production process and carbon emission. Bricks can be stabilized with cement on average consumed less than 10% of the input energy as used to manufacture similar fired clay bricks and concrete units[21].

Table 2.1: Critical Parameters of CSEB for standards[22]

CSEB and Soil for CSEB	Parameter	Minimum required value
Critical parameters related to CSEB	Dry density	1750kg/m^3
	Water absorption	Less than 15%
	Dry compressive strength	More than 2.8 N/mm^2
	Wet compressive strength	More than 1.2 N/mm^2
	Flexural strength(bending strength)	More than 0.5 N/mm^2
	Pitting depth(Erosion resistance)	Less than 10mm
	Linear expansion of block upon saturation with water	Less than 0.10%
Critical parameters Of soil for CSEB block production	Sand and gravel	More than 65%
	Silt	5%-10%
	Clay	10%-15%
	Plasticity index	equal to (less) than 12
	PH. Value	Between 6 and 8
	Cement	No less than 5%

2.5 Characteristics of Compressed Stabilized Earth Blocks

Soil-based blocks shall be manufactured from a mixture of suitable soil and OPC or lime pozzolanic mixture thoroughly mixed, preferably in a mechanical mixer. The mixture is molded and cast into blocks[7]. The most common characteristics used for measuring the standards related to the quality of CSEB blocks are density, compressive strength, durability (water absorption). Indian standards (IS: 1725-1982) of CSEB block gives a relatively clear Characterization of CSEB using the properties mentioned.

2.5.1 Physical Requirements

Compressed stabilized earth blocks can be classified based on average compressive strength, absorption, and other properties. Classes of CSEB and some physical requirements shall be as given in Table 2.1.

Table2.2: Basic physical properties of CSEB[23]

Parameters	Class A	Class B
Dry Compressive Strength(Mpa) @28 days	5-7	2-5
Wet Compressive Strength(Mpa) @28 days	2-3	1-2
Dry tensile strength(Mpa) @28 days		
Water Absorption(% by weight)	5-10	10-20
Shrinkage (mm/m)	0.2-1	1-2

2.5.2 Compressive Strength of CSEB Blocks

The compressive strength of CSEB blocks is depend on the amount of pressure,the amount of stabilizer, the soil type, and the compaction pressure and curing time for the block making process. In British Standard the loads of the building or the wall of the building withstands are small as the compressive strength of 1MPa up to 4Mpa is sufficient standards. Different minimum values of 28th day compressive strength of CSEB all above 1.0 MPa are proposed; some of the other research recommendations by different authors for the minimum compressive strength of CSEB block under the values 1MPa, 1.4 MPa, from 1.4 to 2MPa and 2MPa[6]. FCB and HCB block such as British standards (BS 6073-1, 1981, BSI 1985, BS EN 772-1, BS 1924-2:1990), Standards of Australia (1997, 2733), ASTM 1984, and African regional standard (ARS 674 – technical specification) for ordinary CSEB suggest a minimum 28th-day compressive strength of 2MPa. In practice, typical wet compressive strengths for CSEB building blocks may be between 1-3 MPa. It is comparable, with the minimum British Standard requirements of 2.8MPa for precast concrete masonry units and load-bearing FCBs, and of 5.2MPa for bricks. [14].

2.5.3 Density

The standard density of CSEB block is within the average range of 1500 to 2000 kg /m^3 at 28 days of curing. The density of CSEB is linearly related to its compaction and compressive strengths were applied during production. The density of the block is determined by BS 1924-2 (1990), ASTM C 140, and other standards. In India production of CSEB compressive strength is controlled by density[21].

2.5.4 Water Absorption and Moisture Content

Water absorption is a process of soil and stabilizers content and is usually related to the strength and of earth bricks. As the age of earth bricks increases, the water absorption rate will be decreased. For the cement content decreases, water absorption, as well as porosity, increases with clay soil content[16].

2.5.5 Durability

Durability is the ability of the blocks to resist heavy external factors or weather conditions like winds, rain, rising damp, and direct sunlight for a long time. CSEB blocks have to be durable and water-resistant to some existent to exclude any undesirable influences of the environment such as rain, winds, rising damp, or other severe weather conditions of exposure[20].

To consider that the oldest building structures standing throughout the world today are made of soils. These CSEB blocks or Haydraform blocks have good resistance to fire and pests. For this research, CSEB blocks are defined as a durable material that is produced from a natural or modified soil containing sufficient fines to provide cohesion on densification, to allow unsupported handling or stack curing[14].

Table2.3: Properties of Haydraform block and other walling materials (Adam. E.A. 2001)**.**

Property of Materials	CSEBs Blocks	FCB	Calcium Silicate Bricks	Dense Concrete Blocks	Aerated Concrete Blocks	Lightweight Concrete blocks
Wet Compressive Strength (MPa)	1-40	5-60	10-55	7-50	2-6	2-20
Moisture Content in (%)	0.02- 0.2	0.00-0.02	0.01- 0.035	0.02-0.5	0.05-0.10	0.04-0.08
Density in	1700- 2200	1400-	1600- 2100	1700-2200	400-950	600-1600

(Kg/m3)		2400				
Thermal Conductivity (W/m 0C)	0.81- 1.04	0.70-1.30	0.10-1.60	1.00-1.70	0.10-0.20	0.15-0.70
Durability against Rain	Good to Very Poor	Excellent to very poor	Good to Moderate	Good to Poor	Good to moderate	Good to Poor

2.6 Materials for CSEB production

2.6.1 Soil

Buildings are constructed with soil; have more than 4000 years are in existence. The use of soil for building construction by doing and knowledge has been passed down to generations[22]. It has different qualities and dispositions, depending on where it comes from and the soil must have the right composition before being mixed with cement and water. Before producing CSEB, the soil must be tested to determine if it is suitable for the CSEB-production. Suitability criteria are based on the gradation, plasticity, and chemical composition of the soil. Suitability criteria for soil to be used for CSEB production are described in section 2.8.7. The finer fractions of the soil such as silt and clay contribute to the fresh block not falling apart while the sand and gravel react with the stabilizer to stabilize the cured and dry block. Soil containing cement and it is therefore important not to use the topsoil (30-40 cm). The PH level is also another important factor; soil having a PH level below 4.5 or over 10 should be avoided as well as soils containing more than 2 % of sodium and potassium salts [17].

2.6.2 Cement

Cement is the main stabilizer in compressed stabilized earth block production and it works as a stabilizer and prevents the blocks from decomposed when in contact with water. The blocks will have further durability, strength, and volume stability improved by the addition of cement, due to the chemical reactions taking place between the cement and the soil. The cement quantity and the strengths of the blocks will generally increase linearly with the cement content during the effects of proportion, but using soil at different rates for different. But the addition of more cement in CSEB purpose there is a high cost of cement. The recommended cement rate is normally at a rate of 4-10 % (weight) depending on the type of soil[6].

2.6.3 Water

Soil contains water and pores filled with air and these spaces will be reduced during compaction. The grains will be lubricated and air voids will be replaced making it easier for the grains to slide past one another by adding more water to the mixture. During in hydration process, water is also necessary for the stabilizer [6]

2.6.4 Soil Identification and Selection

Identifications of good soil for building purposes can be performed by considering grain size distributions, plastics characteristics, compressibility, and moisture content. Using good soil the matrix of an additive determination depends upon the soil condition next to the undertaking requirements. The properties of soil are vital just before perform, next to the end, first-rate excellence products make stronger stabilization to enhance the material[24].

For CSEB construction, the sandy soil shall be much more than clayey soil. The proportion of soil contents like gravel, sand, silt, and clay shall be determined through sedimentation test or sieve analysis. Further accuracy requires the use of sieve analysis and hydrometric tests. All soils are not good for every wall building need particularly CSEB. For CSEB production soil contains gravel, sand, silt, and clay[25].

A compressed stabilized earth block is produced from a soil and cement mixture. The soil used in the CSEB block should contain more sand than clay and silt. The sandy part is what bonds with the cement to give the block its ultimate strength and the clay keeps the block together so it is easy to carry the block during block-making. Too much clay will make the block shrink and crack during curing and too little clay will make block handling difficult[14].

2.7 Properties of Soil for CSEBs

Soil is formed by the transformation of the underlying rock under the influence of physical, chemical, and biological processes related to biological and climatic conditions. It is found deposited on the form of the surface of the earth and may consist of many different types and colors. The variation of soil in the present at the surface can be attributed to a series of natural effects working on the area over time. The top on the surface of the soil is a large number of organic compounds. This is not good for block production and it usually contains a proportion of small soil particles that is fines and a cross-section of particle sizes. These are usually defined as particles passing a 75μm mesh and consist of only silt and clay.

Sands or Larger particles found in soil can generally be assessed as minerals that are silica, silicates, or limestone. The gaps of soil between adjoining particles are filled by has a proportion of water and air. This gives natural soil not homogeneous and porous nature[6].

There are different characteristics that one could discover about a sample of soil, it could not be to try and discover them all in every situation that soil is to be used for making CSEB block. Use only a small number of characteristics of soil that are relevant to the scientist testing.

The physical properties of soil are of greater interest for making compressed stabilized earth blocks. To determine its ease of mixing, forming, molding de-molding, porosity, permeability, shrinkage, dry strength, an apparent bulk density. The chemical composition of the soil is not of greater importance once the absence of unstable compounds and organic matter has been established. Chemical properties are also sometimes important particularly when a chemical additive is used. These chemical properties include the mineral content, metallic oxides composition, sulfates, and PH. Levels in the soil[15].

2.7.1 Classification of soil

Soils can be classified in many different ways: by origin, size, texture, use, color and density. For building purposes, they can be characterized in two ways, by plasticity index, and by a particle size distribution analysis. The particle size analysis will give information on the soil's ability to dense structure to pack into and the number of fines present (combined clay and silt fraction), while the plasticity index gives an idea of cohesion of the fines[15].

I. Classification by grain size

According to particle size, Soil types are graded using a system of classification widely used in civil and construction engineering. Soil classifications based on grain size, according to the Ethiopian Building Code of Practice, ASTM, and EBCS, are summarized as shown in the Table below. Soils can be classified, depending on their composition, by grading the proportions of clay, silt, sand, and gravel.

Table2. 4: The grain size classification based on the ASTM 2487 Standards size

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

A poor rough surface finishes and as the large particle size may lead in gravel soil type and is not usually used in soil-cement production. Good soil in CSEB production will contain a mixture of sand, silt, and claysized particles. Distribution of sizes gives a dense structure with a low specific surface area is the advantage of a well-graded soil for production CSEB blocks. A coarse soil containing no fines that are silt and clay is non-plastic and will not have sufficient cohesion to retain its shape on ejection from the mold or to allow easy transportation to the curing area[6].

II. Classification by plasticity or Fine content

The type clay and silt of soil are responsible for its cohesion and it is these fines that provide the fresh CSEB blocks with handle ability. The degree of cohesion provided to the block is dependent both on the degree of compaction used and fines present to form the block. A low-pressure molding process will require higher fines content than a high-pressure molding process[14].The proportion of good soil components have been shown in the following diagram[14].

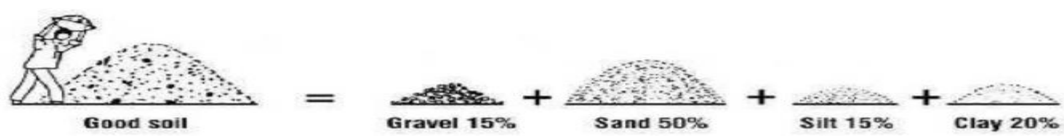


Figure2.4: Different percent of soil compositions

2.7.2 Suitable Soil for CSEB Blocks

A suitable soil type's selection can take place in the field using the following parameters or standards

A. Granular Composition of soils

Composition of granular soil should be preferable fall within the limits of the shaded area of on the diagram below, as which mostly gives satisfactory results. Its approximate limits that were in the shaded area are recommended. If the soil granular composition falls outside the shaded area it may still give acceptable results, but it is recommended that is subjected to a series of tests that enables its suitability[14].

Based on experiences from laboratory investigations and African Regional Standards, if the composition of granular soil falls within the limits of the recommended shaded area of Figure 2.8 below, it is usually considered as suitable for Compressed stabilized earth block production. Types of soil the granular composition of 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 them to be assessed their suitability[26].

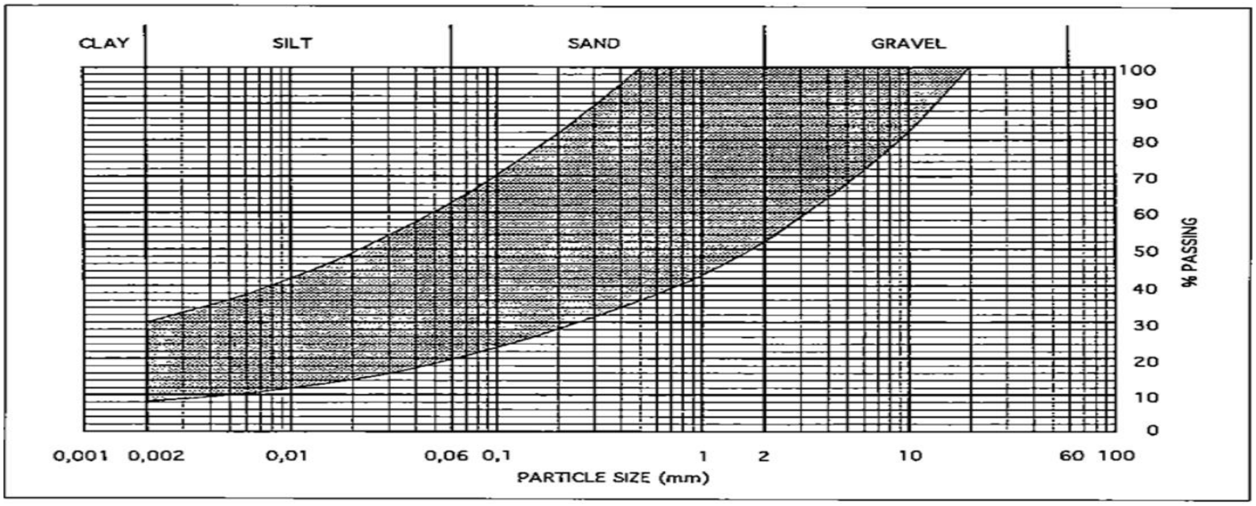


Figure2.5: Granular Composition Criteria based on African Regional Standards[26]

B. Plasticity

The soil plasticity approximately which recommended should fall in the shaded area gives the satisfactory results. It does not mean that the soils which fall outside the shaded area were not suitable to assess its suitability[14]. Additional tests such as the plastic limits and liquid limit and can also be made. Such test results will indicate the plasticity or workability of the soil. If the plasticity of the soil fall preferably within the limits of the recommended shaded area of the diagram of plasticity as shown in Figure 2.9, the soil is considered suitable for compressed stabilized earth block production[26].

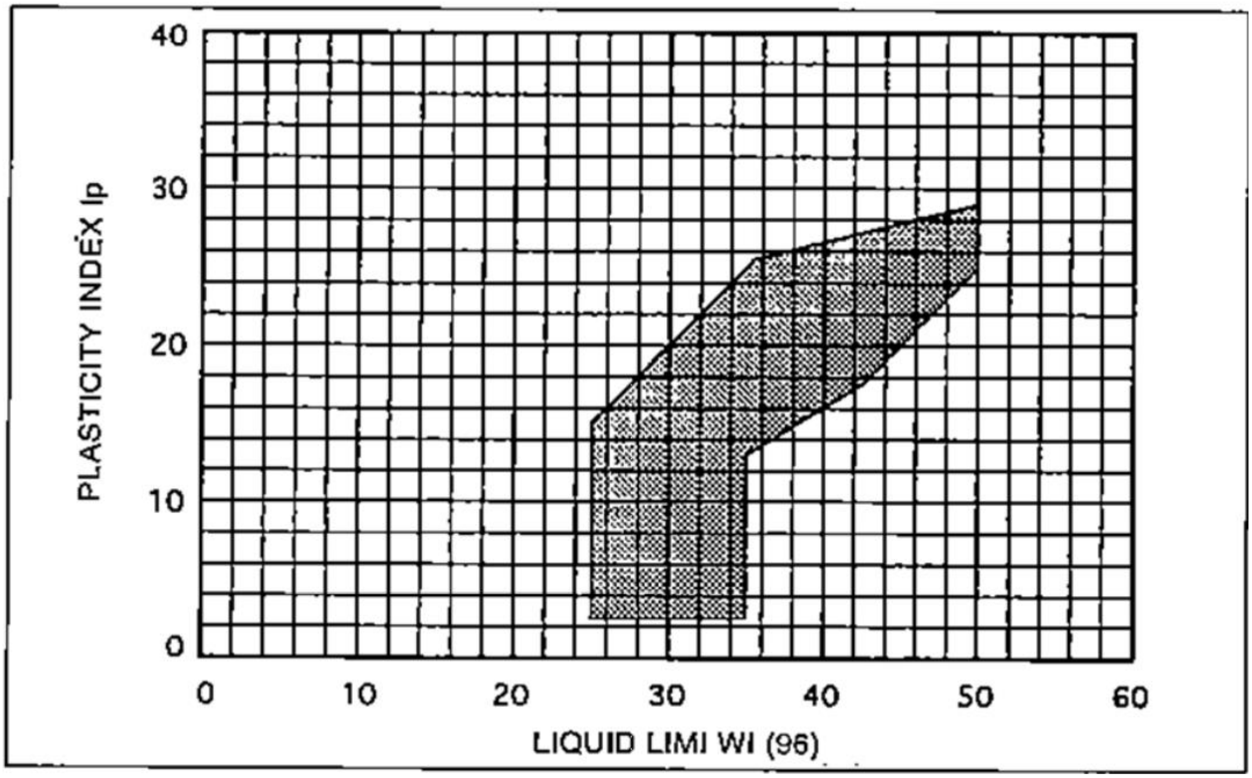


Figure2 6: Diagram of plasticity for soils suitable for CSEB[26]

C. Tests for soils

Compressed stabilized earth block production there are two main types of tests, which may be conducted: Laboratory tests and field tests. The first test is field tests can divide into suitable and unsuitable. The second test is Laboratory tests that can be used to characterize the soils by particle size distribution, plasticity, or other numerical measures for relation to the selection criteria[6].

D. Material Characterizations

X-ray diffraction tests could be used to characterize the soil, MWP, and FAs atomic arrangement of the highly crystalline structure. The instrument was provided detailed information about the mineral by showing the inter-planar distances (representing the physical characteristics of material) and the relative intensities of the peaks in XRD patterns.

The CSEB block samples microstructure morphology analysis was conducted by scanning electron microscopy (SEM). The surface morphology characterization has a basic role in easily understanding the physical and chemical properties of the material. SEM is a technique to study different modes of particle for surface or structures irregularities detection and it is used to investigate. For understanding the microstructural characteristics of the CSEBs, SEM images of the CSEBs were prepared with cement with different MWP and FA contents. The behavior of the CSEB material was analyzed through microstructural investigation, SEM images were taken to ascertain the morphologic changes that occur at different marble dust and fly ash contents[27].

2.8 Stabilizers

Researchers have studied the role of cement as a stabilizer in CSEBs in the past. The utilization of lime stabilizers in the preparation of CSEBs has not found popularity compared to cement stabilizers. Lime has been used in stabilizing clayey soils and has been long time strength. CSEBs will be prepared by using lime as a replacement to cement in certain proportions[6].

Table 2 5: Quantity of soil taken in percentage

Soil for cement stabilization	Gravel	Sand	Silt	Clay
It is more sandy than clayey	4-6%	50-70%	5-15%	0-20%

There are different methods of soil stabilization widely used to improve the quality of compressed stabilized earth blocks. Some of the major stabilization techniques are described below[6].

a. Mechanical stabilization (by using a compressor)

b. Physical stabilization (by improving the soil grading)

c. Chemical stabilization (by using a binder to improve bonding between the soils particles).

The major benefits of stabilizations are continued strength gain with time and long-term durability.

2.8.1 Mechanical stabilization

Mechanical stabilization is involves compacting or taping the soil by using a heavyweight to bring about a reduction in the air void volume, thus leading to an increase in the density of the soil it occurred mechanically. The main effects of compaction on the soil are to reduce permeability and increase its strength[6].It involves compressing the soil particles together to reduce porosity and increase density. The compaction energy used for which forces the particles together and in the process of the air is eliminated from the soil voids. The process of compaction is achieved when the grain size distribution of soil is continuous, not uniform or gap graded. The effect of mechanical stabilization, when used alone, is easily reversed, when the soil comes into contact with water[14].

2.8.2 Physical Stabilization

It involves modification of soil properties by introducing the missing size fractions without any additional binding materials. They are closed due to the closer packing of the grains[28]. It involves modification of soil properties by introducing the missing size fractions in the soil particles distribution. The shape of soil can be by calculated and controlled mixing of the different fractions of soil particles together[14].

2.8.3 Chemical Stabilization

Chemical stabilization involves using the addition of a bonding agent or chemical stabilizer to the soil. Cementation and linkage are the results of chemical reactions involving the binder and water. Cementation creates a strong and inert matrix that can limit movement in soil[25]. The soil voids are filled with insoluble by-products of the hydration reaction while some other particles are coated and firmly held together by the binder. Ordinary Portland cement is generally reported in the literature that the effect of chemical stabilization is more permanent, and may take several years for binding purposes[14].

2.9 Stabilizers for CSEB Production

2.9.1 Cement

Cement is a binding inorganic material when mixed with water and forms a paste that sets and hardens using hydration reaction processes[29]. The cement works as a stabilizer and protects the CSEB blocks from being decomposed when in contact with water. The block's durability, strength, and volume stability improved due to the chemical reactions taking place between the cement and the soil.

The strengths of the blocks and cement increase linearly with the cement content, but at different rates for different soils. The recommended cement rate is normally at a rate of 4-16 % (weight) depending on the type of soil[6].The cement major components that react with water to produce reaction products are dicalcium silicate (C_2S), tricalcium silicate (C_3S), tricalcium aluminate (C_3A), and tetra calcium alumionferite (C_4AF). The important strength-developing hydration reactions are those of C_2S and C_3S. Typical hydration reactions are below[30]:

Equation2.1: $2C_3S + 6H$ (water) $\rightarrow C_3S_2H_3$ (C-S-H) gel + 3C-H (hydrated lime)

The C-S-H gel is responsible for most of the engineering properties of cement paste and not only is it the most abundant reaction product. Calcium hydroxide or mineral name portlandite, also known by its, forms from C_3S and, to a lesser extent, C_2S. Calcium hydroxide reduces the total pore volume by converting some of the liquid water into a solid form. It contributes slightly to the strength and impermeability of the paste because it is much less important than the C-S-H[31].

The compound of Tri-Calcium Silicate (C_3S) and Di-Calcium silicate (C_2S) present in the cement reacts with water forming complex Calcium Silicate Hydrates (C-S-H) gel. The C-S-H gels bind the soil particles together and fill the void spaces and thus imparting strength to the soil mixture[15]. Cement can be used with any soil type, but compared to other stabilizers; it is uneconomical because more cement is required. The range of cement content needed for good stabilization is between 3% and 8% by weight according to soil type[32].

The use of fly-ash and other supplementary cementations material reduces greenhouse gas emissions. Cement production reaches four billion tonnes worldwide and is responsible for 6% of global warming CO_2 emissions. The production of Portland cement is not only costly and energy-intensive, but it also produces large amounts of carbon emissions[31].

2.9.2 Pozzolanic Materials and Reaction

The pozzolanic reaction is the reaction between pozzolanic material and C-H cement pastes with blended, have little or no C-H, as the C-H forms from cement hydration are consumed. Calcium-hydroxide is the most soluble of the hydration products, and thus is a weak link in cement and CSEB block from a durability point of view. If the C-H paste is exposed to freshwater, it will leach out or dissolve, increasing the porosity and thus making the paste more vulnerable to further leaching and chemical attack. Free lime in hardened blocket is also not particularly desirable because it increases the chemical reactivity of the surface including along cracks and can leach out in an unsightly fashion. It reacts with any pozzolana that may have been added to the cement or mix. This has beneficial effects on strength and permeability[31].

Equation2 2: $\mathbf{Silicate\ material\ +\ Calcium\ Hydroxide\ +\ water\ =\ Calcium\ Silicate\ Hydrate\ (gel)}$

Pozzolanic nature contains active silica which combines with the alkalis in the paste thus leaving less alkali available to react with the soils or aggregates, and significantly reduce the hardened concrete’s porosity.

2.9.3 Fly ash

Fly ash is a finely divided by-product resulting from the combustion of coal in power plants and it contains high amounts of composition of silica, alumina, and a small amount of unburned carbon, which pollutes the environment. The particle size ranges between 1-100 microns, the specific gravity of FA is 2.8. Fly ash is a pozzolanic material and it reacts with lime to form a cementitious component that improves the strength and hardness of plaster mixtures. The pozzolanic plaster specimens have no disintegration or weight loss, but there is weight increase tests have shown that fly ash in construction blocks improves resistance to sulfate attack.

Supplementary cementations materials (SCM) are material that contributes to the properties of hardened blocks through hydraulic and pozzolanic activity. Fly ash is pozzolanic that possesses little or no cementations properties by itself but in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds having cementations properties[31].

2.9.4 Properties of Fly Ash

A. Physical properties

The particle size of fly ash is finer than Ordinary Portland cement and it consists of silt-sized particles which are generally spherical and their size typically ranges between 10 and 100 μm. Its surface area varies from 2,000-10,000 cm^2 /g. The fineness of fly ash is one of the important physical properties contributing to the pozzolanic reactivity. The color is depending upon its chemical and mineral constituents. It can be dark gray to tan. Tan and light colors are generally indicated with higher lime content, and brownish cooler indicates the iron content. A dark-gray to black color is attributed to indicate unburned carbon content (LOI)[30].

B. Chemical properties

There are five classes of fly ash composition: carbonates, alumino-silicates (clays), sulfides, chlorides, and silica (quartz). Except for quartz, all minerals are substantially decomposed during coal combustion. At high temperatures, chemical reactions result in the formation of new glassy and crystalline phases. Its bulk chemical composition is glassy and crystalline phases consist of 95-99% by mass of oxides of alumina, silica, iron, and calcium with smaller amounts (0.5-3.5%by mass) magnesium, sulfur, sodium, and potassium[30].

There are two classes of fly ash, Class C and Class F fly ashes. The main difference between class C and class F fly ash is the chemical composition of the ash[33]. Class F fly ash contains at least 70% pozzolanic compounds (silica oxide, alumina oxide, and iron oxide), while class C fly ash has between 50% and 70% of these compounds. Their levels of content class F (high silicate, low calcium content) and class C (low silicate, high calcium content) determined by ASTM 618 requires [33].

Class F fly ash was used and obtained from a power plant and it was analyzed through scanning electron microscopy (SEM) and optical surface profile (PSP). High percentages of quartz (SiO_2) in fly ash increase the sulfate resistance of pozzolanic plaster mixtures; durability depends on the CaO (lime) contents in fly ash. Fly ash with low CaO and high SiO_2 is expected to be more durable than earthen building materials. The fly ash acts only a certain limit that is 10-15% of replacements of cement in the production of CSEB. But using up to 50% and a combination of other stabilizers to utilizes the waste and improve the mechanical properties and durability of the block. Pozzolanic materials are like fly ash fine silica and alumina rich materials which when mixed with hydrated lime produce cementations materials suitable for stabilization and construction needs. They are found in their natural state as volcanic ash or pumice. Pozzolans can also be manufactured from finely ground recycled fired clay bricks and mudstone[34].

Figure2.7: Fly ash in Adama Burayu Paper Factory

2.9.5 Marble

Marble is a type of rock composed of dolomite, which is recrystallized by the influence of heat, pressure, and aqueous solution. This metamorphic rock can be found in nature with different colors and a variety as well as quality. It is composed of as a result of the recrystallization of limestone under the intense pressure and heat of geologic processes. Marble can be of two types of minerals, one composed of calcite and the other of dolomite. The color of marble ranges from the brilliant white of calcite to black, including blue-gray, red, yellow, and green, depending upon the mineral composition[35].

Marble is a metamorphic rock; it contains largely calcium carbonate small amounts other metallic oxides like of silica, iron oxide, mica, fluorine, and organic matters may be found. Marble is calcite or dolomite, which is generally formed from limestone undergoing metamorphism[36]. When exposed to extremes of pressure or heat limestone turns into calcite or dolomite crystals, which are the primary materials in marble[29].

I. Properties of Marble

A. Physical Properties

Table2.6: Typical physical properties of marble and limestone[29].

Properties	Marble	Limestone
Hardness	3 -4 moh‟s scale	3-4 moh‟s scale
Density	2.5-2.65kg/cm3	2.5-2.7kg/cm3
Compressive strength	70-140N/mm2	60-170N/mm2
Water absorption	Less than 1%	Less than 1%
Porosity	Quite low	Quite low
Weather impacts	Resistance	

B. Chemical Properties

Marble is composed of calcite, dolomite, or serpentine minerals in chemical and limestone is composed of the varying proportion of chemicals such as calcium carbonate ($CaCO_3$), magnesium carbonate($MgCO_3$), silica(SiO_2), alumina(Al_2O_3), iron oxide(Fe_2O_3), sulfate (SO_3), and phosphorus(P_2O_5) with calcium and magnesium carbonate being the two major compounds[25]. The main impurities in raw limestone which can affect the properties of finished cement are magnesia, phosphate, leads, zinc, alkalis, and sulfides [26]. Calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) are the major minerals present in marble waste powder.

Marble waste contain metallic oxides are calcium (CaO), silica (SiO_2), alumina (Al_2O_3), and alkaline. Apart from that, iron oxide, mica, fluorine, chlorite, and organic matter have also been presented[37].

C. Marble Wastes

The major producers of marble products are Italy (20%), China (16%), India (10%), Spain (6%), Portugal (5%) followed by France and Brazil in 2018). The rough estimation is that there are about 500 million tons of marble products worldwide in 2018. About 20% losses occur which form a fine grain, during marble cutting and processing operations to attain finished products of required dimension from the raw marble stone. it is expected about 200MT marble processing rejects as a waste powder or sludge have been generated from marble industries generated annually universally in 2018. In India, about 16MT of marble waste has been produced during 2018 and 2019. One state of In India is the world's largest marble deposits in a cluster and accounts for about 90% of marble production in the country. It is dumped on roadsides or the river beds and undulated open land is a major environmental concern and has become a major threat to the surrounding ecosystem. The marble waste particulates dangle in the air around us and tend to be deposited on vegetation, crops in dry conditions [36].

A replacement of cement by marble and granite powder will reduce the amount of cementitious material in the matrix, and, it will consequently affect the development of the mechanical properties, such as elastic modulus and compressive strength This process gives an impression about the number of hydration products formed, and the way they contribute to the formation of the evolution of the mechanical properties, i.e. compressive strength[38].

The total wastage of marble during processing and polishing work is approximately 70% of the total marble waste generated in the world and more than 75% in Ethiopia. This waste is discharged into the water bodies or dumped in vacant spaces leading to serious environmental issues. Today, different researchers are trying to utilize waste materials in construction to control environment-related issues utilization of waste marble powder (WMP) in construction activities is gaining a lot of attention. Marble waste powder can be used as a potential stabilizing agent to improve the properties of very weak clayey soils[39].

Utilization of waste marble dust in cement substations in the production of construction blocks. The properties of cement modified with marble dust forms marble dust blended cement. The replacement of cement by MWP or FA has only a certain limit. That means the amount WMP high of percentage increases that is soundness, compressive strength, and other properties decrease. The necessary strength and durability decrease because the void is increased due to unreacted particles. This study focuses on eliminating the gap of the two wastes using separately[40]. Replacement of cement by two wastes (MWP and FA) that form a composite reaction and the mechanical properties and durability increases. And the percentage of replacement of cement will be increases up to 50% by a combination of the two wastes. The CSEB material mechanical properties and durability will be improved[41].

2.10 Current Application of CSEB

The earth or soil-compressed earth blocks are widely used around the world in the last 30 years. It is used in developed countries like Canada, the USA, French, and Australia. It is also the most popular construction material in Europe, its physical attributes and ability to regulate moisture and temperature. The Haydraform Company in South Africa, The research centers in India Auroville and CRATerre in France have made good progress on the CSEB block. Now a day's compressed stabilized earth block, its flexible size and shape to be used to achieve many different types of build houses of any design. In hot areas or hot countries, and even more in those with a wide thermal variation, a CSEBs wall creates a comfortable living environment compared to cement, sand-based materials, and other common construction materials. This compressed stabilized earth block also has been too low cost or cheap building materials. In India, different researchers are doing researches on CSEB blocks using different soil and stabilization techniques and it has application many in different areas[6].

Figure2.8: EI Haj Yousif Experimental School in India

2.10.1 CSEB Application in Ethiopia

The application of soil blocks as a wall-making building material is in its earlier stage in Ethiopia as different designs styles without stabilizers. CSEB for nowadays used to construct walls for guard houses, schools, fences, offices, and halls, because of its lower speed of construction and low cost especially in the case of interlocking CSEBs. Selam Technical and Vocational Center (STVC) is located in Addis Ababa and was established over 28 years ago has long been experienced by the production of Haydraform interlocking blocks. The most commonly produced block is the interlocking CSEB blocks, with a cement proportion of 10 % is maximum. The productivity is approximately 3 blocks per minute using the electrical Haydraform press and the blocks were then placed under shade after 28 days of drying. Most of the office buildings and the training rooms in this center compound are made with CSEBs.

2.11 Summary of Literature Review and Gap Identification

2.11.1 Summary of Literature Review

The compressed stabilized earth block is the modern molded earth block. The materials used for the construction of a building are normally required to possess adequate erosion resistance and compressive strength. Such properties of the soil can be improved by stabilizing it with different stabilizers like cement, lime, marble waste powder, fly ash, pumice, volcanic ash, etc. Identifying the stabilization and compacting techniques, cheap, strong, and durable material for wall construction is the compressed stabilized earth block[15].

In preparing the soil for CSEB block production, there is a need for correct selection of the soil, mechanical tests of soil like gradation test and plasticity test should be performed and also checked with standards for compressed stabilized earth blocks. Chemical composition analysis test should also be performed for the soil sample. The quality of the materials (stabilizers and soil) should be checked before the production of the blocks. Not only the soil content affects the quality of the blocks but also stabilizer content also affects the quality of the blocks. It should be given proper compaction and curing should also be made which prevents rapid drying[42].

Wastes are used in building materials are gaining a lot of attention in worldwide by reusing or recycling them. For this purpose, marble waste powder is obtained from the marble industry[43]. The addition of FA with cement is found to increase the strength up to certain FA content and beyond that strength begins to drop. The water absorption capacity of the blocks decreases with the increase of cement content and FA content; it varies within 10.2–18.7% based on the mix composition. Microstructural investigation revealed that the development of C-S-H and C-A-H gels due to the addition of fly ash with cement contributed to the strength development[44].

2.11.2 Gap Identification

Researches have been undertaken in modern times to make the earth a sustainable construction material. This has indicate the development of technology using earth soil in the form of unfired bricks and rammed earth popularly known as compressed stabilized earth blocks (CSEBs). Cement is a popular stabilizer used in the manufacture of CSEBs; much effort had not been done in utilizing marble waste and fly ash in a combination of cement. These wastes have been used in stabilizing clayey soils, and as well as sandy soil have been found to impart long-term strength gain as reported in the literature. As MWP and FA are known to impart strength in the long term, their utilization in optimum proportion as a replacement to cement may be beneficial[6]

The researchers conducted so far and indicated above, as an illustration, they fail to show how to substitute contribution of cement in the production of CSEB material by the contribution of marble waste powder and fly ash in some percentage. Hence, the main objective of this research is to fill this gap and produce the CSEB construction material without compromising the quality and gain by using cement as a stabilizer. Moreover, by using the combination of optimum utilization of marble waste powder and fly ash, the researcher tries to:

- Reduce the cost of cement
- Minimize environmental pollution
- Save energy for the production of cement
- Improve mechanical properties and durability parameters.

The gap of the study is only use replacing cement with study on the effects of MWP and FA improves the mechanical properties. Use the maximum optimum utilization limit of MWP and FA with other Pozzolanic stabilizers improves the strength and durability of the material. This paper will attempt to understand the effect of marble waste powder and fly ash in combination with cement as a stabilizer in CSEBs production. Any effort to optimize the number of stabilizers used in combination would help in increasing the strength of the block production.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The four main constituent materials[14] used in the production of CSEB blocks (soil, cement, fly ash and marble waste powder) were obtained from different areas in Ethiopia.

3.1.1 Soil

The soil samples used in this investigation for fabricating CSEBs were obtained from two selected sites around Addis Ababa, Yeka Kotebe Kara (9.0393^{0}N and 38.8513^{0}E), Oromia Alemgen (8.9254^{0}N and 38.6582 9.0393^{0}E).

3.1.2 Fly ash

In this study, fly ash was collected from Burayu Development Service PLC, in Kureftu paper manufacturing in Adama city (8.51447^{0}N and 39.2927^{0}E).

3.1.3 Marble Waste Powder

Marble waste powder samples were collected from the two marble factories in Ethiopia, Kokeb Marble Factory in Bahirdar (11.5768^{0}Nand 37.3383^{0}E) and Tsegaye Marble products Manufacturing Alemgena (8.9254^{0}N and 38.6582 9.0393^{0}E).

3.1.4 Cement

Commercially available Ordinary Portland Cement (OPC) 42.5 grade (Dangote, Ethiopia) was used in this study for CSEB production.

3.1.5 Water

Tap Water around Kotebe locality was used for all CSEB production.

3.2 Instruments and Their Specifications

3.2.1 X-Ray Diffraction (XRD)

CSEB raw materials soil, fly ash and marble waste powder from different sources were characterized by X-ray studies at the Laboratory of Material Science and Engineering department in Adama Science and Technology University. This method is primarily used for quality analysis, due to the fact that it enables the identification of present crystal components, type of crystal lattice, the presence of certain phases, and the size of crystals. It can also be used for quantitative analysis, or more precisely, for an estimation of different components share in the content of the sample [18].

The instrument details: X-Ray Spectroscopic Instrument, X-Ray Diffractometer XRD-7000 SHIMADZU Corporation, (Japan was used for the analysis of the samples). All samples were tested on the powder diffract meter. The diffraction patterns were obtained with K-alpha radiation (λ= 1.5418 A^0) created in the X-ray tube, the source (target) of Cu metal generated by a voltage of 40 kV and filament current at 30 mA and. The sample was performed in the range of 2θ scan range from 5 to 90° with a step or sampling pitch of 0.02°.

Analysis of XRD data was made by using X'pert high score software. X'pert software is software that enables the identification of peaks of crystalline phases and interprets each peak. The software uses the default Inorganic (Crystallography open database) reference database. Reference databases typically contain thousands of peak lists (diffraction patterns of known phases). In this research, the trial version of x'pert software was used to show the existence of common crystalline phases in the sample. The phase purity and crystallinity of samples were examined by X-ray diffraction techniques (XRD).

3.2.2 Scanning Electron Microscopy (SEM)

SEM analysis of CSEB blocks were conducted in Central Laboratory of Addis Ababa Science and Technology University. The SEM is field emission electron, and its model is Inspect f50 and the Company is from Germany/.

3.2.3 Compression Testing Machine (CTM)

Automax5, model 50-C56V2, Italy was used for Compression Testing with the maximum load of 100 KN. The specific load was calculated by the formula F/A (F is the load and A is the sample area).One of the most fundamental types of machine for CSEB block testing with their properties like compressive strength, tensile strength, and more, compression tests are used to determine material behaviors under compressive pressure loads by compressive testing machine. The main aim of the compressive strength testing machine was to determine the wet and dry compressive and also tensile strength values of the blocks. The compressive strength tests were done based on ASTM standards.

3.2.4 Haydraform Block Machine

Haydraform block-M7 EXAM machine Haydraform Company in South Africa that have been installed in TRAE M7E380 hydrafoam used to pressing and compacting the CSEB block.

3.3 Methods

3.3.1 Sample Collection

A. Soil

The field tests of soil is important to preliminary site surveying to identify if the soils suitable and so restrict the number of soils and ready to laboratory tests[6]. First, field tests of soil were conducted based on the natural situations of the soil. Simple field tests were used to divide the soils in to two classes. These classifications are suitable and unsuitable based on the contents of the sand, clay and organic compositions of soil. The soil was identified by visual and manual physical techniques. The suitable soil used to fabricate CSEB block was selected based on organic matter content, particle size distribution (gravel, sand or fines and silt and clay contents), plasticity and biding forces and shrinkage presence of cracks. The soil was inspected using visual and physical properties of soil by simple conventional test methods in the field[45]. The composition of the soil sample in the field determined by touch test, smell test, sedimentation test or Jar test, nibble test, adhesion test, washing test, dry strength test, water retention test shrinkage test, consistency test and cohesion test. Finally, soil samples were collected from two selected sites sources and soil engineering, physical and chemical properties were determined in the laboratory.

B. Cement

Cement was collected from local market based on its standards and specifications. Cement is the main binding materials [30]-within the combinations of fly ash and marble waste powder in the production of CSEB block. A different proportion of cement in the mix was investigated.

C. Fly Ash

For this research, coal ash was collected from only one source. Samples are by-product of coal in the electric power generation plant. Burayu paper factory uses local coal which is extracted and supplied from the Kamash area and used imported coal from South Africa[46]. The fly ash was collected in to the bottom get after burning. After generation of the fly ash and cooled then it was damped in waste open area. The moist fly ash was dried by sun the fly ash content separated in to quality ash form and the other one is in the form of dust. Physical properties of fly ash determined within observation and sample are well-mixed by transferred to plastic bags. By taking visual inspection and then the best quality of the ash was taken randomly and ready to laboratory tests.

D. Marble Waste Powder

Marble waste powder was collected from its sources in different powder forms of and then sun dried in open air. After drying; it was crushed and ground in to powder by using mechanical roller crushing tool. The marble waste powder particle size was determined with seiver scale ranges from 1.18mm to 32µm.Well graded particle size of marble waste powder was identified based on the standard of gradation. The size distribution of particles in marble powder was determined by sieving analysis.

3.3.2 Methods of Sample Preparation

i. Soil Sample Preparation

Before producing CSEB, the soil must be tested to determine if it is suitable for the CSEB-production or not. Suitability criteria are based on the gradation, plasticity and chemical composition of the soil.

Pulverization

Firstly, the soil pulverized to obtain uniform mixing of the components. Larger pieces of soil were broken up by being pressed between two parts or surfaces. Homogeny structure such as stones and gravel left unbroken separated from the soil. Samples are crushed and pulverize using soil crushers required to pulverize dry soil in order to get uniform grain sizes and better quality mixes for the production of blocks.

Screening

To separate the large particles from the soil, a fixed screen was set up at an angle or is suspended. It is a necessary part of the process and is essential when the pulverization has been incomplete and there are large particles in the soil. The soil particles were screened by using local mechanical available machines or materials and the operation was also easily carried out manually. After the soil sample was prepared, the laboratory tests of soil sample were conducted helps to establish numerical values for sample parameters. These values are used to the suitability of the sample for CSEB blocks. The soil was screened by using simple manual made mash tool. Physical properties chemical compositions and others are the main soil tests were conducted to determine the characteristics of the soil.

Figure3.1: Pulverization and screening of soil by simple manual technique

A. **Particle Size Distribution Test**

According to ASTM D 422-Stanadard Test Methods for Particle-Size Analysis of Soil; to determine the size of soil, 500g of dry soil was measured, write down the weight of each sieve upper to bottom pan and recorded the weight of the soil. Before starting testing check the sieves are cleaned, and assembled them in the ascending order of sieve numbers (No.4 sieve at top and No.200 sieve at bottom).
Carefully poured the soil sample into the top sieve and placed the cap over it. The sieve stack was placed in the mechanical shaker and shacked for ten minute. The stack soil was removed from the shaker and weigh and recorded the weight retained soil. It was carried out by sieving a known dry weight of sample through

the set of sieves placed one below dry weight of sample through the set of sieves placed one below the other. The whole set of sieves was given a horizontal shaking for about ten minutes until the weight of soil remaining on each sieve reaches a constant value. To determine the weight of soil sample left on each sieve, the following calculations can be made.

Equation3.1………. $\textbf{Percentage Retained on any Sieve} = \frac{\boldsymbol{Wight\ of\ Soil\ Retained}}{\boldsymbol{Total\ Soil\ Weight}} \boldsymbol{x100}$

Cumulative Percentage Retained =Sum of percentage retained on all any coarser sieves.

Cumulative Percentage of finer (Passing) = 100 percent minus cumulative percentage retained.

Tabl3.1: Sieve analysis of Soil (RSS)

500g of Weight of Soil Sample

Sieve Number	Sieve opening size (mm)	Weight of soil retained(g)	Percentage retained (%)	Cumulative percentage retained (%)	Cumulative Percentage of finer(Passing) (%)
No.(2/3 inch)	9.5	0	0	0	100
No.4	4.75	28.1	5.62	5.62	94.38
No.10	2.0	40.7	8.14	13.76	86.24
No.20	0.85	81.2	16.24	30	70
No.40	0.425	124	24.8	54.8	45.2
No.60	0.250	151.2	30.24	85.04	14.96
No.100	0.150	65	13	98.04	1.96
No.200	0.075	9.4	1.88	100	0
Pan	-	-	-	-	-
Total		500.00		277.26	

B. Silt Content Determination

The soil was washed and the silt content tested. However, it may contain other materials such as dust, loam clay that are finer a soil. The peruse of such materials in the soil used to make CSEB blocks decreases the bond between the materials to be bound together and hence the strength of the mixture the finer particles do not only decreases the strength but also the quality of the mixture produced resulting in fast deterioration. Therefore to make sure that the Ethiopian standard value is the maximum one is 6%.To determine the silt content used the following calculation[47]**.**

Total volume was occupied by soil and silt in measuring cylinder, the volume of measuring cylinder=400ml, content of silt over soil in measuring cylinder=20ml and Content of silt over soil in measuring cylinder=380ml. Silt content (%) $= \frac{(400\text{ml}-380\text{ml})}{380} x100 = 5.2$

Figure3.2: Silt content determination of Soil

C. Moisture Content Determination

Based on ASTM D 2216-Standard Test Method for Laboratory Determination (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures:500 gram soil sample was measured and washed then dried up to Surface Saturated Dry (SSD),The sample was dried for 24 hours by oven-dry within 105^{0}C. After 24hrs the Oven-dry soil sample (OD) was measured. Moisture can be content is calculated in the following ways:

The Original soil sample is 500g and Oven-dry (OD) soil sample=441.3gm

A= Weight of original sample or wet sample (g), B=Weight of oven-dried sample (OD) (g)

W=Moisture content (%)

Equation3.2… … … $\mathbf{W} = \boldsymbol{Moisture\ Content}(\%) = \frac{(\boldsymbol{A-B})}{\boldsymbol{B}}\boldsymbol{X100}$

$$\mathbf{W}(\%) == \frac{(\mathbf{500}\boldsymbol{g} - \mathbf{441.3}\boldsymbol{g})}{\mathbf{441.3}\boldsymbol{g}}\boldsymbol{X}\mathbf{100} = \mathbf{13.30}$$

D. Water Absorption

To determine the water absorption capacity of the soil; First the 1000gm of original soil sample was measured and washed with water. And then the original sample was dried and prepared as surface saturated dry (SSD).The SSD sample was dried by oven-dry for 24 hours within 105^{0}C.After 24hrs the Oven-dried test sample (OD) was measured. Standard Reference: Using ASTM D 2216 - Standard Test Method for Laboratory Determination of Water content of Soil. To calculate Absorption Capacity:

O=Original Soil Sample=1000g, A=Weight of Surface Saturated Dry Test Sample (SSD) =965g and B=Weight of oven-dried sample (OD) =857g

Equation3.3……… $\mathbf{WA = Water\ Absorption}(\%) = \frac{\mathbf{(SSD-OD)}}{\mathbf{OD}}\mathbf{X100}$

$$\mathbf{WA}(\%) = \frac{\mathbf{(A-B)}}{\mathbf{B}}\mathbf{X100}\,,\quad \mathbf{WA}(\%) = \frac{\mathbf{(965g-857g)}}{\mathbf{857g}}\mathbf{X100 = 12.6}$$

(Absorption capacity = 12.6%).

E. Specific Gravity Determination

The specific gravity of soil was reported according to: ASTM D 854-00-Standard Test for Specific Gravity of soil Solids by Water Pycnometer as standard references.500g of the soil samples was prepared and filled with water to approximately 90% of the capacity. The temperature was adjusted about $23+1.7^{0}$C, if necessary, by immersion in circulating water and brings the water level in the pycnometer to its calibration capacity. The total weight of the pycnometer sample was determined and the water recorded.

Data Analysis

Calculate the specific gravity of the soil solids using the following formula: Specific Gravity (G_S),

Equation3.4… … … $\mathbf{Gs} = \frac{\mathbf{WO}}{\mathbf{WO+(WA-WB)}}$

Where: W_O =weight of sample of oven-dry soil=W_{PS}-WP, W_A= weight of pycnometer filled with water.W_B= weight of pycnometer filled with water and soil and W_P = 211.9g, W_{PS}=711.8g, W_B=1210.7g, W_A =515.8g.and W_O = W_{PS}- $W_{P,}$ W_O =711.8-211.9= 499.9g

$$\mathbf{Gs} = \frac{\mathbf{499.9}\boldsymbol{g}}{\mathbf{499.9}\boldsymbol{g} + (\mathbf{515.8}\boldsymbol{g} - \mathbf{1210.7}\boldsymbol{g})} = \mathbf{2.6}$$

The above test results, specific gravity of soil was determined and the obtained result is 2.6.

Figure3.3: Pycnometer+soil+water

ii. Fly Ash Sample Preparation

Fly ash samples were collected and categorized in to suitable sample used for stabilized as production of CSEB blocks. The sample was dried, and then particle size disturbing was measured in the range of 1.18mm and 32µm analysis takes place. Then fly ash ready to laboratory tests such as particle size distributions, fineness modulus, specific gravity and chemical composition analysis tests. Finally the sample was characterized and ready to mix stabilizers [32].

A. Sieve analysis of Flay ash

The particle size distribution test of fly ash, 500 g of ash was weigh, and then, placed in drying for standardized based on ASTM C618[30]. The procedure is the same as the sieve analysis of soil. The weight of retained and percentage of cumulative fly ash in each sieve size found in the table 3.2.

Table3.2: Sieve analysis of Flay ash (FA)

500 gram of FA sample				
Sieve opening (mm)	**Weight of retained(g)**	**Percentage of retained (%)**	**Cumulative percentage retained (%)**	**Cumulative Percentage of finer (Passing)(%)**
1.18	0	0	0	100
0.6	81.4	16.28	16.28	83.72
0.3	143.5	28.7	44.98	55.02
0.15	91.9	18.38	63.36	36.64

0.075	102.1	20.42	83.78	16.22
0.063	37	7.58	91.36	8.64
0.032	36	7.2	98.56	1.44
Pan	7.2	1.44	100	**0**
Total		**100**	**298.32**	

B. Specific Gravity

According to ASTM C77-40: Test Method for Specific Gravity of fly ash: The flask was filled with either of the two liquids to a point on the steam between the 0 ml and 1ml and marked. The inside part of the flask was dried above the level of the liquid, it necessary, after pouring. After the flask has been immersed in the water bath, then the first reading was recorded. The bath shall be maintained in the temperature of the water constant for sufficient period of time to avoided flask temperature variations>0.2^{0}C between the initial and final readings. About 60gram quantity of fly ash was introduced in to the flask. A vibrating apparatus was used to accelerate the introduction of FA sample in to the flask and to prevent the FA from sticking to the neck. The final reading was taken after the flask had been immersed in the water bath and the result was below the analysis[48].

Data analysis

Initial volume=1ml, Final volume=22ml and Change volume=22ml-1ml=21ml

Mass of fly ash=60g, to change the ml in to cc 1cc=1ml,

$$\text{Density of FA (D)} = \frac{\text{Mass}}{\text{Displaced Volume(CC)}}$$

$\mathrm{D} = \frac{60\mathrm{g}}{21\mathrm{cc}}$ = D_{fa}=2.86g/cc

Equation3.5… … … $\textbf{Specfic Gravity (Gs)} = \frac{\boldsymbol{Density\ of\ Sample}}{\boldsymbol{Density\ of\ Water}}$

$$\mathrm{Gs} = \frac{2.86g/cm3}{1g/cm3} = \mathbf{2.86}$$

iii. Marble Waste Powder Sample Preparation

First the marble waste powder sample was collected and the collected samples were mixed and dried by sun. After drying; it was crushed in the required grain size in the form powder of its fineness modulus used in the preparation of block and keeping in fresh air before sieving analysis takes place. The marble sample was prepared in to test of sample preparations and samples were examined after graduation of their fineness and chemical composition. The following tests such as gradation(particle size distribution between 1.18mm and

0.032mm) or fineness, specific gravity, chemical compositions and characterizations are the main types of tests were carried out in marble powder sample preparation and ready to mix stabilizing of CSEB block[15].

A. Sieve analysis of Marble Waste Powder

500 g of marble waste powder sample was measured, and then, kept in drying by sun dry (air).After drying, keeping in fresh air before sieving analysis takes place. Table 3.3 shows, the retaining marble waste powder. The procedure was the same as the sieve analysis of cement. The Fineness Modulus of MWP was determined 3.The marble waste powder was sieved after grading.

Table3.3: Sieve analysis of Marble waste powder (MWP)

500 gram of MWP sample				
Sieve Size	**Weight of retained(g)**	**Percentage of retained** (%)	**Cumulative percentage retained (%)**	**Cumulative Percentage of finer(Passing) (%)**
1.18mm	0	0	0	100
600µm	150.6	30.12	30.12	69.88
300 µm	55.4	11.08	41.2	58.8
150 µm	111.8	22.36	63.56	36.44
75 µm	92.2	18.44	82	18
63 µm	19.8	3.96	85.96	14.04
32 µm	55.0	11	96.96	3.04
Pan	15.2	3.04	100	0
Total	**500**	**100**	**302.84**	

B. Specific Gravity

Determine of the marble waste powder specific gravity (Gs MWP) the procedure was the same as that of fly ash and cement. The data were given as Initial volume (V_O) =1.5ml and Final volume (Vf) =24ml

$$\text{Change Volume} = \text{Vf} - \text{Vo} = 24\text{ml} - 22.5\text{ml},$$

$$\text{Density of MWP} = \frac{64\text{g}}{22.5\text{cm3}} = \frac{2.84\text{g}}{\text{cm3}}$$

$$\mathbf{GsMWP} = \frac{\mathbf{2.84}}{\mathbf{1}} = \mathbf{2.84}$$

3.3.3 Chemical analysis of Samples

The chemical composition of material samples were used for this study, and chemical properties of all samples like oxides contents, metallic contents, mineral contents, compositions, sulphates and PH values were investigated and very basic when there is chemicals have to be used as additives for the productions of blocks. Chemical composition or silicate analysis of materials was conducted at the Geological Survey of Ethiopia laboratory center and the results were presented in the table form and Appendix in the result and discussion sections.

3.4 CSEB Block Preparation

CSEB block samples were prepared by applying the following Procedures According to the ASTM D-698-12 standard: CSEB construction has four phases

- Digging the soil: the soil is dug out from the top layer of earth
- Mixing of the stabilizer (cement, FA, MWP) and soil: the soil is mixed properly with cement, FA and MWP in predetermined proportion.
- Adding water and preparing the soil for compression: the soil-stabilizer mix along with water is again mixed and workable mix for compression is prepared
- Compression of the mix: the prepared mix is then compressed in compression machine, and keep for drying and further use
- Then it is dried for 28 days
- Strength determination on CTM machine and durability tests were conduct

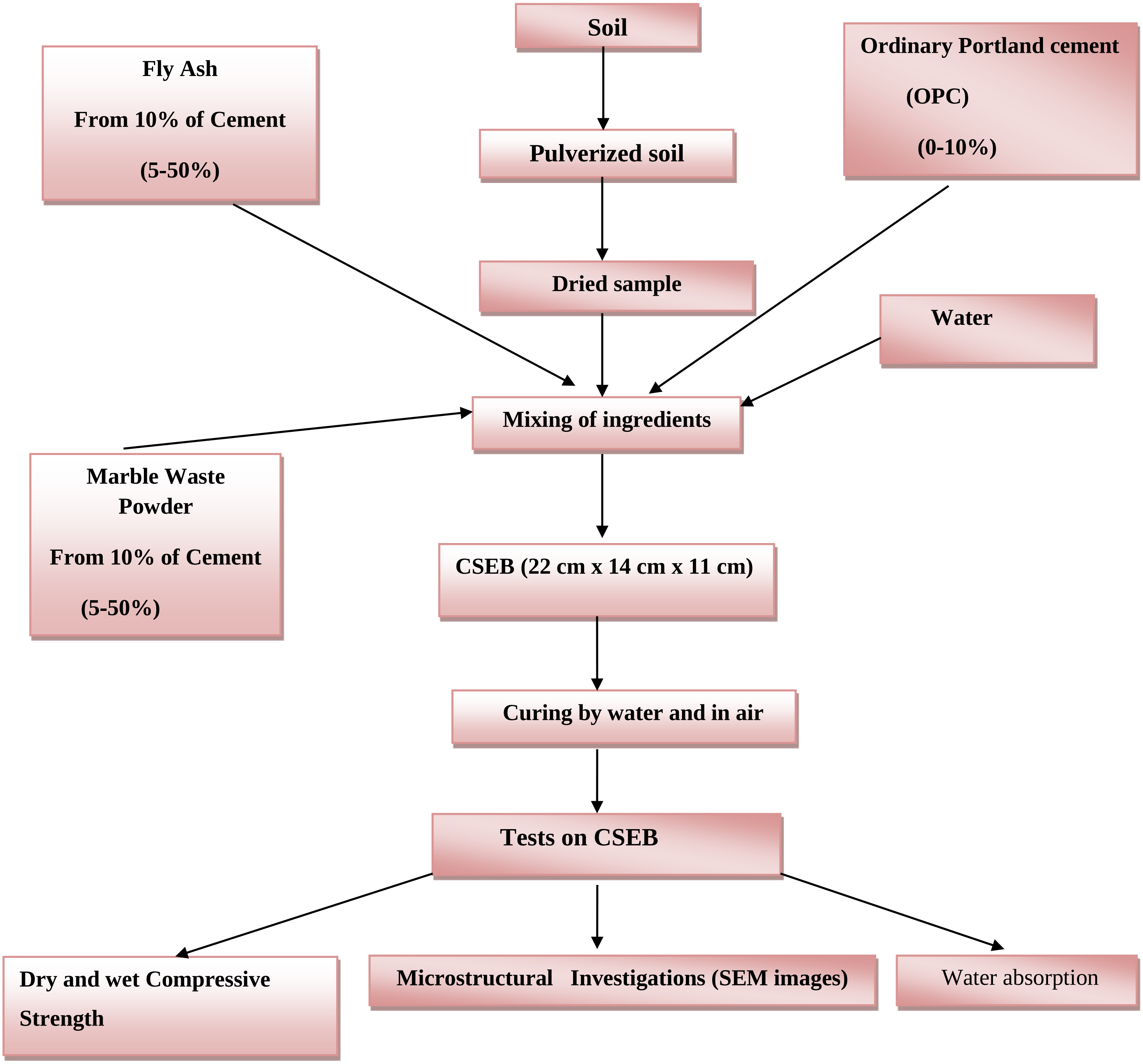


Figure3.4: Sequential process of the preparation and testing of CSEB Block in this study

3.4.1 Proportion and Mix Design

A block size is 220 x 140x 110mm; about 5.5 to 6 kg of soil materials and 0.5 kg of stabilizing agents for one CSEB block is needed depending on the compaction pressure[49]. Materials proportions should be maintained constant throughout the production prcess.The weigth and volume of each material used in the CSEB making process shall be measured at same physical state for subseqent batchs of block [23].

The substitution of a portion of cement in the mix by fly ash was made between 5-50%, (by volume of the cement). In the same manner, the portion of cement replaced by the marble waste powder was optimized between 5-50%, by volume of cement. The CSEB blocks are prepared within a water-binder ratio of 0.5 were made to investigate the effect of marble wastes and ashes on the strength of block.

Table3.4: Mix Design of CSEB samples

No	Mix Proportions (in percent)	Cement (in kg/m^3)	Fly ash (in kg/m^3)	Marble waste powder(in kg/m^3)	Soil (in kg/m^3)	Water (in kg/m^3)
1	FA0+MWP0	140.5	0	0	1627.22	70.4
2	FA5+MWP0	133.5	7.03	0	1627.22	70.4
3	FA0+MWP5	133.5	0	7.03	1627.22	70.4
4	FA10+MWP0	126.5	14.05	0	1627.22	70.4
5	FA0+MWP10	126.5	0	14.05	1627.22	70.4
6	FA10+MWP5	119.4	14.05	7.03	1627.22	70.4
7	FA15+MWP10	105.4	21.07	14.05	1627.22	70.4
8	FA20+MWP15	91.3	28.1	21.07	1627.22	70.4
9	FA25+MWP20	77.3	35.1	28.1	1627.22	70.4
10	FA30+MWP25	63.22	42.15	35.12	1627.22	70.4
11	FA35+MWP30	49.17	49.17	42.15	1627.22	70.4
12	FA40+MWP35	35.12	56.19	49.17	1627.22	70.4
13	FA50	70.25	70.25	0	1627.22	70.4
14	MWP50	70.25	0	70.25	1627.22	70.4
15	FA50+MWP50	0	70.25	70.2	1627.22	70.4

CSEB samples have been prepared without and with partial replacement of cement with weight percent of (5-50) of FA and with weight percent of (5-50) of MWP. Fifteen mix series of sample blocks were prepared by varying the total stabilizer content of cement, fly ash, marble waste by 0% to 10 %. The second and fourth, the third and fifth series of mixes for sample preparation were prepared by using generic fly ash and marble powder in combination with cement as stabilizer, with varying total stabilizer content by 2% from 4% to 10%. And the sixth up to fifteen series of mixes were prepared by using fly ash and marble powder in combination with cement as stabilizer, by varying the content ash and marble powder. Additional sample blocks were also prepared by cement with fly ash and cement with marble powder only from two series of mixes by varying compaction pressure on the blocks from 5MPa to 10Mpa.

The elements of the mixed soil preparations were separately weighed using and weighing machine. To improve on the degree of mix, used the mechanical mixer. To produce the blocks, was used compression principal was used for the entire samples. The mould lining was slightly oiled with used engine oil and cleaned before filling. The soil was carefully poured into the mould, all pre-weighed and packed. After each pouring, and the soil was leveled in the mold.

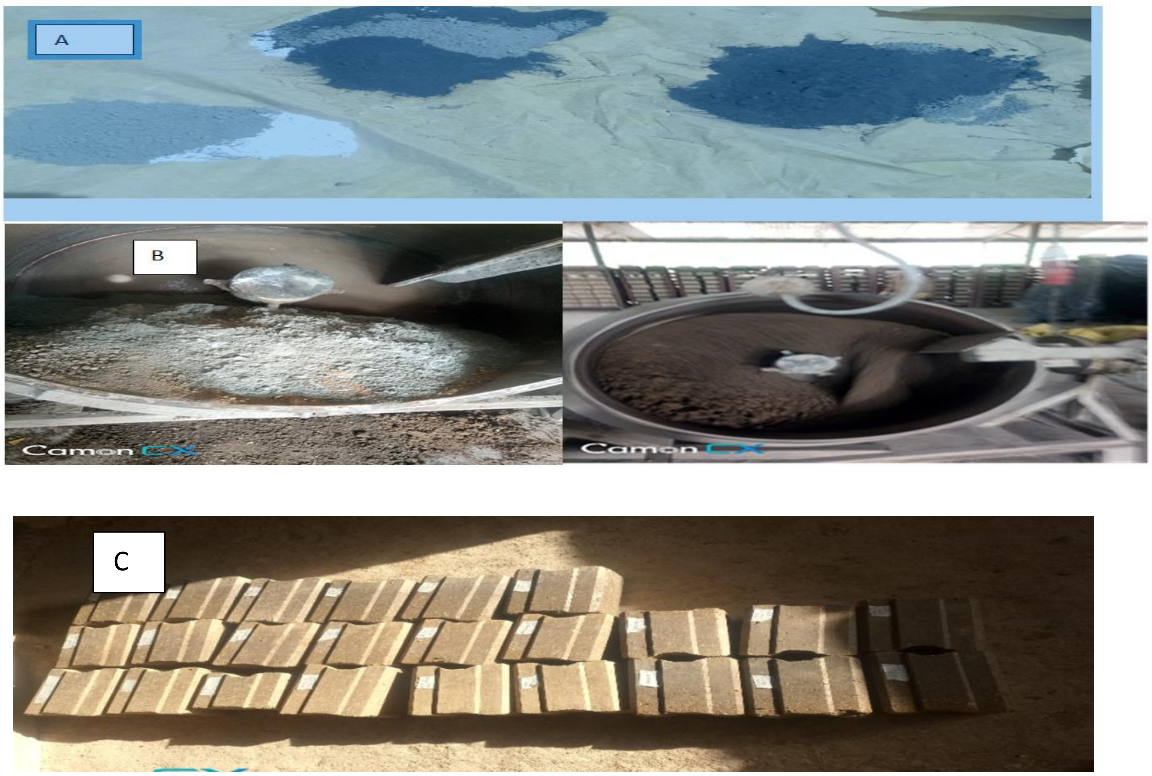


Figure3.5: A) Different raw materials to be mixed together b) Materials well mixed c) Different CSEB specimens

3.4.2 Moulding

During moulding, special precautions applied in order to produce uniform size and well compacted blocks. To produce the blocks, pressing machine was used. Before filling and compression of the mixed soil, the mould lining was lightly cleaned and oiled with used engine oil. The blocks were carefully removed from the mold and stacked correctly.

3.4.3 Compacting of CSEB Blocks

The wet blocks were then removed with the base plates, and immediately placed on a plastic mat and left to be cured in shade with metal roofing. The pressed blocks were transported to a product room, at a close distance to the pressing machine.

Figure3.6: Wet and Dry sample products of CSEB blocks

3.4.4 Curing

Curing is the final phase and it is essential for blocks future strength and durability. During the first seven days the blocks were wetted, by water once a day and covered with plastic sheeting. According to the ASTM C-39, the block samples were dried in moist room before test and then, the weight of block specimens were measured. The compressive strength, splitting tensile strength and water permeability tests have been conducted and, then the average of each block mix at the same age has been determined. The blocks are then remove out in the sun to cure without using firewood needed and water is sprinkled to aid curing. The blocks must then be stored correctly, often under sheeting, awaiting transportation/house building.

Figure3.7: CSEB block curing of the shade

3.4.5 Testing the Product of CSEB

The compressed stabilized earth blocks strengths were tested in 7^{th}, 14^{th}, 21^{th} and 28^{th} days and Water absorption of the blocks was measured at the 28th day. Compressive strength and water absorption tests were conducted based on ASTM C140 standard. The block characterization was conducted by SEM analysis.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Tests on Soil Sample

The use of suitable soil and binding materials are fundamental to successful CSEB production. Several Suitability Tests are available in the literature, but few of them which have a direct effect on the strength and durability were only considered. This section presents the results of complete laboratory analysis, including soil, fly ash, and marble waste gradation, physical and chemical composition, characterizations, mechanical tests, and durability tests.

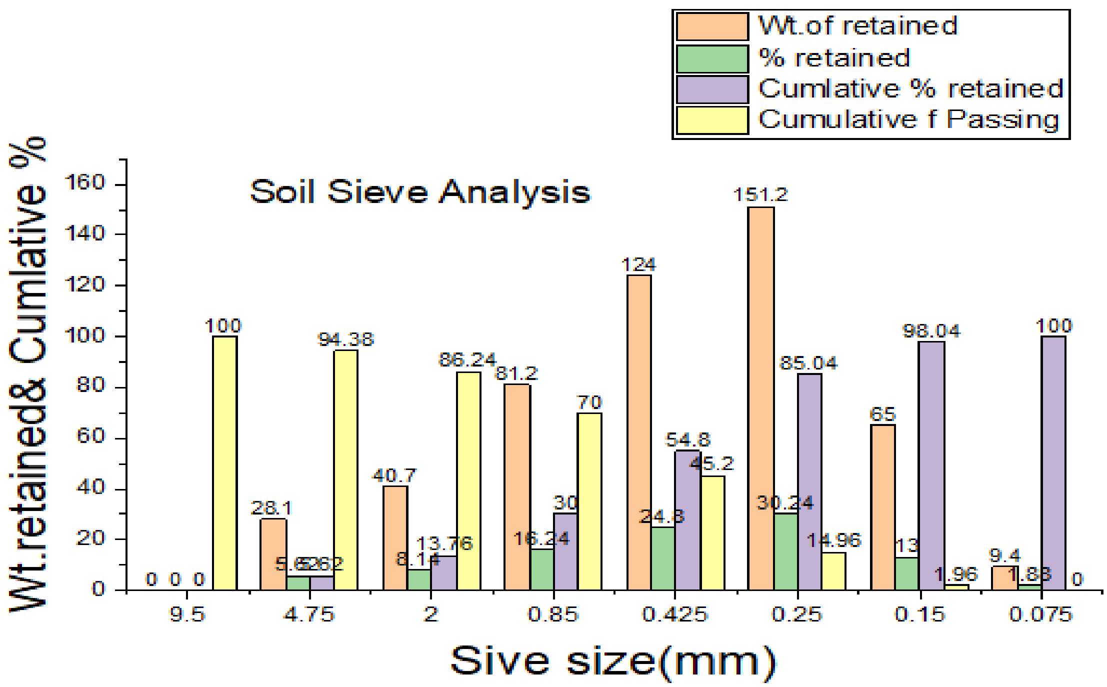
The physical test results and standard references of soil results obtained from these tests are presented in Table 4.1. As can be observed from the test results, the soils under investigation are within the acceptable ranges.

Table4.1: Physical properties of the soil and standards

No.	Physical properties	Values(Results)	Reference Standards	Acceptable Ranges
1	Specific gravity	2.6	ASTM D 854-00	2.65-2.75
2	Moisture Content%	13.0%	ASTM D 2216	10-20%
3	Clay (%)	10.8%		10-20%
4	Silt (%)	5.2%	ASTM D 422	5-15%
5	Sand (%)	72%	and BS test 7(B)	50-75%
6	Gravel (%)	12%		6-15%
7	Fineness (m^2 /kg)	277(m^2 /kg)		2.6 – 2.9
8	Water Absorption%	12.6%	ASTM D 2216	10-15%

4.1.1 Grain Size Analysis or Particle Size Distribution (Gradation)

Particle size analysis of the soil samples was done according to ASTM D 422 Standard Test Methods. The analysis result is presented in Figure 4.1. From the particle size distribution analysis, soil particle size distribution was within sieve scale range from 9.5 mm to 150 µm, and its fineness was considered more than fine aggregates (even less than cement). The Fineness Modulus of the soil used is 2.77, which is within the limit of the standard acceptable range.



: **Figure4.1:** Graphical Representation for particle size distributions of soil

The result shows that the actual composition of the soil used for the production of the CSEB was grouped as follows: Sand -72%, gravel 12%,Silt -5.2% and Clay -10.8%, the fineness modulus of the soil used is 277 (m^2 /kg). It accepts the African Regional Standard (ARS) of soil classifications.

4.1.2 Silt Content Determination of Soil

The silt content obtained from the test result is 5.2%, which is below the Ethiopian Standard of 6%. According to the Ethiopian Standard, if the silt content of the soil is more than 6%, the soil shall not be used for construction. Therefore, the silt content is within the limit of the standard.

4.1.3 Water (Moisture Content) Determination of Soil

ASTM D 2216-Standard Test Method for Laboratory Determination (Moisture) Content of Soil, Rock was used to determine moisture content of the soil samples. The moisture content of the soil samples used in CSEB production is 13.4 percent, which is less than 20 percent [14].Therefore, the moisture content of the soil sample is found to be within the standard value range.

4.1.4 Water Absorption Determination of Soil

ASTM D 2216 - Standard Test Method for Laboratory Determination of Water Absorption of Soil was used. The standard values of absorption based on ASTM standards are less than 15%. The absorption capacity of the soil samples used in CSEB production is 12.6%, which is less than 15 %. Therefore, the absorption capacity of the soil sample is found to be within the standard value range.

4.1.5 Specific Gravity Determination of Soil Sample

Specific gravity analysis of the soil samples was done according to ASTM D 854-00-Standard Test for Specific Gravity of Soil Solids by Water Pycnometer as standard references. The analysis result is presented in Table 4.2.

Table4.2: Specific gravity of soil sample

Specimen number	**1**	**2**
Pycnometer bottle number	95	47
W_P=Mass of empty, clean pycnometer(grams)	211.8	212
W_{PS}=Mass of empty pycnometer+dry soil(grams)	511	512
W_B=Mass of pycnometer + dry soil + water (grams)	1210	712
W_A = Mass of pycnometer + water(grams)	515.8	75.2
Specific gravity(Gs)	**2.6**	

The standard specific gravity value of sandy soil is found between 2.65-2.75 [15]**.** In the above test results, the specific gravity of soil was 2.6. Hence, the specific gravity of the soil sample is found to be close to Sandy Soil standard value range.

4.1.6 Chemical analysis of Soil

The chemical composition of the soil used for the study was investigated, and the results are presented in Table 4.3 and Appendix A. From the chemical components, SiO_2 (64.14%) is the major one. The higher silica and alumina (SiO_2 and Al_2O_3) content is essential for effective interaction with CaO from cement, MWP, FA, and water.

Table4.3: Chemical composition of Soil (RDSS)

Chemical composition of Soil	
Compound	**Percentage by weight**
SiO_2	64.14
Al_2O_3	18.32
Fe_2O_3	6.10
CaO	< 0.01
MgO	0.30
Na_2O	1.54
K_2O	1.32
MnO	0.18
P_2O_5	0.12
TiO_2	0.23
H_2O	2.35
LOI	4.80
SiO_2 +Al_2O_3+ Fe_2O_3	**88.56**

4.2 Tests on Fly Ash Sample

4.2.1 Sieve analysis of Flay ash (FA)

Particle size analysis of the fly ash samples was done according to ASTM C618 Standard Test Methods [30]. The grain size distribution of the fly ash is shown in Figure 4.2. The fly ash particle size distribution is within the seive scale range from 1.18 mm to 32 μm, and the Fineness Modulus is 290 (m^2/kg). Its fineness is between marble waste powder and cement. This fineness of the fly ash is good to be used a binding material for the production of CSEB blocks.

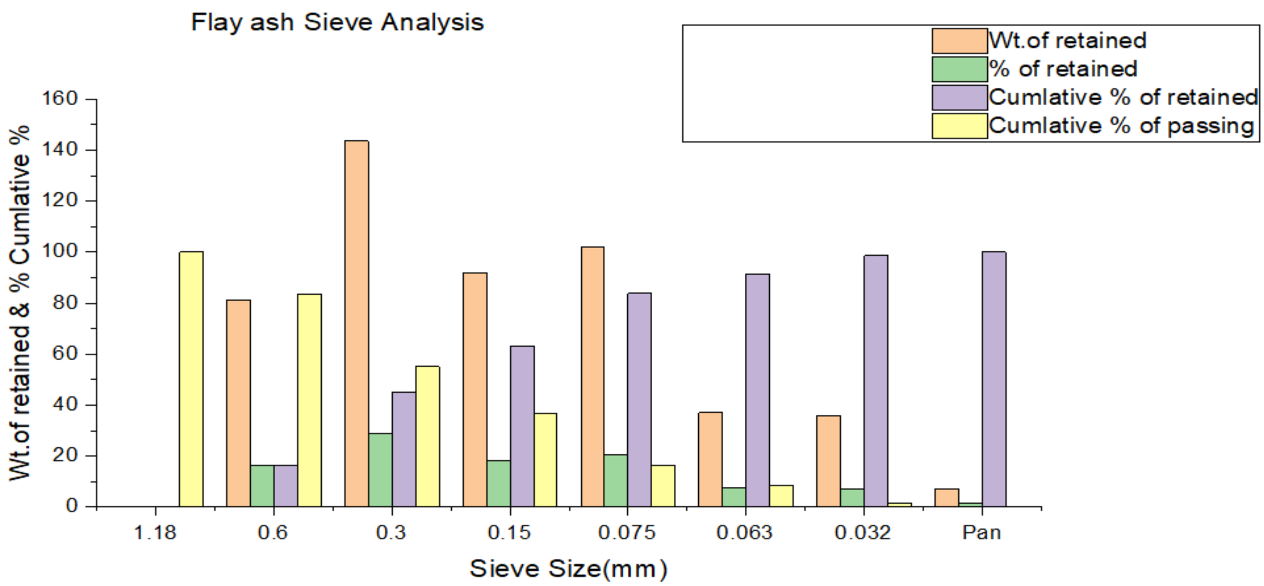


Figure4.2: Graphical Representation of Flay ash

4.2.2 Specific Gravity Results of Flay Ash

Specific gravity analysis of fly ash samples was done according to ASTM C77-40-Standard Test for specific gravity. The standard specific gravity fly ash is between 2.2 and 2.The specific gravity analysis result for fly ash is 2.86. The value indicates, it is good to be used as a binding material for production of blocks.

4.2.3 Chemical Analysis of Fly Ash

Complete result for the chemical composition or silicate analysis of fly ashes given in Table 4.3. There are two classes of fly ash, Class C and Class F fly ashes. The main difference between class C and class F fly ash is the chemical composition of the ash. ASTM 618 requires that class F fly ash contain at least 70% pozzolanic compounds (silica oxide, alumina oxide, and iron oxide), while class C fly ash has to be between 50% and 70% of these compounds.

The Chemical analysis result is attached in the Appendix section B. As shown in the Table 4.4, the fly ash has high silica content that makes it to be classified as Class F fly ash.

Table4.4: Chemical composition of fly ash (FA)

Compound	Percentage by weight
SiO_2	28.44
Al_2O_3	12.69
Fe_2O_3	8.38
CaO	3.10
MgO	1.02
Na_2O	< 0.01
K_2O	1.32
MnO	< 0.01
P_2O_5	0.34
TiO_2	0.26
H_2O	2.41
LOI	41.93

The fly ash has high amount of SiO_2, Al_2O_3, and Fe_2O_3), and CaO is 3.1% which is less than 8%. The loss on ignition is 41% which is greater than 6%. These values indicate that the fly ash sample used in this study is classified as class F fly ash.

4.3Tests on Marble Waste Powder Sample

4.3.1 Sieve analysis of Marble waste powder (MWP)

Particle size analysis of the MWP samples was done according to ASTM D 422 Standard Test Methods. The result of the particle size distribution is presented in Fig. 4.3.

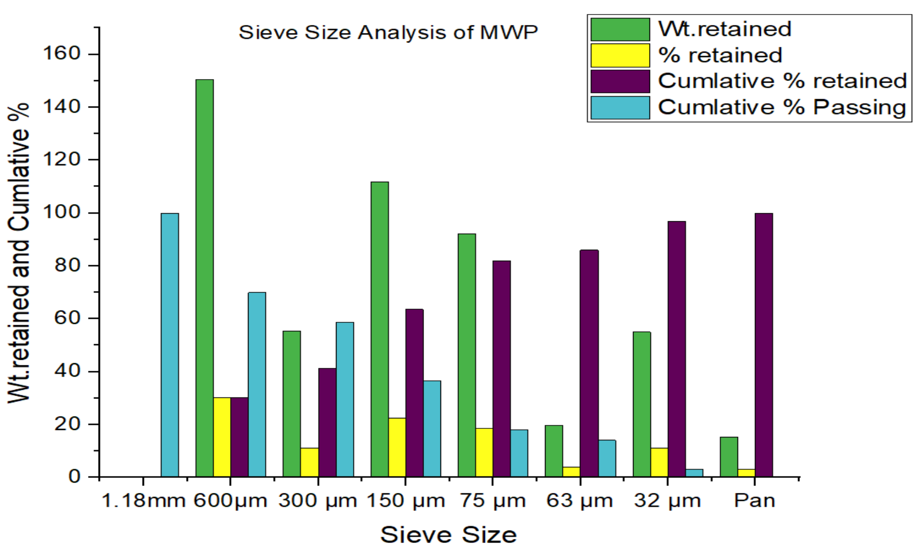


Figure4.3: Graphical Representation of sieve analysis of marble was**tes**

The particle size distribution of MWP was within the seiver scale range from 1.18 mm to 32 μm, and its Fineness Modulus was 3. The finesses of marble powder are less than that of cement (2.35), but it can be considered as comparable value and used as a binding material for the production of CSEB block.

4.3.2 Specific Gravity Determination of Marble Waste Powder

The specific gravity of marble waste powder was determined based on ASTM C77-40-Standard Test Methods. The specific gravity of marble waste powder is 2.84 while its standard value is 2.5. The standard specific gravity value of cement is 3.15.

4.3.3 Chemical Properties of Marble Waste Powder

The chemical composition test results are presented in Table 4.5. The amount of lime (CaO) content of marble is high (45.16%) and may exist in the form of limestone (CaO_3). Other metallic oxides also exist in the form of silicates as there is silica content of 11.04%.

Table4.5: Chemical composition of Marble waste powder samples (MWP)

Compound	Percentage by weight
SiO_2	11.04
Al_2O_3	< 0.01
Fe_2O_3	0.72
CaO	45.16
MgO	3.06
Na_2O	0.66
K_2O	< 0.01
MnO	< 0.01
P_2O_5	0.12
TiO_2	< 0.01
H_2O	0.30
LOI	39.91
CaO(High)	**45.16**

The marble waste powder has lime content but lower silicate amount. This composition may decrease the binding capacity to a certain limit. But by using the combination of these industrial wastes could improve the mechanical properties of CSEB materials products without degrading its quality. The detail chemical composition of marble waste powder is attached in the Appendix A.

4.4 Analysis of Cement

4.4.1 Particles

4.4.2 Size Distribution of Ordinary Portland cement (OPC)

Particle size analysis of cement samples was done according to ASTM Standard Test Methods. The analysis result is shown in Table 4.5. Therefore, the particle size distribution of OPC was within a seiver scale ranging from 300 μm to 32 μm.

Table4.6: Particles size distribution of Ordinary Portland Cement

Sieve size	Weight of retained (OPC) in G	Cumulative % passing
600 μm	0	100
300 μm	1.	97.4
150 μm	20.3	77.6
75 μm	23.6	74.3
32 μm	50.9	48.0

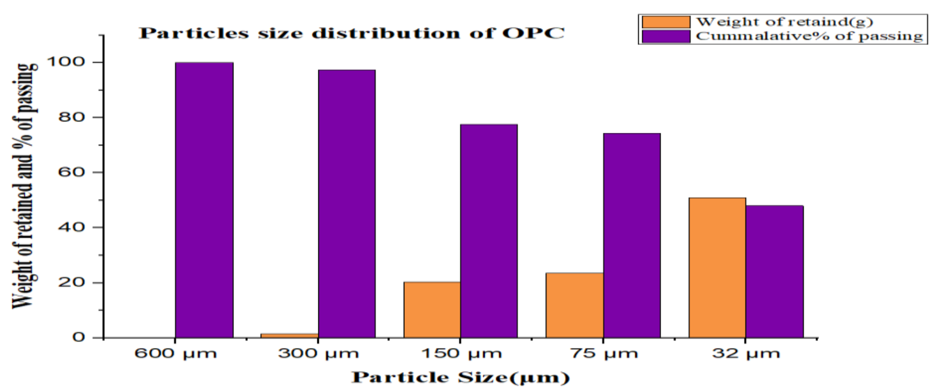


Figure4.4: Particle size distribution of Cement

4.4.3 Chemical Analysis of Cement

Ordinary Portland cement CEM I (43 Mpa) is used in the production of CSEB blocks. The chemical composition is clearly shown in 4-7. The fineness modulus of the cement is 2.35, and specific gravity of 3.15. The current actual test result of Dangote cement tested by Dangote Cement Ethiopia PLC is attached in Appendix C.

Table4.7: Composition and properties of cements produced in Ethiopia.

Compound	OPC Percentage by weight
SiO_2	20.2
Al_2O_3	5.74
Fe_2O_3	3.55
CaO	61.64
MgO	0.82
SO_3	2.51
Na_2O	0.2
K_2O	0.26
LOI	3.96
IR	2.59

4.5 Mechanical Tests Results on CSEB Blocks

4.5.1 Compressive strength Tests

Compressive strength tests were conducted based on ASTM C140 standard Test Methods. The test results for the compressive strength against curing ages for samples are presented in Table 4.8

Table4.8: Dry Compressive Strength test result of CSEB in MPa

		Dray Compressive Strength of CSEB, Mpa			
S.No.	**Mix Codes**	**7 Days**	**14 Days**	**21 Days**	**28 Days**
1	FA0+MWP0	1.78	2.68	2.89	3.92
3	FA0+MWP5	1.75	2.56	2. 77	3.46
4	FA10+MWP0	1.73	2.65	2.85	3.57
5	FA0+MWP10	1.68	2.54	2.84	3.60
6	FA10+MWP5	1.71	2.62	2.97	3.84
7	FA15+MWP10	1.59	2.56	2.76	3.75
8	FA20+MWP15	1.51	2.53	2.52	3.55
9	FA25+MWP20	1.42	2.41	2.47	3.41
10	FA30+MWP25	1.12	2.21	2.31	3.12
11	FA35+MWP30	0.92	2.01	2.07	2.97

12	FA40+MWP35	0.72	1.72	1.20	2.49
13	FA50+MWP0	0.56	1.02	0.97	1.6
14	FA0+MWP50	0.45	0.87	0.83	1.2
15	FA50+MWP50	0.41	0.81	0.92	1.04

For mix codes (6-10), the compressive strength values of CSEB were high and comparable to the international standards value of the block in this result was-code 6(FA 10% + MWP 5 % value of 3.84 Mpa after the 28th day of curing. The minimum British Standard requirement of strength is 2.84N/mm^{2}and for the international standard is within the range between 3-6 Mpa after 28th days curing. Therefore, some of the studied CSEB blocks produced by partial replacements of cement with fly ash and marble waste powder have shown compressive strength within the international standard range.

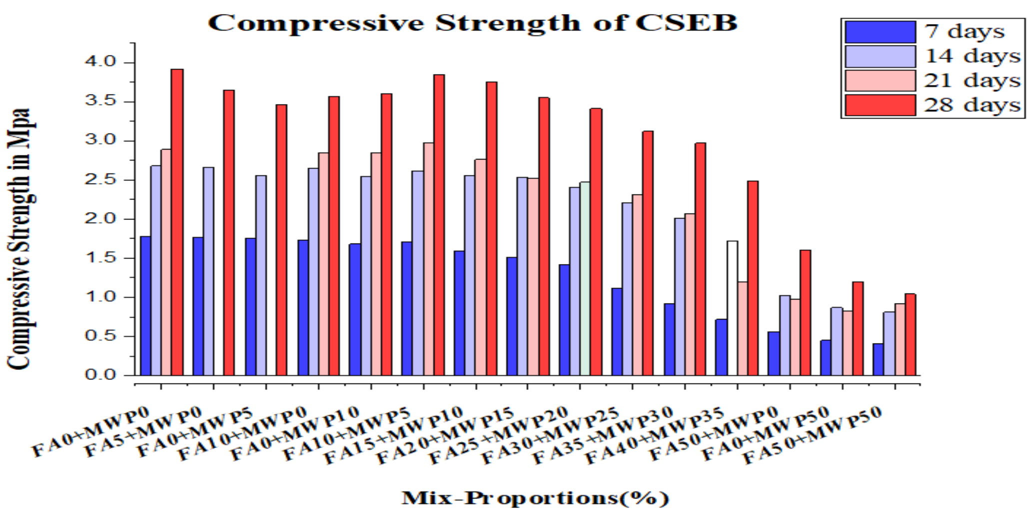


Figure4.5: Dry Compressive strength of CSEB Blocks

Table4.9: Wet Compressive Strength of CSEB @ 28 days in MPa

Mix Code	Wet Compressive Strength of CSEB @ 28 days in Mpa
FA0+MWP0	2.97
FA5+MWP0	2.91
FA0+MWP5	2.94
FA10+MWP0	2.93
FA0+MWP10	2.89
FA10+MWP5	3.01
FA15+MWP10	2.74
FA20+MWP15	2.71
FA25+MWP20	2.14
FA30+MWP25	2.05
FA35+MWP30	1.93
FA40+MWP35	1.52
FA50+MWP0	1.6
FA0+MWP50	1.51
FA50+MWP50	1.25

The wet compressive strength test result is shown in Table 4.10. To fit the given international strength standard that is found between 2Mpa to 3 Mpa at 28th days. The maximum wet compressive strength (3.01 Mpa) was obtained for FA10% and MWP5% substitutions.

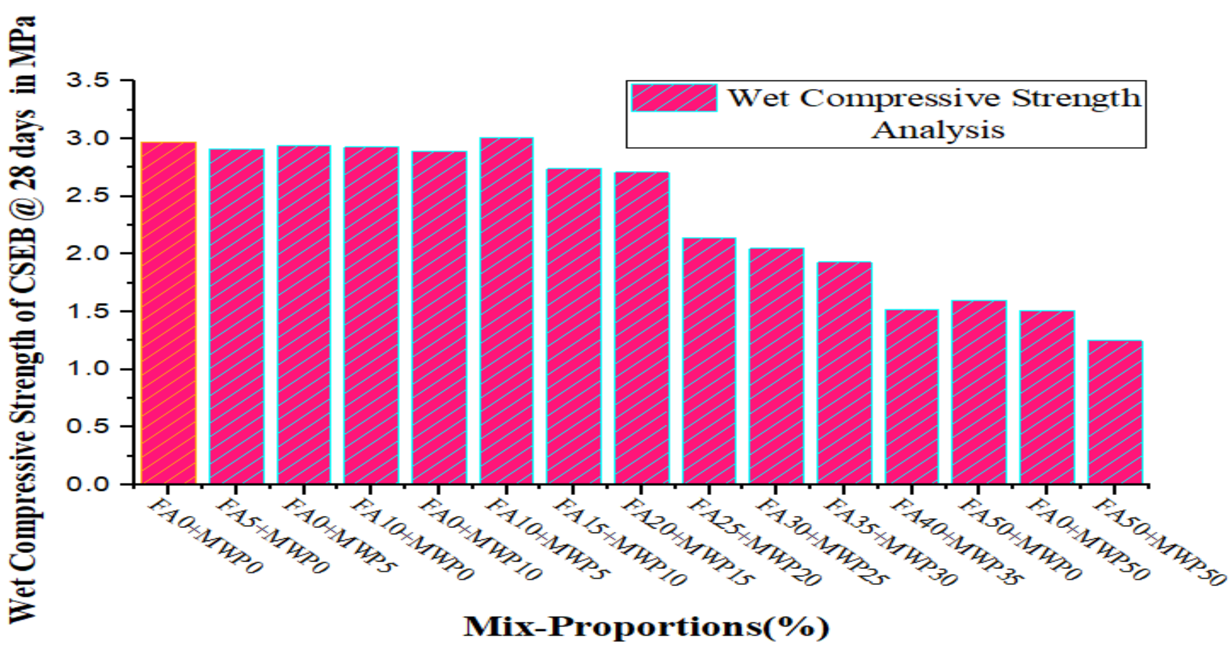


Figure4.6: Wet Compressive strength of CSEB Blocks

When the compressive strength of CSEB blocks was cured from 7 days to 14 days and from 21 days to 28 days, there was better increment in strength in all mix types. The reasons behind is improvement is due to the cement, fly ash, and marble waste hydration process led to the generation of C-S-H gels than the previous days.

Figure4.7: Compressive strength testing of CSEB

4.5.2 Splitting Tensile Strength

Tensile strength tests of CSEB blocks were conducted based on ASTM C140 Standard Test Methods. The test results are shown in Table 4.11.

Table4.10: Tensile Strength test result of CSEB

Mix Code	Splitting Tensile Strength of CSEB, MPa			
	Testing Days			
	7	14	21	28
FA0+MWP0	0.38	1.09	1.06	1.21
FA5+MWP0	0.5	1.12	1.17	1.19
FA0+MWP5	0.45	1.00	1.2	1.17
FA10+MWP0	0.38	0.9	0.93	1.27
FA0+MWP10	0.42	1.00	1.04	1.19
FA10+MWP5	0.33	1.02	1.11	1.06
FA15+MWP10	0.31	0.98	1.13	1.33
FA20+MWP15	0.5	0.76	0.81	1.09
FA25+MWP20	0.57	0.70	0.86	0.98
FA30+MWP25	0.62	0.71	0.83	0.97
FA35+MWP30	0.52	0.61	0.76	0.92
FA40+MWP35	0.42	0.42	0.45	0.49
FA50+MWP0	0.44	0.40	0.47	0.5
FA0+MWP50	0.24	0.36	0.49	0.48
FA50+MWP50	0.30	0.31	0.32	0.44

The block material modified with (15 % FA + 10% MWP) has shown greater splitting tensile strength than the other block types after 28 days. Tensile strength is improved by accelerating the early cement hydration process and the dissolution of CH, and generating additional C-S-H gels. The MWP and FA incorporation may have improved the prevention of crack initiation and propagation. The international standards recommended for splitting tensile strength is between 1-2 Mpa.

4.6 Durability Test of CSEB

4.6.1 Water Absorption

Water absorption test of CSEB block was done based on ASTM C140 - Standard test methods for sampling and testing block, bricks and concrete masonry units, and related materials. Another Standard method used to determine water absorption is ASTM C 140, BS EN 771-2, and Australian Standards 2733 (for the initial absorption rate). The water absorption result of the blocks with different stabilizers compositions is shown in Table 4.12.

Table4.11 : Water absorption capacity of CSEB block with different compositions

S.No	Composition of FA and MWP%	Water absorption Capacity (%)	ASTM Standard of CSEB Less than 15%
1	FA0%+MWP0%	11.3	✓
2	FA10%+MWP0%	12.3	✓
3	FA0%+MWP10%	13.4	✓
4	FA10%+MWP5%	11.6	✓
5	FA15%+MWP10%	13.9	✓
6	FA25%+MWP20%	14.5	✓
7	FA30%+MWP25%	14.9	✓
8	FA35%+MWP30%	15.3	***Above the given standards***

The water absorption value of the block made using only cement stabilizer was less than other mixes studied. The block (using 10% fly ash and 5% marble waste powder) also has a relatively similar water absorption value as that of using only cement. Mix proportions 1-7 fit the ASTM standards of water absorption. But from mix proportions eight and above, the absorption values are greater than 15%. The test results showed that water absorption and porosity increase with fly ash and marble waste content and decreasing cement content.

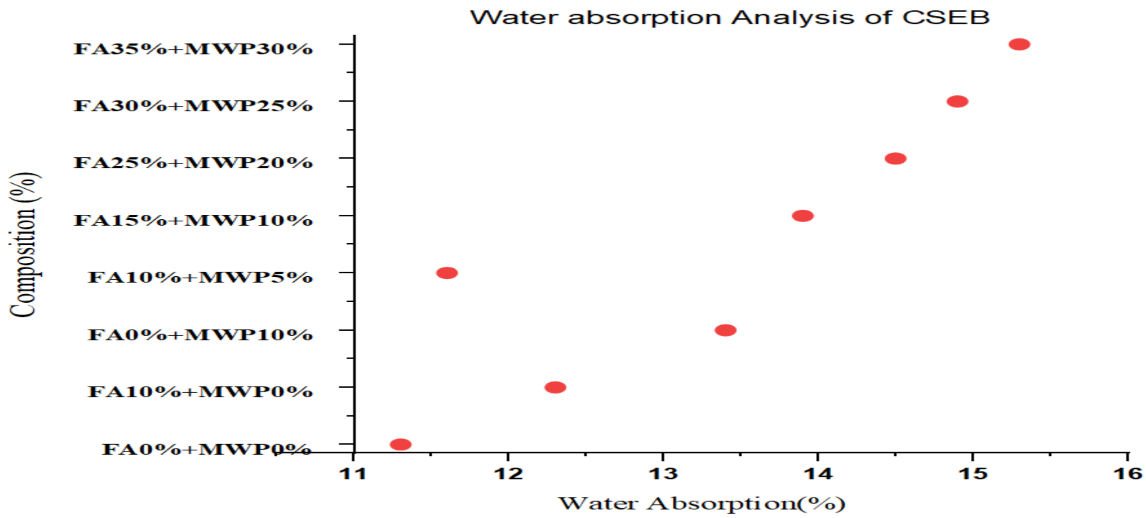


Figure4.8: Water Absorption Capacity of CSEB at 28 days curing

4.6.2 Density of CSEB Block

Density of CSEB block produced by using fly ash and marble waste powder composite was less than that of CSEB produced by cement. The international standards of CSEB block density is between 1500kg/m^3-2000kg/m^3. The normal CSEB block density value of in this research was 1,764kg/m^3 and the other mixes density values are within the limit of the standard.

4.7 Material Characterization

4.7.1 X-Ray Diffraction (XRD) Analysis of Materials

The X-ray analysis results are shown in **Fig 4.9-11.**

A. XRD Analysis of Soil

The soil sample is a composite material that has more than one crystalline material. Two primary crystalline materials were identified in the soil sample; Kaolinite (Aluminum silicate hydrate $AlSi_2O_5(OH)_4$) and Quartz (Silicon dioxide, SiO_2).The peaks of SiO_2 were high intensity because there was more periodicity than the other direction that is $AlSi_2O_5(OH)_4$. The height of the peak could be high if there is a preferred crystal orientation. And also higher the electron density variation, the higher the intensity for that plane reflected in the Xrd pattern.

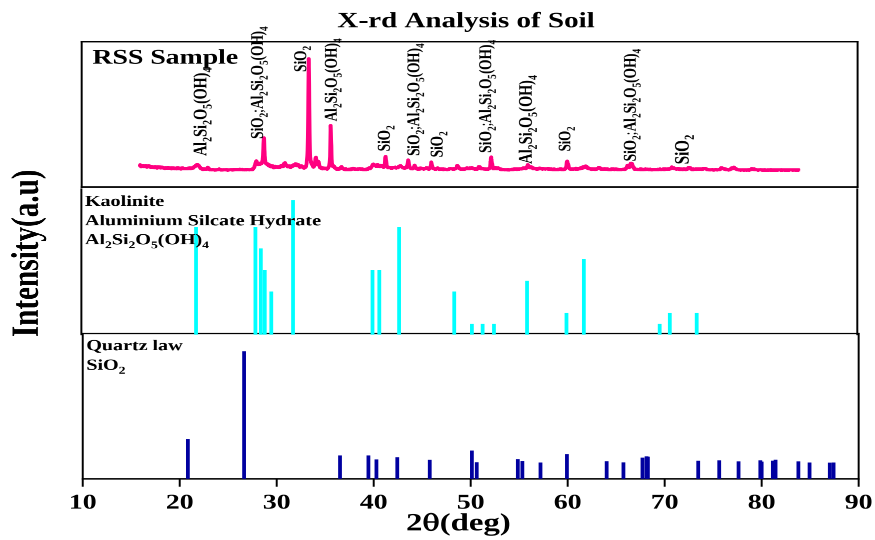


Figure 4.9: XRD Analysis of Soil (RSS) Sample

The characteristic of the peaks of the mineral composition of the soil is shown in **Figure 4.9**. X-ray examination has shown that the soil is mainly presented with crystal phase kaolinite, aluminum silicate hydrate, and quartz. As observed in the intensity peaks; the most common minerals of soil are constituents of silicon dioxide and Aluminum silicate hydrates (Kaolinite). The amount of silicon dioxide in soil was 64.14%. The major diffraction peaks were observed at $2\theta=27^o$, 37^o, 43^o, 50^o, 60^o, 68^o, and 74^o at (100), 101), (110), (112), (211), (203), and (301). The three highest peaks have existed in the soil sample at 2θ; 29.6^o, 26.8^o, and 21^o.The intensity of which increases systematically with increases the concentration of silicon dioxide. In the spectra shown, some peaks shift from the standards values. In general-ray peak shift occurs due to lattice parameters change, presence of residual stress and defect concentration.

B. X-Ray Analysis of Flay Ash

The characteristic of the peaks of the mineral composition of fly ash is shown in **Figure 4.10**. X-ray examination has shown that the fly ash is mainly presented crystal phase's hydrogen, iron oxide, and quartz. As observed in the intensity peaks; the most common minerals of ashes were constituents of silicon dioxide (Quartz). Moreover, about 28.44 percent of the sample was quartz and it is the highest mineral in fly ash. It plays a significant role in fly ash hydration behavior because it participates along with tricalcium aluminate and other soluble aluminates. The major diffraction peaks were observed at $2\theta=21^o$, 27.5^o, 50^o, and 81^o at (100), 101), (110), (112), and (203). The three highest peaks existed in soil sample at 2θ; 26.7^o, 50^o, and 20.88^o.

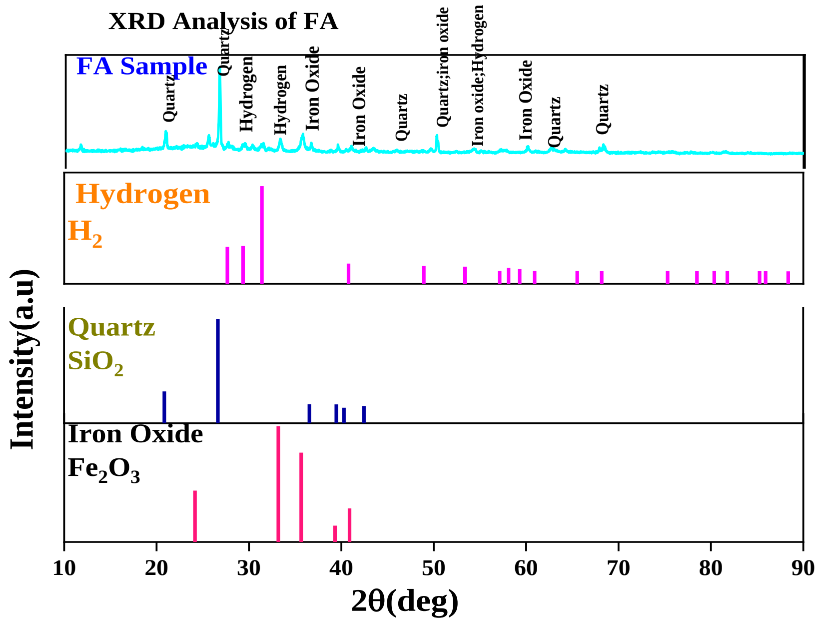


Figure 4.10: XRD Analysis of Fly Ash (FA) Sample

C. X-Ray Analysis of Marble Waste Powder

The results of the X-ray diffraction (XRD) analysis from samples of marble waste powder was collected after the sieving process, which showed the main chemical elements that compose the samples. The XRD of the marble waste powder is shown in **Figure 4.11.** Well-defined peaks of minerals, such as quartz, limestone, calcite, dolomite, and others were observed. These peaks indicated the presence of crystalline phases, which was shown in the samples; therefore, it is possible to say that the material that generates the residue constituted well-defined crystals.

The X-rays from the diffractometer spectrum, showed peaks of characteristic diffractions of the crystalline phases related to limestone in the form of calcite ($CaCO_3$), which was the largest observed peak, demonstrating the presence of marble. It was determined a predominance of quartz (SiO_2), calcium carbonate ($CaCO_3$), and calcium magnesium carbonate CaMg $(CO_3)_2$ in the residue. It was verified that the marble had a smaller size in its average diameter, which suggests a larger interaction in the formation of the composite. The major diffraction peaks observed were at $2\theta=29^o$, 36^o, 39^o, and 51^o at (333), (541), (710), and (831) of calcium silicate. The three highest peaks have existed in marble waste powder samples from 47.6738, 31.0373, and 29.5465.The intensity of which increases systematically with increases the concentration of calcium oxide.

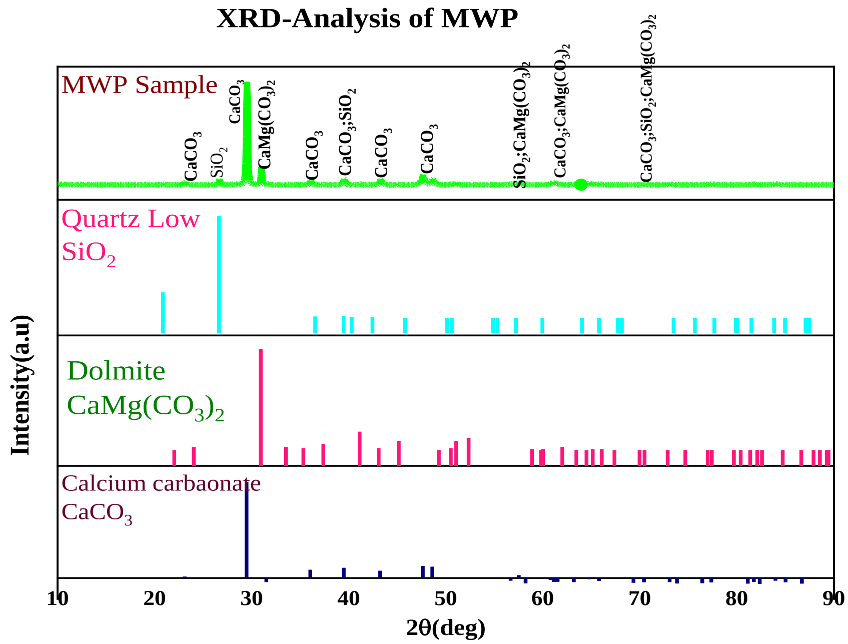


Figure4.11: XRD analysis of Marble Waste Powder (MWP) Sample

4.7.2 SEM Analysis

The SEM analysis was used to investigate microstructure of CSEB blocks (normal block using soil and cement only, replacing cement with components like flay ash and marble waste powder). The test was examined in the form of cutting the block in solid form. The SEM images are shown in **Fig 4.12-4.15.**

Fig. 4.12 shows the SEM image of CSEB prepared with only 10% cement stabilizers without flay ash and marble waste powder in the composite. During using cement as binding of soil materials for the production of CSEB block pores, CH plates, C-S-H (Calcium Silicate Hydrate), and C-A-H (Calcium Aluminate Hydrate) gels are indicated in the figure. C-S-H and C-A-H are mainly responsible for strength in the blocks, because of the hydration reaction. The compressive strength and durability of the block were high due to high hydration reactions are occurred between the soil and the paste. The block was highly denser than other CSEB blocks and the porosity of the block decreases.

Fig. 4.13, SEM image of the block with 15% substitutions of cement by 10% FA and 5% MWP is shown. This means to convert into 10% of stabilizers 1% FA.0.5% MWP and 8.5% it indicates a compact matrix where most of the pores are filled up with FA, MWP, soil particles, C-S-H, C-A-H gels, and C-C-A. The presence of the nucleation centers can lead to accelerated hydration of silicate and aluminate phases, especially tricalcium-aluminate (C_3A) to form calcium-carbonate aluminate-hydrate ($3CaO\ Al_2O_3\ 3\ CaCO_3\ 32\ H_2O$). A well-coordinated connection can be observed which signifies the reason of 10% FA and 5%

MWP being the optimum content as indicated from strength and durability test results. The composite material formed from these mixes was the highest compressive strength occurred.

Fig. 4.14 shows the image of CSEB block made with 15% FA, 10%MWP and 7% cement. It was seen that the number of voids has increased significantly, and few unreacted fly ash and MWP particles are also noticed. The presence of unreacted materials implies that the required amount of cement is decreas0ed in the mix, FA, and MWP to take part in bonding. Then these substitute particles tend to reduce the inter particle and somewhat it has an effect on strength and durability.

Fig. 4.15 shows the image of a block made with 25% FA and, 20 with 5% cement. It was seen that the number of voids has increased significantly in the composite, and a few unreacted fly ash and marble waste powder particles were also noticed. The presence of unreacted particles implies that the required amount of cement is not present in the mix for FA and MWP to take part in bonding. As a result, these FA and MWP particles tend to reduce the inter-particle. Finally, with the substitution of cement by these particles high in the mix proportions, the durability of the block can be decreased.

Calculation of Scale Bar and Magnification of SEM

To calculate scale bars from SEM images by measuring the scale bar image (besides drawing) in mm, convert to µm (multiply by 100) and magnification-scale bar image divided by actual scale bar length/written on the scale bar. The measure of scale bars in SEM micrographs the real size calibration in the image file Meta data.

SEM magnification is defined as the ratio of a length measured from the SEM monitor-Lm-to the same length measured on the sample-Ls. M equals Lm over Ls. The length measured can be anything from the side of a single pixel all the way up to the entire horizontal or vertical field of view. The scale bar range is determined using scale size bar determination.

$$\mathbf{M} = \frac{Lm}{Ls}$$

Where; M=Magnification, Lm=Image width and Ls=Scan length

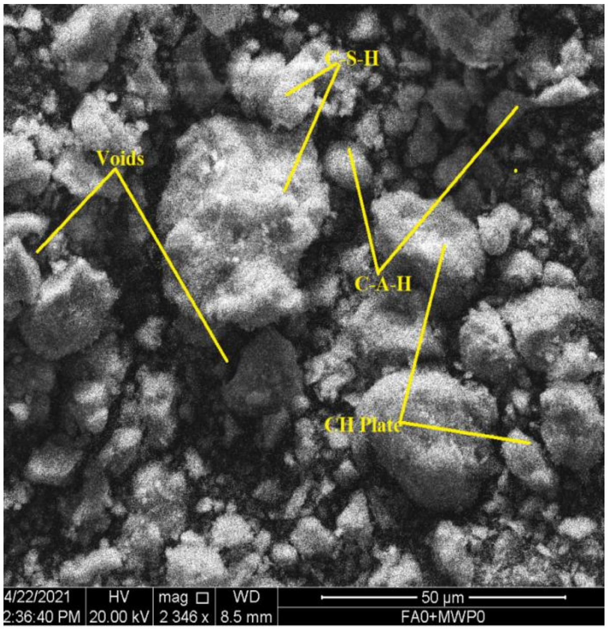


Figure4.12: SEM image of CSEB (With 10% cement, 0% FA and 0%MWP

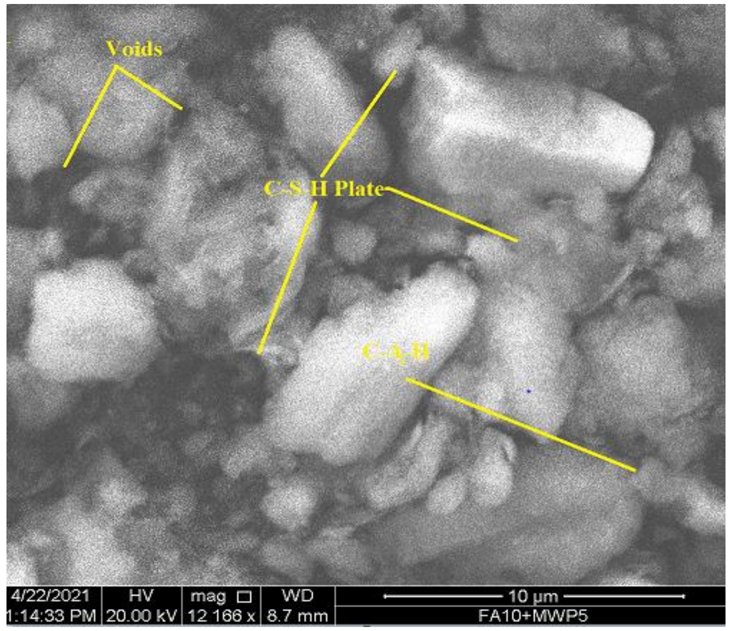


Figure4 13: SEM image of CSEB With 10% FA and 5% MWP

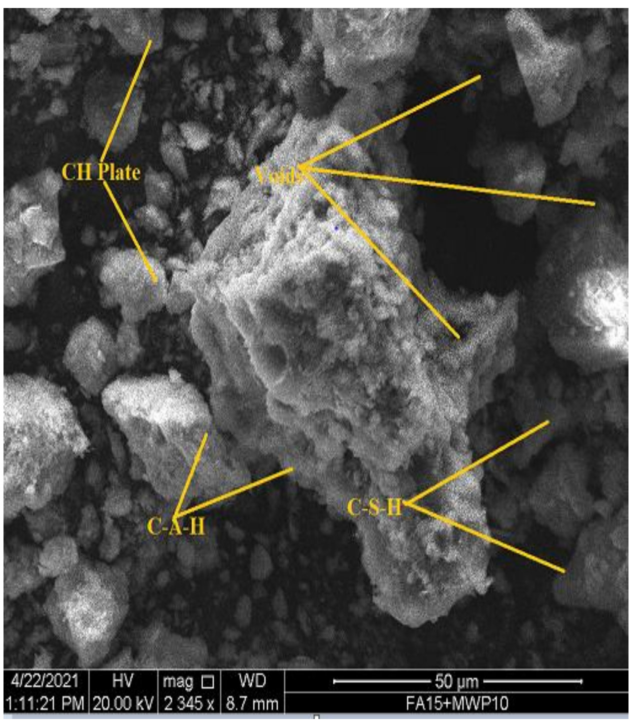


Figure4.14: SEM image of CSEB With 15% FA and 10% MWP

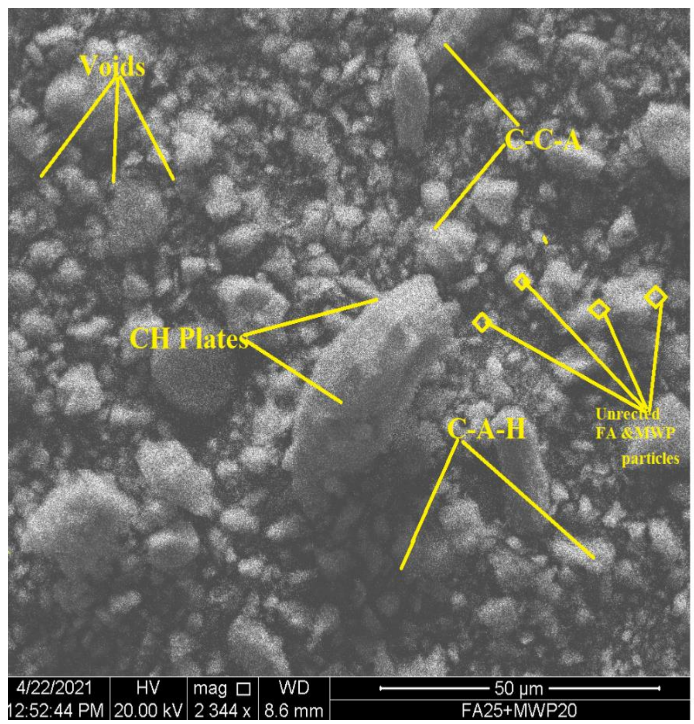


Figure4 15 : SEM image of CSEB With 25% FA and 20% MWP

4.7.3 Economic Analysis of CSEB

CSEBs stabilized with cement and fly ash, marble waste is found to reduce the cost by 22–35% indicating the economic superiority of cement-fly ash and marble waste powder stabilized CSEBs. The cost of interlocking CSEB block is more economical than compared to other construction materials like hollow concrete block (HCB) and fired clay bricks (FCB). Because HCB block needs high cement content during production. And also during building construction HCB requires cement for plastering and rendering. The current market price of single HCB block is 15 Ethiopian Birr. But one piece price of CSEB block is 9 birr.

CHAPTER FIVE:

CONCULSION AND RECOMMENDATIONS

5.1 Conclusions

This research was conducted to check the use of soils for CSEBs in construction by analyzing its performance in terms of strength and durability. Fly ash and marble waste powder are used along with cement as stabilizer for making CSEBs. The main objectives of this study were to assess the effectiveness of FA, MWP and cement for stabilizing sandy soil. The study was only used replacing cement with optimum utilization of MWP and FA improves the strength and durability of the material. Based on the the result and findings the following conclusions can be drawn:

1) According to ASTM D 422 for particle-size analysis and classifications of soil the grain size distribution was between sieve No.4 (sieve size 4.75 mm) and sieve No.200 (sieve size 75µm), the actual soil used in block production had sand content of 72%, silt content of 5.2%, gravel content of 12% and clay content of 10.8%.
2) Production of compressed stabilized earth block using marble waste powder, fly ash and cement with soil matrix composites can be easily produced with different weight proportions.
3) In CSEB production replacement of cement by fly ash and marble waste powder gives comparable compressive and tensile strength of fly ash and marble waste powder free CSEB block specimens; but increasing the replacement range beyond 30% ash and marble waste results in strength reduction. The maximum dry-compressive strength of 3.84N/mm^2 was obtained from samples with FA10% & MWP5%, and the tensile strength was 1.33 N/mm^2 the block material modified with (15 % FA + 10% MWP).The rest was cement content at the curing age of 28 days. The amounts of marble waste powder and fly ash was increased, the compressive strength of CSEB block decreases.
4) When the strength of CSEB blocks were cured from 7 days to 14 days and from 21 days to 28 days there was better strength increment in all mix types. The reasons behind that improvement were due to the cement; flay ash and marble waste hydration process led to extra generation of C-S-H gels than the previous days.
5) Water absorption capacity of the blocks decrease with the increase of cement content and certain amounts of FA and MWP content; it varies within 11.3–15.3% based on ASTM standards of water

absorption capacity value of CSEB less than 15 %.The water absorption values of the first seven mixes are within the limit of the standard.

6) Economic analysis is performed to assess the cost effectiveness of CSEBs stabilized with cement-FA-MWP and was compared to the cost of construction with FCBs, HCB and cement-sand stabilized CSEBs in literature. The cost of interlocking CSEB block is more economical than compared to other construction materials like hollow concrete block (HCB) and fired clay bricks (FCB). Due to the high cement content the cost of HCB block production is high. Also the building that built with HCB requires plastering and rendering so that its appearance and finishing surface to be produced

5.2 Recommendations

Depending on the findings of this research the following recommendations are drawn:

1) Compressed stabilized earth block produced from soils and stabilizers can be used as an alternative wall making construction material.
2) The local community in rural area used compressed stabilized earth blocks manufactured from locally available materials, affordable and environmental friendly blocks for construction materials.
3) Using marble waste powder and fly ash stabilizers in combination with cement could be help in reducing the cost of cement and transportation easy.
4) Compressed stabilized earth block is used to cheap, locally available, light weight, bio-degradable, cost effectiveness, high fire resistance and minimum mortar required construction materials.
5) The alternative use of natural soil, fly ash, marble and granite wastes are used for the production of light, easy constructible CSEB construction materials
6) This research was limited to only red sandy soil as the main ingredients of CSEB block production, mixing of white sandy soil, red clay soils, with marble waste powder and fly ash wastes by appropriate gradation is future research; due to these soils are available in different areas of Ethiopia.
7) New artificial composite construction materials should be made by grinding of marble and granite wastes together with natural available materials is further research topics.

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APPENDICES

Appendix A: Chemical Composition (Complete Silicate Analysis report) of Soil and Marble Waste Samples

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

Customer Name:- Nigat Melak

Issue Date: -15/03/2021

Request No:- GLD/RQ/574/21

Report No:- GLD/RN/253/21

Sample type :- Soil

Sample Preparation: - 200 Mesh

Date Submitted :-20/01/2021

Number of Sample:- Two (02)

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

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

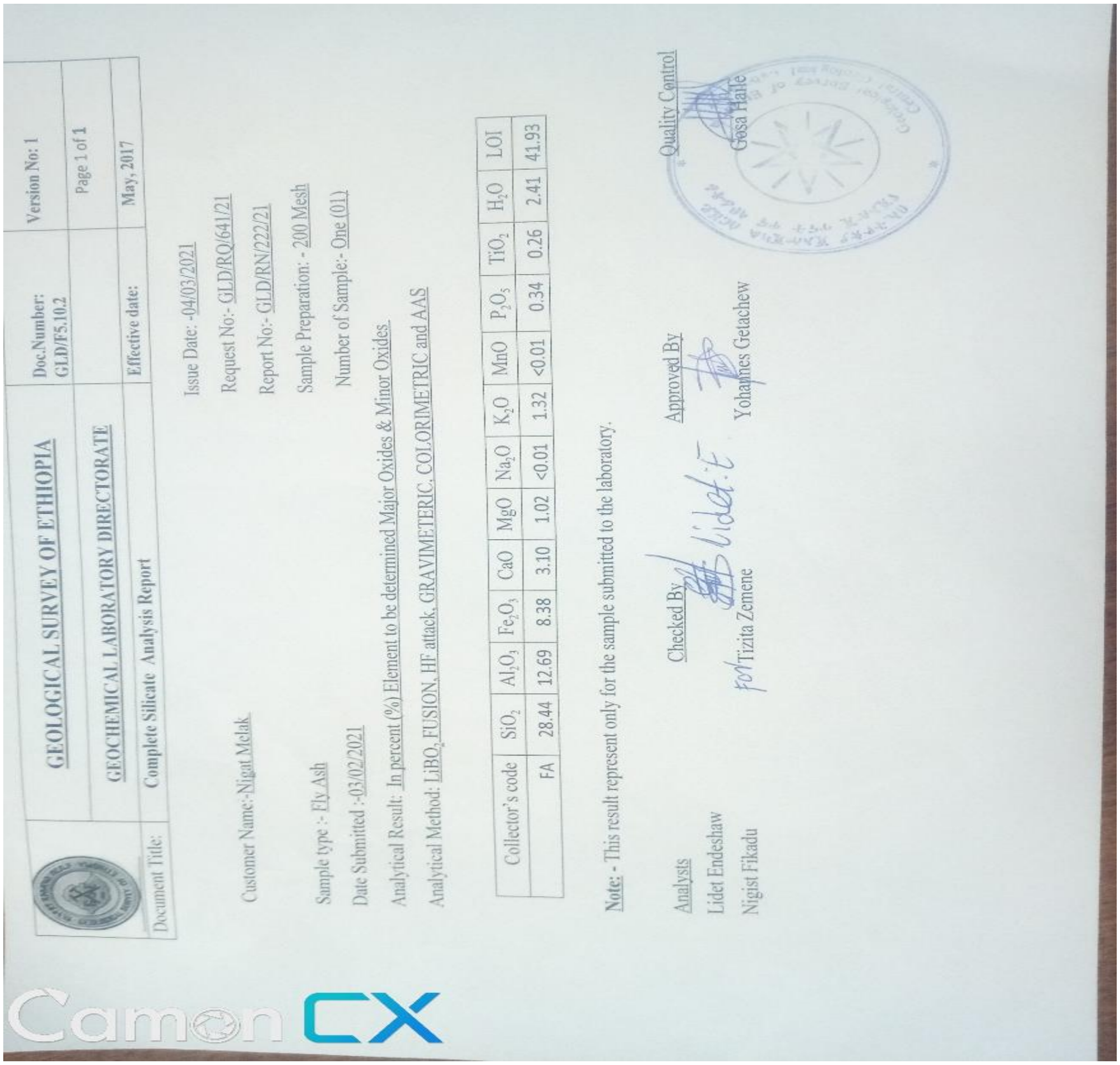
Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
RD-SS	64.14	18.32	6.10	<0.01	0.30	1.54	1.32	0.18	0.12	0.23	2.35	4.80
MWP	11.04	<0.01	0.72	45.16	3.06	0.66	<0.01	<0.01	0.12	<0.01	0.30	39.91

MWP

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

Analysts	Checked By	Approved By	Quality Control
Lidet Endeshaw	Tizita Zemene	Yohannes Getachew	Gosa Haile
Nigist Fikadu			
Durasa Abdisa			
Yirgalem Abreham			

Appendix B: Chemical Composition (Complete Silicate Analysis report) of Flay Ash Samples



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

Issue Date: -04/03/2021

Request No:- GLD/RQ/641/21

Report No:- GLD/RN/222/21

Sample Preparation: - 200 Mesh

Number of Sample:- One (01)

Customer Name:-Nigat Melak

Sample type :- Fly Ash

Date Submitted :-03/02/2021

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

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

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
FA	28.44	12.69	8.38	3.10	1.02	<0.01	1.32	<0.01	0.34	0.26	2.41	41.93

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

Analysts	Checked By	Approved By	Quality Control
Lidet Endeshaw	Lidet.E		
Nigist Fikadu	For Tizita Zemene	Yohannes Getachew	Gosa Haile

Appendix C: The table below shows the current test results of Dangote cement tested by Dangote Cement Ethiopia PLC.

DANGOTE	DANGOTE CEMENT ETHIOIPIAPLC	**Document No:**OF/DCEP/QA/044	
	Quality Certificate	Issue No: 1	PAGE 1 OF 1

ORDINARY PORTLAND CEMENT (42.5 N)

Month of : May 2021

Date of Issue: June 4,2021

Chemical Composition (%)- Test Method: ES1176:Part 2			
		Results (%)	Standard Requirments Maximum
Silicon Dioxide	SiO_2	20.20%	
Aluminium Trioxide	Al_2O_3	5.74%	
Ferric Oxide	Fe_2O_3	3.55%	
Calcium Oxide	CaO	61.41%	
Magnesium Oxide	MgO	0.82%	
Sulphate	SO_3	2.51%	< 3.5 %
Potassium Oxide	K_2O	0.26%	
Sodium Oxide	Na_2O	0.20%	
Chloride	Cl	0.03%	< 0.1 %
Insoluble Residue	IR	2.09%	< 5.0 %
Loss On Ignition	LOI	3.96%	< 5.0 %

Physical Properties		
Compressive Strength (Mpa)-Test Method ES1176:Part 1		Standard Requirments
	Results	Minimum
2 Days	21.6	10.0
28 Days	57.1	42.5
Setting Time- Test Method ES1176: Part 3		Standard Requirments
	Results	Minimum
Initial Time (Minutes)	188	60
Final Time (Minutes)	248	
Soundness- Test Method ES1176: Part 3		Standard Requirments
	Results	Maximum (mm)
Le-Chatelier Expansion (mm)	1.1	10
Fineness by Blain (Cm^2/g)	3663	
Standard Consistency	25.8	

Appendix D: Particle Size Distributions of Materials

Table-4.3: Sieve analysis of Soil (RSS)

500 gram Weight of Soil Sample

Sieve Number	Sieve opening (mm)	Weight of soil retained(g)	Percentage retained (%)	Cumulative percentage retained (%)	Cumulative Percentage of finer(Passing)(%)
No.(2/3 inch)	9.5	0	0	0	100
No.4	4.75	28.1	5.62	5.62	94.38
No.10	2.0	40.7	8.14	13.76	86.24
No.20	0.85	81.2	16.24	30	70
No.40	0.425	124	24.8	54.8	45.2
No.60	0.250	151.2	30.24	85.04	14.96
No.100	0.150	65	13	98.04	1.96
No.200	0.075	9.4	1.88	100	0
Pan	-	-	-	-	-
Total		500.00		277.26	

Table-4.6: Sieve analysis of Flay ash (FA)

500 gram of FA sample				
Sieve opening (mm)	**Weight of retained(g)**	**Percentage of retained**	**Cumulative percentage retained**	**Cumulative Percentage of finer(Passing**
1.18	0	0	0	100
0.6	81.4	16.28	16.28	83.72
0.3	143.5	28.7	44.98	55.02
0.15	91.9	18.38	63.36	36.64
0.075	102.1	20.42	83.78	16.22
0.063	37	7.58	91.36	8.64
0.032	36	7.2	98.56	1.44
Pan	7.2	1.44	100	**0**
Total		**100**	**298.32**	

Table-4.8: Sieve analysis of Marble waste powder (MWP)

500 gram of MWP sample				
Sieve Size	**Weight of retained(g)**	**Percentage of retained**	**Cumulative percentage retained**	**Cumulative Percentage of finer(Passing)**
1.18mm	0	0	0	100
600µm	150.6	30.12	30.12	69.88
300 µm	55.4	11.08	41.2	58.8
150 µm	111.8	22.36	63.56	36.44
75 µm	92.2	18.44	82	18
63 µm	19.8	3.96	85.96	14.04
32 µm	55.0	11	96.96	3.04
Pan	15.2	3.04	100	0
Total	**500**	**100**	**302.84**	

Appendix E: Compressive Strength test results

Table 4.13: Dry Compressive Strength test result of CSEB in MPa

		Dray Compressive Strength of CSEB, Mpa			
S.No.	**Mix Codes**	**7 Days**	**14 Days**	**21 Days**	**28 Days**
1	FA0+MWP0	1.78	2.68	2.89	3.92
3	FA0+MWP5	1.75	2.56	2. 77	3.46
4	FA10+MWP0	1.73	2.65	2.85	3.57
5	FA0+MWP10	1.68	2.54	2.84	3.60
6	FA10+MWP5	1.71	2.62	2.97	3.84
7	FA15+MWP10	1.59	2.56	2.76	3.75
8	FA20+MWP15	1.51	2.53	2.52	3.55
9	FA25+MWP20	1.42	2.41	2.47	3.41
10	FA30+MWP25	1.12	2.21	2.31	3.12
11	FA35+MWP30	0.92	2.01	2.07	2.97
12	FA40+MWP35	0.72	1.72	1.20	2.49
13	FA50+MWP0	0.56	1.02	0.97	1.6
14	FA0+MWP50	0.45	0.87	0.83	1.2
15	FA50+MWP50	0.41	0.81	0.92	1.04

Appendix F: Tensile Strength test result of CSEB

Table 4.15: Tensile Strength test result of CSEB

Mix Code	Splitting Tensile Strength of CSEB, Mpa			
	7 Days	14 Days	21 Days	28 Days
FA0+MWP0	0.38	1.09	1.06	1.21
FA5+MWP0	0.5	1.12	1.17	1.19
FA0+MWP5	0.45	1.00	1.2	1.17
FA10+MWP0	0.38	0.9	0.93	1.27
FA0+MWP10	0.42	1.00	1.04	1.19
FA10+MWP5	0.33	1.02	1.11	1.06
FA15+MWP10	0.31	0.98	1.13	1.33
FA20+MWP15	0.5	0.76	0.81	1.09
FA25+MWP20	0.57	0.70	0.86	0.98
FA30+MWP25	0.62	0.71	0.83	0.97
FA35+MWP30	0.52	0.61	0.76	0.92
FA40+MWP35	0.42	0.42	0.45	0.49
FA50+MWP0	0.44	0.40	0.47	0.5
FA0+MWP50	0.24	0.36	0.49	0.48
FA50+MWP50	0.30	0.31	0.32	0.44

Appendix G: Optical Surface Profile (OSP) images of CSEB

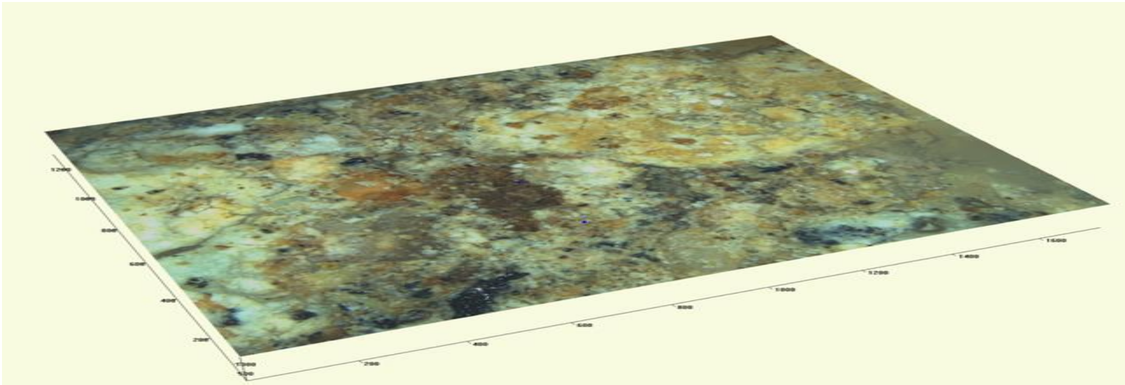


Figure a: OPS images of CSEB FA10 and MWP5

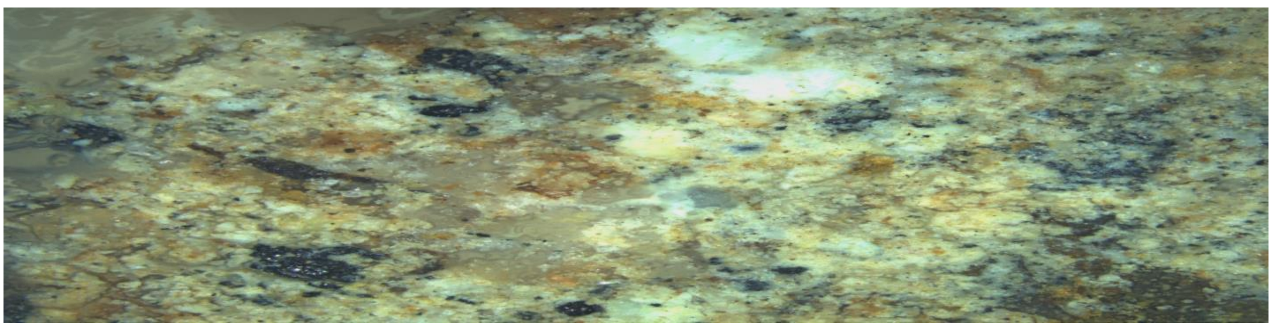


Figure b: OPS images of CSEB FA20and MWP15

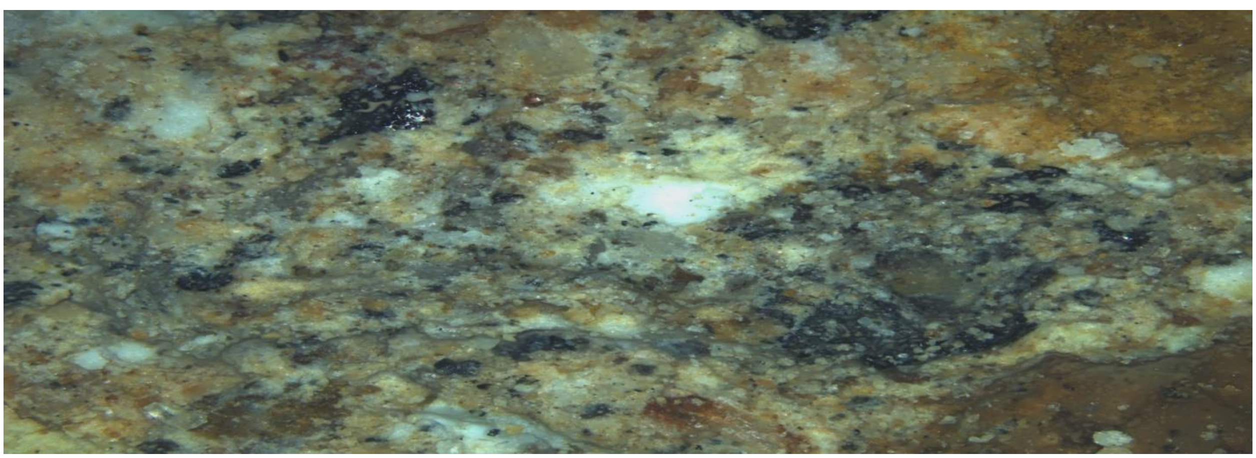
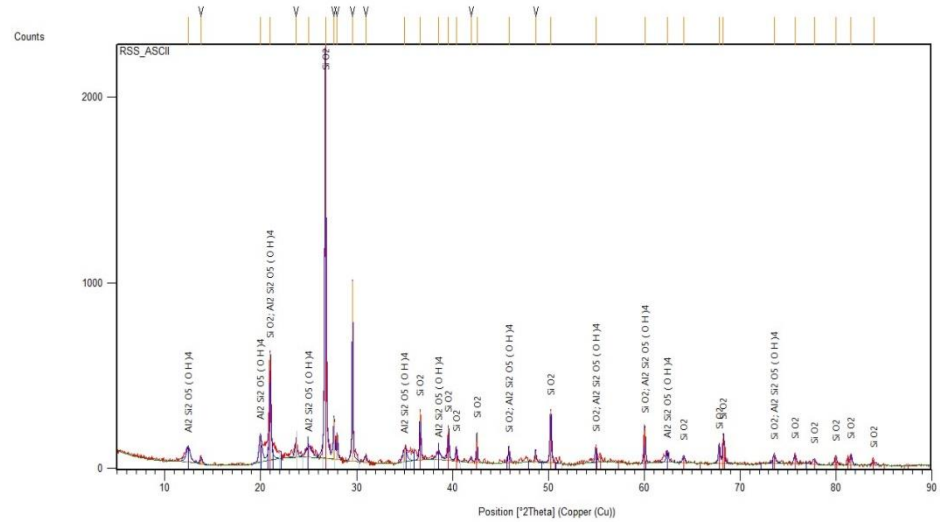


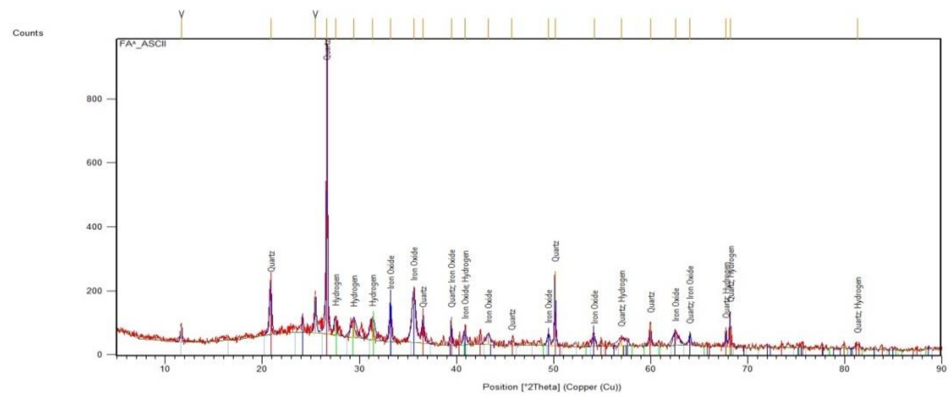
Figure c: OPS images of CSEB FA25 and MWP 20

Appendix H: XRD Analysis of Materials

A. XRD Results of Soil Sample



B.XRD Results of Fly Ash Sample



C.XRD Results of Marble Waste Powder Sample