ADDIS ABABA UNIVERSITY SCHOOL OF GRADUATE STUDIES

Ethiopian Institute of Architecture Building Construction and City Development (EiABC)

EXPERIMENTAL STUDY ON THE USE OF PLASTIC STABILIZED HYDRA FORM BLOCKS AS AN ALTERNATIVE WALLING MATERIAL

HABEN LEMMA BIRARA

ADVISOR: ASS. PROF. MESKEREM ZEWDIE (PHD)

A Thesis Submitted to School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Master of Science in Architecture (Advanced Architectural Design)

October, 2023

ADDIS ABEBA UNIVERSITY SCHOOL OF GRADUATE STUDIES

EXPERIMENTAL STUDY ON THE USE OF PLASTIC STABILIZED HYDRA FORM BLOCKS AS AN ALTERNATIVE WALLING MATERIAL

HABEN LEMMA BIRARA

OCTOBER 2023,

ADDIS ABEBA, ETHIOPIA

Approved by board of adjudication

ASS. PROF. MESKEREM ZEWDIE __________________ ______________

Advisor Signature Date

ASS. PROF. LEULE MEBRATIE __________________ ______________

Internal examiner Signature Date

ASS. PROF. ASREGIDEW KASSA __________________ ______________

External examiner Signature Date

ASS. PROF. DAGNACHEW ADUGNA __________________ ______________

Chairperson Signature Date

ASS. PROF. DAGNACHEW ADUGNA __________________ ______________

Post graduate program director Signature Date

DECLARATION

I declare that this research is an original work that previously haven't been submitted to any degree or diploma programs. The materials and sources used in this research have been properly cited and acknowledged to the best of my knowledge.

SIGNATURE: ______________________

ACKNOWLEDGEMENTS

First and foremost, I give thanks to the Lord God Almighty for giving me the strength and grace to complete my thesis work. It gives me great pleasure to thank Dr. Meskerem Zewedie, one of my thesis advisers, for her helpful collaboration, ongoing support, and insightful comments during the development of my thesis.

Additionally, I would like to thank Dr. Alazar Assefa for giving me the drive and guidance I needed to complete my thesis. I also want to express my gratitude to Selam Technical and Vocational Center for providing me with the research center facilities, priceless resources, and technical support that were absolutely necessary for my work.

Finally, I would want to express my gratitude to all of my family and friends for their wonderful support and inspiration.

ABSTRACT

Cement is a common stabilizer used in the production of hydra form blocks (HFBs), but limited studies has been done to use plastic as a replacement for cement. This study is intended to investigate the technical and cost of plastic stabilized hydra form blocks to use as an alternative wall-making material. The results of laboratory tests on the soil utilized for the research demonstrated the soil's appropriateness for block manufacturing by providing thorough information on the soil's plasticity, grading, and chemical composition. The investigation has revealed that blocks produced at varying total stabilizer contents from 50% in increments up to 80% at constant compressive pressure, the blocks stabilized with 70% plastic have an increased 28th-day compressive strength than that of the blocks stabilized with cement only. The water absorption of the blocks stabilized with plastic is lower than that of the blocks stabilized with cement. An increment of compaction pressure with the same stabilizer content has shown an increased compressive strength. Two types of plastic material were used in this research, Polyethylene (PE) and the other type is Polyethylene Terephthalate (PET). The cost of hydra-form blocks stabilized with cement is higher than the plastic stabilized hydra-form blocks since the current price of cement is higher than that of plastic material. The cost comparison with the cement-stabilized hydra form has revealed that PHFBs are preferred because it is an economical walling material and permits the use of economical building techniques. This experimental study on PHFBs prepared using plastic as a total replacement to cement has demonstrated the effectiveness of plastic material in enhancing the 7th, 14th , and 28th-day compressive strength than using cement alone. The research findings indicate the need to review the grading of the number and quality of stabilizers to produce high-quality building blocks. It is also advised that hydraulic machinery be used to strengthen the material and reduce air voids by compaction pressure. The experimental research result concludes that it is possible to produce plastic stabilized hydra form blocks using Kara soil to fulfill the compressive strength, which uses no cement, contributes sustainable activity by recycling plastic material, and is adaptable to the environment as walling material for low-cost housing.

Key Words: Hydra form blocks, Polyethylene Terephthalate (PET), Polyethylene (PE), Soil stabilization, Material property.

Table of Contents

DECLARATION iii

ACKNOWLEDGEMENTS iv

ABSTRACT v

Table of Contents vi

List of Tables xi

List of Figures xii

CHAPTER ONE: INTRODUCTION 14

1.1. Background 14

1.2 Problem Statement 15

1.3. Research Questions 16

1.4 Objectives 16

1.5 Scope of the study 17

1.6 Limitation of the study 17

1.7 Significance of the study 17

CHAPTER TWO: LITERATURE REVIEW 19

2.1. Introduction 19

2.2. Soil 19

2.3. Traditional housing construction in Ethiopia 21

2.4. Practices and Application of Soil as a walling material 22

2.4.1. Rammed earth 22

2.4.2. Adobe Blocks 23

2.4.3. Cob 23

2.4.4. Compressed Stabilized Soil Flooring Material 24

2.4.5. Compressed soil blocks (Hydra form) 24

2.5. Compressed Soil blocks (Hydra form) 24

2.6. Advantages and Limitations of Hydra Form Blocks 26

2.7. Soil Property 27
2.7.1. Compressive strength 27
2.7.2. Density and Thermal Properties 28
2.7.3 Moisture contents 28
2.7.4 Durability, Maintenance, and Appearance 29
2.8. Code of practices used for Hydra form blocks 29
2.8.1. General Properties 30
2.8.2. Soil classification 30
2.8.3. Soil Particles 31
2.8.4. Atterberg Limits 32
2.9. Soil Selection 33
2.9.1. Soil 33
2.9.2. Topsoil 34
2.9.3. Clay soil 34
2.9.4. Soil Plasticity 34
2.10. Soil Stabilization 34
2.10.1. Background 34
2.10.2. Mechanical Stabilization 35
2.10.3. Physical stabilization 35
2.10.4. Chemical Stabilization 36
2.10.5. Gypsum stabilization 36
2.10.6. Pozzolanas stabilization 36
2.10.7. Sodium Silicate Stabilization 36
2.10.8. Lime stabilization 36
2.10.9. Bituminous Stabilization 37
2.10.10. Cement Stabilization 37
2.10.11. Plastic stabilization 38
2.11. Why Plastic Material 39
2.12. Plastic Pollution 39
2.12.1. Plastic Pollution in Ethiopia 40

The low moisture barrier of polypropylene (PP) is a result of its high coefficient of thermal expansion, which restricts its use in high temperature environments. 44
• Profound flammability 44
• Bonding property is poor. 44
PE and PET plastic materials are chosen for the experimental investigation after data on the physical characteristics, benefits, and drawbacks of each type of plastic has been gathered.2.14. Main Constituent Material Used for Plastic stabilized Hydra form blocks 44
2.14.1. Plastic Material for Binding the Soil Particles 44
2.14.2. Characterization of Soil for Hydra from Block Production 45
2.15. Previous Studies 45
2.16. Current Application of Plastic stabilized blocks 46
2.17. Local Studies and efforts on soil blocks in Ethiopia 51
2.17.1. Selam Technical and Vocational Center Addis Ababa 51
2.18. Summary of literature review and gap identification 53
2.18.1. Summary of literature review 53
2.18.2. Gap identification 54
CHAPTER THREE:PROPERTIES OF MATERIAL, MIX PROPORTION, AND TEST 55
3.1. Introduction 55
3.2. Methodological Approach 55
3.4. Properties of Materials 55
3.4.1. Soil 55
3.4.2. Plastic Material 57
3.5. Mix Proportion 58
3.6 Specimen preparation 59
3.6.1 Pulverization 59
3.6.2 Screening 59
3.6.3. Mould Preparation 59
3.6.4. Mix Proportion 60
3.7 Tests on Blocks 60
3.8 Compressive strength 61

3.10 Water Absorption ... 61

CHAPTER FOUR: LABORATORY TEST AND DISCUSSION ON SOIL SUITABILITY FOR MAKING THE HYDRA FORM BLOCKS ... 62

4.1. Introduction ... 62

4.2. Laboratory Test Result on Soil Sample ... 62

I. Particle Size Distribution ... 63

II. Atterberg's Limit ... 64

III. Soil Compaction Test ... 66

IV. Chemical Analysis ... 67

CHAPTER FIVE: TEST RESULT AND DISCUSSION ON THE PRODUCTION OF HYDRA FORM BLOCKS ... 68

5.1 Introduction ... 68

5.2. Compressive Strength Test ... 68

5.3. Effects of Plastic on the Compressive Strength ... 68

5.4. Water Absorption ... 70

5.4.1 Water Absorption Test Result for Plastic Stabilized Hydra Form Blocks ... 71

5.5. Summary ... 72

CHAPTER SIX: PRODUCTION COST ... 73

6.1. Production Cost of Hydra form blocks ... 73

6.2. Factors that affect the price of producing hydra form ... 73

6.3. Unit Price ... 75

6.5. Cost Comparison between Cement stabilized and plastic stabilized Hydra forms ... 78

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATIONS ... 79

7.1. Conclusion ... 79

7.2. Recommendation ... 80

BIBLIOGRAPHY ... 81

APPENDIX A ... 86

APPENDIX B 99

APPENDIX C 102

APPENDIX D 103

APPENDIX E 104

APPENDIX F 105

APPENDIX G 106

APPENDIX H 107

APPENDIX I 108

APPENDIX J 110

APPENDIX K 112

List of Tables

TABLE 2.1 Soil classification. ……………………….……………..……………......................30

TABLE 2.2 Table of summery ……………………………………………….....................48

TABLE 3.1 Physical properties of soil…………...54

TABLE 3.2 Chemical composition of soil…….……...54

TABLE 3.3 Physical properties of PET (Polyethylene terephthalate) 55

TABLE 3.5 Mix Proportion …………...……………………….…………………………….…56

TABLE 4.1 Atterberg’s limit test results of soil used in the study…………….…………………..63

TABLES 5.1 Mean Compressive Result………………...………………………………..67

TABLE 6.1 Factors affecting Unit Cost……………………..………………………………73

TABLE 6-2 Unit Cost of a block with 70% Plastic stabilized …………..……..……..……...74

TABLE 6-3 Unit Cost of a block with cement stabilized ………………...…………………75

List of Figures

FIGURE 2.1 The tombs of Ramasseum and Great Sphinx. 20
FIGURE 2.2 Mud housing in Northwest Ethiopia 22
FIGURE 2-3 Cinvaram, the first press for compressed earth blocks 26
FIGURE 2.1 Curves for grain size distribution in (AASHTO) soil classification 32
FIGURE 2.2 The Atterberg limits (Das, Ch.3)... 33
FIGURE 2.4 Plastic stabilized Pavement bricks in India 47
FIGURE 2.5 Plastic Pavement blocks in Kenya 48
FIGURE 2.6 Hydra form blocks from Selam vocational school 52
FIGURE 2.7 Conceptual Frame work 19
FIGURE 3.1 Mould Preparation.. 60
FIGURE 4.1 Distribution of Particle size in the soil used.. 63
FIGURE 4.2 Particle size distribution of the test soil seen on the texture diagram. 64
FIGURE 4.3 Soil Plasticity chart.. 65
FIGURE 4.4 Proctor compaction curve test for Kara Soil 66
FIGURE 5.3 Effects of Compaction Pressure on compressive strength with plastic content....... 69
FIGURE 5.4 Effects of Plastic stabilizer in the water absorption property of Hydra form Blocks 72

Abbreviations

AA	Addis Ababa
EBCS	Ethiopian Building Code Standards
HDPE	High-Density Polyethylene
HFB	Hydra Form Blocks
LDPE	Low-density polyethylene
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PET	Polyethylene Terephthalate
PHFB	Plastic Hydra form Blocks
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
SPI	Society of Plastic Industry
TCQ	Time, Cost, and Quality
UCS	Unconfined Compression Strength

Chapter One - Introduction

1.1. Background

Shelter is one of the most essential needs of human life and plays an essential role in creating a sense of belongingness, reduction of vulnerability, and building resilience. Housing refers to a safe physical space with socially, and economically acceptable viable living environments. (UN-Habitat, 2021) In developing nations, most of the population are without adequate housing facilities. (MoFED, 2006)

According to a 2007 identified World Bank report on 152 developing countries, one in three people is without adequate shelter. To address these issues, stakeholders should focus on the provision of low-cost, long-lasting, and technologically advanced materials. While also recognizing the importance of providing adequate shelter for all, access to basic services, safe and healthier shelter is essential to physical, socioeconomic, and psychological well-being, as well as helping to reduce statistics. (World Bank, 2007)

According to (World Bank, 2015), Housing informality is the result of both economic factors that limit household and commercial investment in housing, which limit the production of affordable housing units at a scale to meet needs. Due to a discrepancy between the cost of an affordable housing unit and households' capacity to pay for it, formal housing makes up a very small portion of housing production and consumption in Sub-Saharan Africa, in contrast to developed economies where formality is the norm in both supply and demand. In order to solve the shortage, more efforts are being made to provide more serviceable, cost-effective, energy-efficient sustainable soil construction materials such as, interlocking soil blocks, adobe blocks and sun-dried soil blocks. (Tadege, 2007)

Housing is a major problem in Ethiopian context. The obstacle to the economic development of Ethiopia is related to the access to adequate and affordable housing for the urban poor. Even the existing housing units are categorized as slums due to poor standards, lack of basic services, sanitation, and infrastructure problems (Habtemariam Molla, 2012). In the scheme of poverty reduction providing adequate housing for low and middle-income groups is the major component of urban development. (Ayele, 2001)

The housing situation is the manifestation of demographic factors related to urbanization. An increase in population rate and migration towards urban areas creates overcrowding and squatter settlements. Inadequate housing production has become a distinctive characteristic of most cities. In addition, the extent of such housing problems varies from one urban area to the other due to various constraints like unsafe living condition, sanitation, high density, and insecurity that are common in such urban areas (UN-2 NUN-Habitat, 2008).

According to (Tadege, 2007), there is a need to provide a sustainable low-cost dwelling for the community. It's significantly important to use existing technologies and easily implement them with available resources in different regions.

Hydra form blocks are among these technologies (Baba Shehu Waziri, 2013). In this research, Hydra form blocks (HFB) are considered as an alternative walling material. Stabilizers play a vital role in the production of Hydra form blocks (HFB) so as to provide adequate compressive strength and durability (Ahmed, 2015). As a result, this experimental study on HFB will be performed by using plastic stabilization as a full replacement for cement to stabilize the blocks based on cost and material property efficiency value.

1.2 Problem Statement

Construction industries are among the fastest-growing industries in the world. In addition to the rapid population growth in our context, the sector is working towards facilitating housing needs. However, this mainly affects the low-income group of the community, as it is the least affordable. The unbalanced gap between the demand and supply is the factor for the upsurge in the sector. Due to this, individual households take responsibility for constructing residential units.

For low-income group who wish to build their own homes on time and at a reasonable cost, delivering housing using traditional construction materials is a difficult undertaking. In this regard, creating technologically advanced, affordable housing construction materials and systems for the low-income group is a key responsibility for Ethiopian builders and policymakers.

Literature suggests that upgrading locally available construction materials will help to reduce costs. Mud/soil is among the widely used locally available walling material in Ethiopia. Among the various soil construction types, Hydra form blocks (HFB) are one of preferable and more practical than the others in our context due to the ease of construction, cost reduction related to labor, availability in the market, and easily recyclable as an alternative walling material.

Numerous kinds of research have been carried out in Ethiopia regarding the use of Hydra form Blocks (HFB) as an alternative walling material using various stabilization methods like cement, lime, bituminous, electrical, mechanical, chemical, thermal, as well as grouting via fabric and geotextile. Yet the problem didn't get utterly eradicated due to the high cost of stabilizations used in the production of these mud blocks. Recently, researchers have introduced an innovative way of soil stabilization using plastic waste material, which also reduces the cost of stabilization at a large rate and simultaneously solves problems regarding poor and improper plastic waste recycling systems.

Thus, this research aim is to deliver locally available walling material made of soil using plastic stabilization. This research is a start-up that seeks to explore an empirical investigation and fill the gap. The research is expected to create a doorway for other researchers through the engagement of experimental research methodology. The research's main aim is to use plastic stabilization as a full replacement for cement in the production of Hydra form blocks (HFB) based on cost and material property.

1.3. Research Questions

1. To what extent does using plastic stabilization improve the material properties of Hydra form blocks (HFB)?
2. How much can the cost of producing Hydra form blocks (HFB) be decreased by using a plastic stabilizer instead of cement?

1.4 Objectives

1.4.1. General Objective

The general objective of the research is to assess the influencing factors affecting the use of hydra form blocks (HFB) as an alternative walling material while studying its suitability using plastic stabilization considering the cost and material properties as a major pillar of the study.

1.4.2. Specific Objective

- To establish an experimental setup in assessing plastic stabilization capacity (specifically the material property of Hydra from blocks.)
- To compare the cost between cement-stabilized and plastic-stabilized hydra form blocks (PSHB).

1.5 Scope of the study

The spatial scope of the study will be undertaken in a specific location in Addis Ababa Selam Technical School, using a specific soil type (Kara soil) whereas the assessment will include the cost and physical property of the material with the production of a prototype. In general, this study will discuss performance of the material regarding the material property and economic viability as an alternative walling material. This research will not cover other wall construction materials.

The thematical scope of this study focuses on the production of stabilized blocks using plastic in a controlled environment through an experimental study. The study will undertake an empirical investigation mainly based on international investigation and explanations on the production of stabilized blocks using plastic stabilizations as well as justify the explanations through the production of prototypes based on an iterative and parallel experiment. The experimental investigation will cover mechanical properties such as compressive strength and water absorption properties.

1.6 Limitation of the study

Since the study will be taken on a specific area, it has its own unique characteristics related to contexts, geographical location, socio-economic, cultural, and other demographics that the study may not lead to generalization for other cities. Furthermore, this research has additional limitations like time constraints for data collection, and budget constraints to undertake the study.

1.7 Significance of the study

This research focuses on alternative -affordable walling materials using locally available materials. Thus, the research has significance for various groups. Among these groups, the research significance is for the University by aiming to build sturdy knowledge using existing literature as well as realistic findings and identifications of factors that influence the affordability of urban housing in the particular study area.

The other significance of the research is for the end-users mainly for the low-income groups of the community through the provision of durable, cost-effective, and environmental-friendly materials as well as change the perspective towards locally available materials in the use of constructing dwelling units and developing the proper valuation of their land.

Additionally, this research will activate the housing sectors through the use of locally available materials and lead local, national, and non-governmental organizations to intervene and take measures in the promotion of the material. Also, professionals like designers, contractors, and others will benefit and get the chance to work with new affordable materials which can make a big difference in the total construction cost and in the creation of aesthetics.

Lastly, the significance is to the policymakers to consider the material as durable, cost-effective, environmentally friendly, and get the chance to develop the policy accordingly. The purpose of this research to develop a prototype in Addis Ababa is because of the availability of construction materials and the strong habit of unpleasant way of plastic bottle disposal.

Chapter Two: Literature Review

2.1. Introduction

Building material choice is an important criterion that plays a vital role in the determination of the quality, strength, and cost of the construction. The history of housing development facilities reveals the evolution of technologies through our ages. Formerly materials like stone, earth, logs, as well as grass, had been used in their crude form. Later on, as the technologies get advanced, the crude started to blend with other refined materials made for different purposes (Adam, 2001).

Soil is the most popular construction material that had been used for many centuries. Due to the flourishment of technologies efforts have been made to increase the performance of the earth as a building material. Hydra-form blocks are one of the advanced forms of earth construction. (H.B. Nagaraja, 2013). Hence, this chapter is dedicated to discussing the main constituent material property, characteristics, and factors affecting each component in the production of Hydra form blocks. It also gives further information on how the blocks stabilized (Tekle, 2018).

2.2. Soil

The term "soil" refers to an organic substance or mineral found on the surface of the earth that has been exposed to and demonstrates the impacts of macro and microscopic organisms, conditioned by relief, working on parent material over time. A product, like soil, can be distinguished from its original material in a variety of physical, chemical, biological, and morphological ways (Staff, 2017).

2.2.1. Soil as a construction material

Various literature points out that earth has been used as a construction material for over 9000 years from the early Mesopotamian civilization and remained popular construction material throughout history. Throughout the journey as a construction material, it encompasses several progresses like the sundried adobe blocks, cob construction, rammed earth, wattle, and daub, earth sheltering, and Hydra form blocks (H.B. Nagaraja, 2013).

There are numerous historical monuments that can be cited as an example of earth construction among these are the temples in Egypt, the great wall of China, the Potala Palace of Tibet, the citadel of bam in Iran, etc (Habtemariam Molla, 2012). Figure 2.1 below shows one of the ancient tombs made of soil, it is the great Sphinx and the tombs of Ramasseum, found in Egypt.

Figure 2.1- The tombs of Ramasseum and Great Sphinx.

Picture Source

https://www.google.com/search?q=The+tombs+of+Ramasseum+and+Great+Sphinx&sxsrf=APwXEdcKBAVcRKx_IKtn5TGhXREl05RTZQ:1681893463205&source=lnms&tbm=isch&sa=X&ved=2ahUKEwiulbKzxbXAhUElGoFHYEzC7oQ_AUoAXoECAEQAw#imgrc=8s8bZZWDsMPN6M

Soil is abundantly available and has invariably been the main ingredient for housing construction. It offers numerous benefits regarding lower embodied energy, high thermal mass as well as increased use of locally available materials. However, it's vulnerable to moisture and eroded easily. It is composed of both macroscopic and microscopic discrete particles, which are not strongly bonded yet the addition of stabilizers like cement, lime, bituminous materials, and others stabilize soil to a varying degree (Tekle, 2018).

In developing nations like Ethiopia, earth construction had been the most effective material for building construction which shows a promising result for an economical solution in the sector.

Dreadful defects in addition to unpleasing appearance leads people to consider soil as a low-grade material. The knowledge regarding modern techniques of soil in our context is poorly interpreted in a way to discourage the community and lead them to consider soil construction is not sustainable and can cause harm to the natural environment. Instead, this encourages society to use modern construction materials like concrete (Ahmed, 2015).

2.3. Traditional housing construction in Ethiopia

Soil has been widely used for various years as a major construction material in Ethiopia. The soil was extensively used as a walling material all over the country, especially in the central, northeast, northwest, and southeastern rift valley areas of the country. The walling material is traditionally known as ‘‘Chika’’ which is a mixture of clay, water, and fine and short straws. After thoroughly mixing these constituents using human treading with the help of barefoot let the mix stay a little while or use it immediately then use it as plaster or clad on the erected wooden poles (Yazew, 2015).

These traditional techniques adopt serious defects, which cause extended cracks and dreadful defects that weaken the walls. Such walls are easily eroded during the rainy seasons. The traditional measure in order to avoid this was to coat the mud walls using animal dung which serves as a wearing surface. This requires consistent maintenance and renewal every year. The withdrawal of such techniques leads the walls to become deteriorated, unpleasing as well as appear with dreadful defects. This led most people to the misconception that walls using soil appear to be of poor quality and unfit for walling material (Tadege, 2007).

Figure 2.2- Mud housing in Northwest Ethiopia

Picture Source: https://newlifeethiopia.org/2011/03/18/home-improvements/?doing_wp_cron=1681896076.5028650760650634765625

In Addition, for the traditional techniques, lots of wood are required for the construction of the pillars of the walls which is highly practiced in forest areas. This habit affects forestry as well as plays a vital role in the promotion and acceleration of deforestation. Recently deforestation is a major issue in Ethiopia which leads to land degradation and is considered unsustainable activity (Habtemariam Molla, 2012). In Ethiopia, various types of soil construction are being practiced as a walling material among these are Rammed earth, adobe blocks, compressed blocks of soil, and cob.

2.4. Practices and Application of Soil as a walling material

2.4.1. Rammed earth

Rammed earth is an ancient construction technique used as walling, foundation, and flooring using natural materials. It consists of moist subsoil compacted in a shuttering layer. Sometimes coarser soils are sieved to eliminate larger aggregates. The construction technique takes place between heavy wooden forms. Once the shorter section of the wall Is completed then the forms are moved along or upwards for the construction of the other walls. This activity will be repeated until the construction is completed. The process may be done using pneumatic tampers or using hands. The soil has to be rammed until it becomes firm and dense. The exact composition of the soil and water is the most critical part of the construction technique (Tekle, 2018).

A well-made rammed earth wall is among the most durable kind of walls, some even lasted for centuries but it’s not easy to construct, especially the heavy wooden forms that consume time, are not cost-effective as well as need skilled masons to build the whole construction (A.G.Kerali, 2000).

2.4.2. Adobe Blocks

Adobe blocks are among the oldest and most popular forms of wall construction techniques. They are also known as dried mud walls. The blocks are made through a mixture of clay soil, and water /fiber with a mud-like consistency and place all the mix into boxes. These boxes are removed in a shorter period of time after casting the mix and allow the adobe blocks to cure for about 30 days (Geyer, 2017).

In the construction of openings using Adobe Blocks, walls are raised and loadbearing elements are inserted directly into the mud walls. Adobe bocks are advantageous due to their simplest construction method, ability to carry significant loads as well as it can be built with the least number of masons. Though adobes are used for a maximum of two-story buildings 10 story building is built in Yemen using this material (Jean-Claude Morel, 2007).

Yet adobe blocks also have disadvantages during casting minor shrinkage might occur that gives the material a rough looking and also adobe blocks are not suited for rainy climatic zones. These factors are considered shortcomings of the material (A.G.Kerali, 2000).

2.4.3. Cob

In the construction of cob, stiff mud is molded into balls on a larger scale and piled the balls in a thicker layer to form walls without any kind of formworks. Thus, the mud must be durable and stiff enough to prevent any kind of collapse. If any slumping or dispersion occurs the mud will be put back in place then sliced off and placed back into the top. In order to avoid such activity, the construction process takes place slowly and lets each layer harden slowly without any scaffolding. Cob walling is easy to construct using less construction equipment. However, serious defects like cracks, shrinkage, and slumping occur in the walls and this is a disadvantage of cob as a walling material (Yazew, 2015).

2.4.4. Compressed Stabilized Soil Flooring Material

In most landscapes pathways are necessary and create an easy route to walk around and move equipment. The materials used for pathways vary from concrete to crushed rock. Mostly concrete is used for such pavements which are formal type and most expensive (Yazew, 2015). Recently stabilized soil types of pavement s are used in most African countries, these pavement materials are durable and used for steep slopes and are surprisingly cost-effective. Nowadays plastic stabilized soil pavements are getting familiar (Baba Shehu Waziri, 2013).

2.4.5. Compressed soil blocks (Hydra form)

Numerous types of research have been conducted in modern times to make soil a sustainable construction material, these studies led to the development of soil in the form of rammed earth known as compressed soil blocks (Afkari, 2010). Compressed soil blocks are descendent forms of adobe blocks. The idea of compressing the soil is adopted from the adobe blocks in order to improve the quality and performance of the soil. Thus, blocks are introduced in standardized sizes (Adam, 2001). The block might take place in small drying and storage spaces. The finished products are ideally suited to skills that really facilitate the transfer of the production technique to wide application (Tadege, 2007).

2.5. Compressed Soil blocks (Hydra form)

2.5.1. Historical Background

Soil is the most popular construction material used for centuries. In many ancient cities of the world soil as a construction material was entertained like on the shores of the Nile in Egypt, the Andes mountains in Peru, the fertile valley of China, and other ancient places of the world where the soil was widely used as a construction material. The oldest soil construction is in Egypt which was built around 1300 BC, and the vaults of Ramasseum, in Thebes. These constructions were using adobe blocks, the sun-dried mud bricks (Baba Shehu Waziri, 2013).

In traditional methods of construction, soil blocks are molded by hand and use reinforcing mechanisms like adding straws and sun-dried the material. The wall finishes of these blocks are using mud renders. The walls require annual maintenance using new mud layer plastering, especially in the area of higher rainfall Like the adobe blocks the traditional technique of wall construction uses the combination of soil, sand, clay, animal dung, and straw daubed as well as wattle by hand with a sticky material in the erected load-bearing wooden frames with wall panels in between the two frames (Rob. F, 2012).

The first attempt at the production of compressed soil blocks is in the 19^{th} century in France, Francois Cointeraux invent the idea of the machine and fervent advocate, he was inspired by the winepress, but the machine was not practical till the beginning of the 20^{th} century, then the first mechanical presses were designed using heavy lids forced down into molds. some type of machine was motor-driven. The brick industry starts to use static compression presses in which the soil is compressed in between two converging plates (Humphrey Danso, 2015). The turning point of the machine came up with Hydra form blocks which are widely used for architectural purposes came after the invention of the machine CINVA-RAM press which was designed by engineer Raul Ramirez in Bogota, Columbia. The machine becomes a new generation tool in the 1970s and 1980s. The machine was mechanical and motor-driven, which recently leads to the mass production of the material in the market for wide use as a walling material (Rigassi, 1985).

Wooden frames are used instead of hand to mold the soil, the soil is formed through compression in a steel press. When compared to the traditional hand mold the blocks are very regular in size, shape, and also the change in the material property which is denser, with better resistance to compressive strength and water absorption as shown in the picture below. Compressed soil blocks have architectural benefits like being aesthetically pleasing as they are cost-efficient, fire-resistant, durable, soundproof, and have better strength which makes the material provide architectural freedom available from raw materials (Morton, 2001).

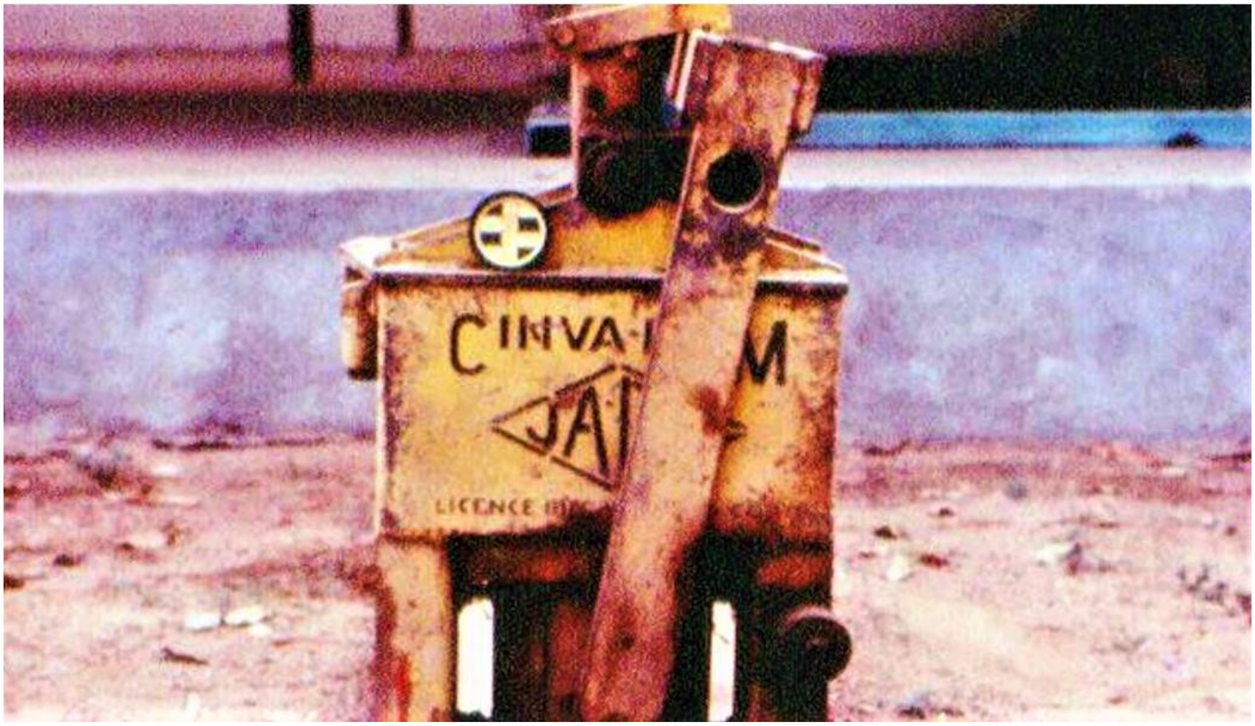


Figure 2-3: Civaram, the first press for compressed earth blocks

Picture source: https://www.earth-auroville.com/compressed_stabilised_earth_block_en.php

Soil has been the major building material from the earliest times to recent days and we can find various evidence of this fact from all around the world. The invention and vast use of concrete and steel suppressed the use of soil in the construction industry. Yet the re-awaking of the use of this traditional building material in both the developed and developing countries revise the use of soil as the oldest sustainable construction material. Thus, the soil has a worldwide tendency to achieve economy in the final cost of a building (Spon.E.&F.N. Ltd, 1985).

2.6. Advantages and Limitations of Hydra Form Blocks

2.6.1. Advantages

As Auro ville Earth Institute (AEI) reports on the advantages of interlocking mud blocks (Ahmed, 2015).

- Environmentally friendly material
- Easy to use

- Affordable and decrease mortar costs while making
- Sustainable
- Eco-friendly
- Aesthetically pleasing
- Reusable
- Easily available
- Time efficiency
- Good thermal behavior and sound absorbent
- Structurally durable for 2 story buildings
- Resist water pressure when using it for water tanks and sanitation.

2.6.2. Limitations

The major drawback of this material is the gap in between the blocks since there is no use of mortar or plasterwork while connecting blocks the gap will allow (Ahmed, 2015).

- Airflow into the internal spaces is difficult at night time.
- Insects to hide inside it.
- Rainwater might penetrate through the walls during the rainy seasons.
- The rain will deteriorate the structure over time.
- Weather variation will also change the color of the blocks.

2.7. Soil Property

2.7.1. Compressive strength

The compressive strength of Hydra form blocks (the amount of pressure they can withstand before collapsing) is determined by the soil type, stabilizer type and amount, compaction pressure, and curing conditions employed during the block-making process. Maximum strength is achieved through the blending of appropriate ingredients, as well as proper compacting and curing. Several minimum 28-day wet compressive strength values, all above 1.0MPa, have been recommended; some of the recommendations for the minimum compressive strength of Hydra form blocks made by different compressions include 1MPa, 1.4MPa, from 1.4 to 2MPa, and 2MPa (Ahmed, 2015).

In practice, Hydra form building blocks may have wet compressive strengths of less than 4MPa. Its strength makes it ideal for a variety of construction projects. It also competes favorably with British Standard standards of 2.8 MPa for precast concrete masonry units and load-bearing fired clay blocks, and 5.2 MPa for bricks. The loads that the building or its walls could sustain were minimal, as the compressive strength of 1 to 4 MPa was suitable for the structure, allowing for many building regulations around the world (Adam, 2001).

2.7.2. Density and Thermal Properties

Hydra form blocks are often denser than aerated and lightweight concrete blocks, for example. While having densities that range from clay to calcium silicate to concrete bricks, When Hydra form blocks are manufactured at or near the construction site, their high density may be regarded as a negative due to their dead weight on the structure and when the blocks must be carried over large distances; nevertheless, it is of little significance. Hydra form blocks with a lower density perform better as thermal insulators than those with a higher density. This is especially beneficial in hot, arid settings, where severe temperatures can be mitigated inside hydra form block structures (Adam, 2001).

2.7.3 Moisture contents

When utilized for wall construction, building materials with a high porosity may expand slightly in both wet and dry situations. Building cracking and other flaws may emerge from such motions. The expansion of interlocking mud bricks varies depending on the soil qualities; certain soils expand or shrink more than others. This expansion will be reduced by adding a stabilizer. In general, however, constructions made of hydra form blocks may move more than those made of other materials. However, proper block manufacturing and construction processes will limit mobility (Civeira, 2019).

Moisture movement is expressed as a proportion of total volume. It's worth noting that when two materials with distinct movement qualities are employed in construction, moisture movement becomes even more significant. Differential movement causes stress, which can cause the materials to separate or create severe damage. Because of their distinct expansion qualities, cement renderings frequently tear off earth walls or hydra form blocks (Civeira, 2019).

2.7.4 Durability, Maintenance, and Appearance

For fair-faced walling, identical-sized blocks of sufficient, decent quality and shape with a high-quality finish can be utilized. Their appearance is determined by soil color, particle size, and compaction level. External or even internal rendering should be unnecessary with high-quality blocks. On limit solar gain, a whitewash finish placed directly to the blocks as a render coat could be employed (Civeira, 2019).

Interlocking mud blocks, like other types of blocks and bricks, would require suitable steel reinforcement if utilized in places prone to earthquakes, cyclones, and other natural disasters. Interlocking mud blocks are not particularly vulnerable to termites, bacteria, fungi, or fire. However, organic matter in the soil may compromise the structure (Tadege, 2007).

2.8. Code of practices used for Hydra form blocks

There are various standards and guidelines related to compressed earth blocks and construction techniques using earth as a building material. Some widely recognized standards in this field include,

American Association of State Highway and Transportation Officials (AASHTO)

The American Association of State Highway and Transportation Officials (AASHTO) system, also known as the AASHTO Classification System, is a method used in the United States to classify and categorize highways based on their functional and design characteristics. It is widely used by transportation agencies and engineers for planning, design, and maintenance purposes (AASHTO, 2001).

American Society for Testing and Materials (ASTM)

ASTM's masonry standards are instrumental in specifying, testing, and evaluating the basic units and materials used in masonry construction. These standards cover multiple materials, systems and products to encourage consistency and safety among manufacturers (ASTM Standards, 2008).

African Regional Standards (ARS)

ARS standard is to define the standards terms applying to compressed earth block technology in African countries. This code of practice applied to all manufacturing enterprises except in locations where earthquakes, severe floods, or cyclones occurred, necessitating the employment of proper management measures (CDI, 1996).

British Standard (BS)

British Standard is a standard published by the British Standards Institution (BSI) that pertains to methods of test for soils for civil engineering purposes. This particular part of the standard focuses on the laboratory test procedures for determining the classification and compaction characteristics of soils (BSI, 2016).

2.8.1. General Properties

Physical qualities are more important for manufacturing Hydra form blocks since they affect mixing, forming, and de-molding, as well as the porosity, permeability shrinkage, dry strength, and an apparent bulk density. In order to make compressed stabilized soil blocks, it is necessary to control or monitor the clay fraction. Too much clay causes unacceptably high expansion when wet, necessitating the use of extra cement to compensate. Too little clay promotes low particle adhesion, resulting in high breakage rates when the compressed stabilized soil block is de-molded (Afkari, 2010).

The basic material needed to make compressed stabilized earth building blocks, on the other hand, is soil with a minimum amount of silt and clay to aid cohesiveness. Chemical properties can also be interesting, especially when a chemical additive is applied. The composition, mineral concentration, metallic oxides, PH levels, and sulfates in the soil are all chemical features (Civeira, 2019).

2.8.2. Soil classification

The classification of soil is the initial step in its identification. Knowing what kind of soil, you have and what features it has will help you get the most out of it when making Hydra form blocks. Soil classification can be done on soil particles smaller than 6mm in diameter, according to the literature (Head, 1980).

Soils are classified according to their use, origin, size, texture, color, and density, among other factors. A particle size distribution analysis and a plasticity index can both be used to characterize soil for building purposes. Engineers have utilized two different soil classification schemes that are based on particle distributions and Atterberg limits. These major classifications are, (Head, 1980).

- Unified Soil Classification System (Preferred by Geotechnical Engineers).
- American Association of State Highway and Transportation Officials (AASHTO) system.

2.8.3. Soil Particles

Disintegrated rock, degraded organic matter, and soluble mineral salts make up all soils. A technique of categorization extensively used in civil engineering is used to grade soil types according to particle size. Texture classifications that are important the size ranges shown below are based on the Unified Soil Classification system (Head, 1980).

Table 2.1 Soil classification according to particle size distribution (BS 1377 Part 2 1990; ILO, 1987).

Name	Sub-division	Max. Size in Diameter in (mm)	Min. Size in Diameter in (mm)
Clay	-		<0.002
Sand	Coarse	2	0.6
	Medium	0.6	0.2
	Fine	0.2	0.06
Gravel	Coarse	60	20
	Medium	20	6
	Fine	6	2
Silt	Coarse	0.06	0.02
	Medium	0.02	0.006
	Fine	0.006	0.002

Furthermore, coarse-textured soils like gravel and sand can be categorized as coarse, whereas fine-textured soils like silt and clay can be classified as fine. A mechanical grain examination of soil is depicted in the Figure 2.1. (AASHTO).

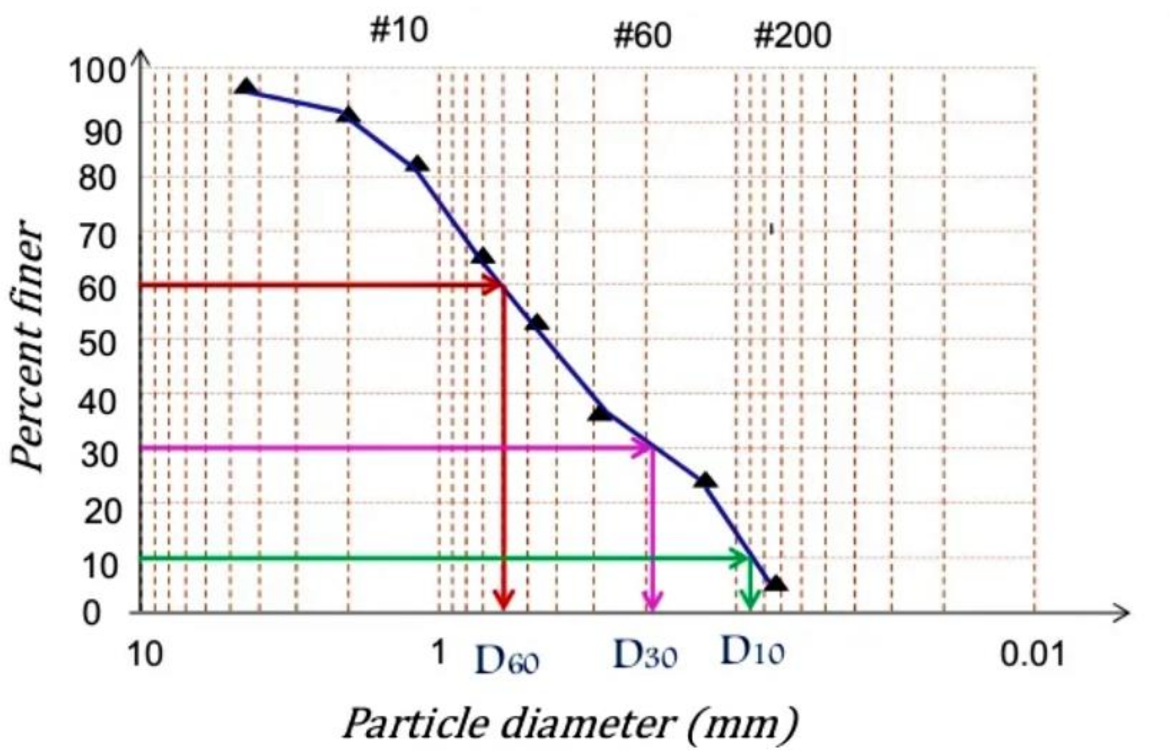


Figure 2.1. Curves for grain size distribution in (AASHTO) soil classification

2.8.4. Atterberg Limits

The analysis that compares the liquid limit and plastic limit tests is known as the Atterberg limit analysis. These restrictions were developed by Swedish soil scientist Albert Atterberg in 1911 with the intention of observing and quantifying the different important changes in fine-grained soils based on their water content (B. P. Kagonbé, 2021). The graph below displays the consistency of soils based on Atterberg limits. The following graphic depicts the consistency of soils according to Atterberg limits (Bashir,2015).

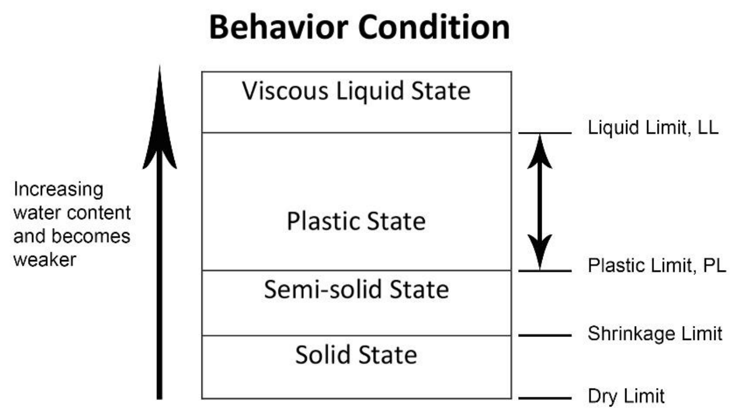


Figure 2.2 the Atterberg limits (Das, Ch.3)

2.9. Soil Selection

To achieve desired engineering qualities, soil stabilization is typically done on soft soil types (clayey, peat, silty, and organic soils). The simplest technique to guarantee stability is to utilize fine-grained granular materials because of their enormous surface area and particle diameter. Due to its elongated and flat particle structure, clay soil has a higher surface area than other types of soil. While silty soil can be challenging to stabilize since it is generally sensitive to little moisture changes (Ahmed, 2020).

2.9.1. Soil

Sand, clay, and silt make up the majority of this material. Pure sand (which does not compress) or soil with a high clay content (>35 percent) cannot be molded into Hydra form blocks. To prevent the blocks from cracking, high-clay soils necessitate the addition of sand and a higher cement percentage. The soil must be free of organic matter and contain no dangerous amounts of salts; it should just contain enough clay to bind the blocks so that they may be handled immediately after creation without dissolving (Ahmed, 2015).

2.9.2. Topsoil

Topsoil isn't used since it always has organic matter (roots, leaves, and grass) in it, which prevents cement from setting. Borrow the topsoil away from the digging site when clearing the area to be dug (Ahmed, 2015).

2.9.3. Clay soil

This is 'plastic,' as it stretches and contracts to give the soil the 'plasticity' required for stable soil block formation and cohesiveness. When excessive clay content (>35%)'relaxes' after high compression, it causes surface cracking. The majority of these fissures are less than 1 mm deep, however, blocks built from clay-rich soils can crack clear through (Tekle, 2018).

2.9.4. Soil Plasticity

This is a complex subject that is just touched on briefly to excite your interest. The compressibility, stability, and cohesiveness of soil determine its 'plasticity,' or 'workability' (the ability to deform underweight and hold that deformation after the load has been removed). A measure of plasticity is the 'plasticity index (Assefa, 2019).

2.10. Soil Stabilization

2.10.1. Background

Soil stabilization was an ancient practice used to improve the properties of the soil for construction purposes. This trend was passed from one generation to the other without an initial understanding of the main mechanisms involved. But, since the 1920s systematic scientific approaches emerge (Spon.E.&F.N. Ltd, 1985).The need to stabilize soil is due to the appearance of the material found in its natural state which is not durable for long-term use in the construction sector. The stabilization process focuses on altering its phase structure in the interphase of soil-water-air. The main of adding stabilizers is to reduce interstitial voids, increase the bond between particles and increase the cohesion and other mechanical properties. With such an approach, the material achieves better resistance to severe exposure conditions, reduced porosity, and limited dimensional changes.

While stabilizing soil some stabilizers result in irreversible changes while the others result in reversible changes. Reversible changes occur due to the lack of resistance of soil to that of environmental agents, mostly water. This is usually eradicated by properly stabilizing the soil. Especially additional a stabilizer to a suitable binder will help the soil to retain its shape and size (Yazew, 2015).

As numerous input variables are involved the stabilization process is likely to remain a complex process. There are several soil stabilization methods that targeted the effective improvement of bonds between particles which will improve the cohesion and bonding in the soil (Habtemariam Molla, 2012).

Stabilization used around the world is divided into three main categories, these are Mechanical stabilization, physical stabilization, and chemical stabilization. Further explanations of the stabilization methods are explained in the section below.

2.10.2. Mechanical Stabilization

The process of mechanical stabilization requires tamping or compacting the soil with a heavyweight to reduce the air space volume and thus the density of the soil will increase. Compaction has two main effects on soil, is to it strengthens it and reduces its permeability. However, the type of soil utilized, the moisture content during compaction, and the compression effort exerted all have an impact on the degree of compaction that can be achieved. Mixing the right quantities of sand and clay in soil yields leads to the best results (Ahmed, 2015).

Improved compaction has a substantial impact on the sample's compressive strength as well as the effectiveness of the additional stabilizer. If a compressed stabilized soil block could be compacted to a higher density, the chemical stabilizer concentration might be lowered while maintaining the same final strength. The tradeoff is a higher energy cost in exchange for fewer chemical additions (Ahmed, 2015).

2.10.3. Physical stabilization

Physical stabilization requires changing soil characteristics by inserting missing size fractions into the particle size distribution of the soil. The texture of soil can be changed by mixing different fractions of soil particles together in a measured and controlled manner. Because the grains are closely bonded together, most of the holes that existed previous to physical stabilization are filled. A sturdy network is formed, which restricts grain movement in the soil. Unfortunately, unlike mechanical stabilization, the impact of physical stability on its own is not durable. Soil grains are easily distributed or washed away when saturated with water. Physical soil stabilization should therefore be integrated with the other procedures for a better outcome (Yazew, 2015).

2.10.4. Chemical Stabilization

The chemical stabilization requires binders to improve the material property and increase the bond between the soil particles. Chemical stabilization plays a vital role in changing the material property and the bond In between the particles through the chemical reaction of the binders. Most findings regarding the change in material properties of Interlocking mud blocks chemical stabilizations take place through various binders. These various methods are explained briefly in the below section (Makusa, 2012).

2.10.5. Gypsum stabilization

Many Mediterranean and Middle Eastern countries use gypsum as a traditional building material. Gypsum was utilized in the construction of ancient civilizations, mostly for plasters and mortars. Gypsum has an advantage over Portland cement and lime in that it requires a lower calcination temperature (approximately 1/7th that of cement and 1/5th that of lime). which is also used as a stabilizer in the production of the interlocking mud blocks (Makusa, 2012).

2.10.6. Pozzolanas stabilization

Pozzolanas are fine silica and alumina-rich minerals, when combined with hydrated lime, generate cementitious materials that can be used for stabilization and building. Pozzolanas can be found naturally as volcanic ash or pumice, or they can be created artificially (Habtemariam Molla, 2012).

2.10.7. Sodium Silicate Stabilization

Sodium silicate is used as a raw ingredient in the production of adhesives, cement, pulp and paper, detergents, and soap, among other things. Sodium silicate is also used in the construction of concrete sealants. In sandy and silty soils, sodium silicate is employed as a binding agent in amounts of roughly 5% to boost compressive strength (Makusa, 2012).

2.10.8. Lime stabilization

Lime can be made in traditional kilns. It is anticipated that using lime and other lime-related binders in masonry mortars could save up to 40% of the cement needed in building construction.

Lime has the benefit over Portland cement in that it uses less fuel and requires very basic equipment to manufacture. Using lime in the soil stabilization four reactions occur which are flocculation, cation exchange, carbonation, agglomeration, and pozzolanic reactions (H.B. Nagaraja, 2013).

The pozzolanic reaction, which happens between lime and certain clay minerals with moderate to high plasticity, is thought to be the most important. Because calcium cations provided by hydrated lime replace the cations ordinarily present on the surface of the clay mineral, soil stabilization occurs, which is aided by the high PH environment of the lime-water system (H.B. Nagaraja, 2013).

2.10.9. Bituminous Stabilization

Bitumen can help to stabilize the soil in two ways. The first method involves a binding process that increases soil strength, which is especially important in granular soils. Small levels of bitumen (2 percent to 6 percent) provide soil cohesiveness in most cases. When these percentages are exceeded, the bitumen acts as a lubricant, which separates the particles and reduces the strength. The bitumen functions as a water repellent in a second way. Both mechanisms are present in most soils, albeit to varying degrees depending on the kind of soil. Sandy soils are good candidates for bituminous stabilization. For best effects, clays require a greater quantity (Tekle, 2018).

2.10.10. Cement Stabilization

Cement is a well-researched and well-understood stabilizing substance with well-defined characteristics. Portland cement is one of the most common types of cement and is readily available in most urban and semi-urban regions, as it is one of the most important components in any building construction. Cement has already been proved to be a viable stabilizer for use with soil in the creation of compressed stabilized soil blocks in previous investigations (H.B. Nagaraja, 2013).

The hydrates in Portland cement create the reaction that forms a cementitious gel that is independent of the soil when water is introduced. Calcium silicate hydrates, calcium aluminate hydrates, and hydrated lime make up this gel. The first two chemicals make up the majority of the cementitious gel, whereas the lime is deposited as a crystalline solid phase separately. The cementing process results in the deposition of an insoluble binder capable of embedding soil particles in a cementitious gel matrix between soil particles (Afkari, 2010).

The lime released during cement hydration reacts with the clay fraction further, generating more cementation linkages. Cement is a good soil stabilizer for sandy soils, but not so much for clays. Cement can be utilized with any soil type in general, although it is uneconomical with clays since more cement is required. Depending on the soil type, a cement percentage of 4 to 16 percent by weight is required for adequate stabilization (Afkari, 2010).

2.10.11. Plastic stabilization

Polymers derived from oil or combustible gas subsidiaries are known as plastics. Plastic is divided into seven categories by the Society of Plastic Industry (SPI) (Yang, 2006).

These are High-Density Polyethylene (HDPE), Polyethylene Terephthalate (PET), Polyvinyl Chloride PVC, Polypropylene (PP), Polystyrene (PS), Low - density polyethylene(LDPE), and other materials such as Polyester, Polyamides, and Polycarbonate (Yang, 2006).

Polypropylene(PP)- is the most commonly used integration in soil fortification research center testing. PP filaments are currently being used to improve the dirt quality qualities, reduce shrinking, and combat synthetic and natural degradation (Assefa, 2019).

Polyethylene (PE)- To a limited extent, the idea of strengthening soil with polyethylene (PE) strips or filaments has been investigated. The proximity of a small division of high thickness Polyethylene strands has been calculated to increase the crack liveliness of the soil. They discovered that a 0.25 percent waste angling net material provided the greatest increase in compressive quality. As can be observed, environmental designs are the primary motivations for using PE filaments or maybe strips in geotechnical construction to landfill waste PE-based products (A.K. Choudhary, 2010).

Polyethylene Terephthalate (PET) - The use of PET fiber in smaller sand enhances the maximum quality, which is determined by fiber content. Kumar (2008) used folded polyester strands to evaluate very compressible soil in an unconfined compression strength (UCS) test with 0 percent, 0.5 percent, 1.0 percent, 1.5 percent, and 2.0 percent levels. Level strands were chosen in three lengths of 3 mm, 6 mm, and 12 mm, whereas wrinkled filaments were sliced to 3 mm. The results reveal that when fiber length and fiber content increase, the UCS value increases. As the number of strands decreases, the UCS increases slightly (Rebecca Belay Kassa, 2020).

Recent research has demonstrated that soil stabilization with PP and LDPE plastics is more cost-efficient than traditional soil stabilization methods such as cement and lime additive stabilization. Cost-benefit analysis is carried out in countries such as the United States, Japan, and Europe, where international laws and conventions, as well as regulations, are available and applicable (Jai Prakash, 2017).

2.11. Why Plastic Material

Plastic is being used for this research for a number of reasons, including its widespread availability, environmental pollution, and the requirement for an effective disposal method. Studies have shown that unwanted plastics can be properly blended with soil to stabilize it by increasing its durability and strength, such as shear strength and tensile strength, rather than being continuously dumped there. The soil quality used to build road infrastructure can be significantly improved. Plastics are a viable choice for soil stabilization due to their higher quality, Flexibility, elasticity, water resistance, corrosion, and chemical resistance, high strength-to-weight ratio, low electrical and thermal conductivity, good durability, etc. are some of its characteristics (Boniface Chidi Okoro, 2007).

Over the past 30 years, plastic consumption has doubled, spurred by expansion in emerging markets. Between 2000 and 2019, the world's plastics manufacturing increased to 460 million tones. 3.4% of the world's greenhouse gas emissions come from plastic. Between 2000 and 2019, the amount of plastic garbage generated globally more than doubled to 353 million tones. The plastic waste nearly two-thirds comes from polymers with lifespans of under five years, with packaging accounting for 40%, consumer products for 12%, and apparel and textiles for 11%. 15% of plastic garbage is collected for recycling, However, only 9% of it is recycled (the remaining 40% are disposed of as residues). A further 19% is burned, 50% end up in landfills, and 22% elude waste management systems and end up in unregulated dumps (Manjula, 2022).

2.12. Plastic Pollution

The term "plastic pollution" refers to the widespread build-up of plastic items in the environment that poses a threat to wildlife and other living organisms. Plastic pollution significantly impacts terrestrial and marine ecosystems. They have added to pollution because they are durable and affordable. The buildup of plastic items in the environment that puts both the natural world and living things in peril is known as plastic pollution. Plastic pollution significantly impacts terrestrial and marine ecosystems. Pollution has gone up since they are more inexpensive and long-lasting (B. P. Kagonbé, 2021). It is particularly harmful in this form and challenging to regulate due to its tiny size and possible impact on the food chain. Despite the many benefits that plastic offers, it is associated with high amounts of waste and environmental leakage. This is because single-use plastics are widely used, end-of-life management is subpar, recycling and reuse rates are low, and there is a big chance that microplastics may form (Geyer, 2017).

Even while there is an urgent need for greater research on the subject, it is clear that only a very small portion of discarded plastic is recycled or used to generate energy through burning. The study also demonstrates that freshwater and marine environments are substantially less polluted with microplastics than land is. Even though the entire impacts of microplastic pollution on the environment have not yet been identified, some of the effects include the fact that the majority of plastics are not biodegradable and end up in sewers (Geyer, 2017).

2.12.1. Plastic Pollution in Ethiopia

Plastic consumption in Ethiopia increases tremendously from time to time. That the average annual plastic use per capita in Ethiopia rose from 700 grams in 2007 to a projected 3.8 kg in 2022. This is a 540% increase in 15 years. That the average annual plastic use per capita in Addis Ababa is almost twice as high as the national average. High-income households not only use more plastic but also a wider variety of plastic products (Programme, 2021).

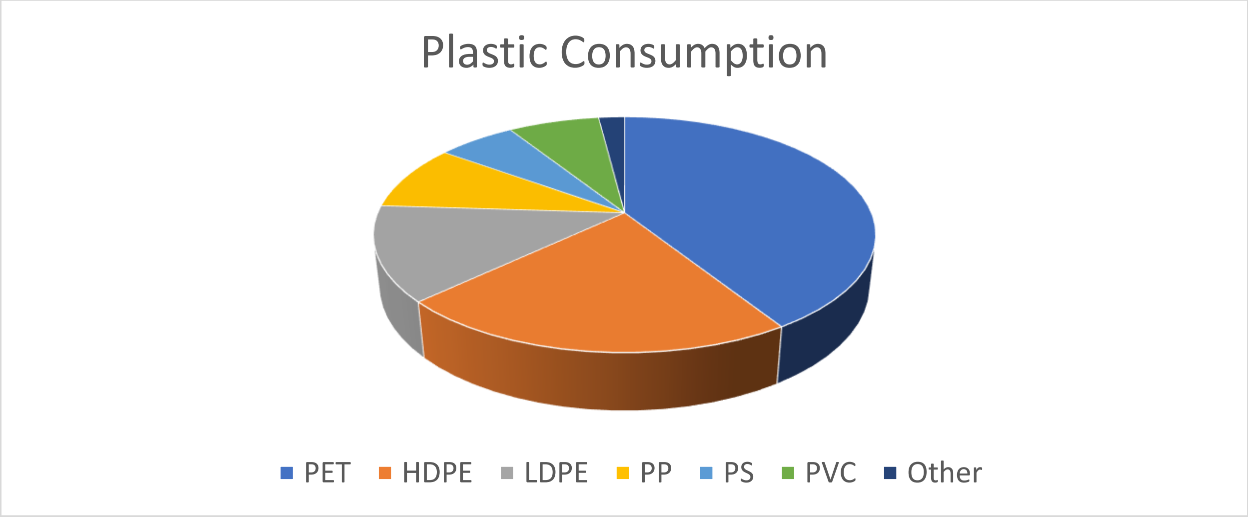


Figure2.3. Plastic Consumption in Addis Ababa, Ethiopia 2021 (Programme, 2021)

According to (Programme, 2021), PET, which is used for plastic bottles is by far the most popular plastic in Addis Ababa, followed by HDPE. HDPE is often used for various products such as cosmetics, shopping bags, and even water pipes, which are used to collect water from collective water points. PET and HDPE account for almost two-thirds of the total plastic consumption.

Plastics are incredibly practical, portable, flexible, affordable, and adaptable. They can't decompose naturally. Due to their nature, plastics have the potential to contaminate the ecosystem for hundreds of years, harming biodiversity and the environment. Plastics unintentionally enter human food systems (Programme, 2021)**.**

2.12.2. Drawbacks of plastic waste in Ethiopia

Plastic material has its own drawbacks in Ethiopian context among these, **(**Programme**,** 2021**)**

- Clogging drainage systems during the rainy season,
- Clogging leads to over flooded streets, neighborhoods
- Affecting the diet of urban livestock,
- Poor damping creates unpleasing atmosphere which leads to unhealthy environment.

2.13. Plastic Materials

1. Polyethylene terephthalate (PET)

One of the most important technical polymers, polyethylene terephthalate (PET), is utilized extensively in a wide range of products. It has a wide range of applications, from packaging to fibres because of its many important properties.**(**Hoog**,** 2021**)**.

Advantages

- Clarity: PET has excellent clarity, making it suitable for packaging applications where transparency is important.

- Lightweight: PET is a lightweight material, which can help reduce transportation costs and energy consumption.
- Recyclable: PET is widely recycled and can be turned into a variety of products, including new PET bottles and fibers for textiles.
- Barrier properties: PET has good oxygen and moisture barrier properties, which help to preserve the freshness and quality of packaged goods.

Limitations

- Not suitable for high-temperature applications: Due to its heat sensitivity, PET is not recommended for applications that involve high-temperature processing or prolonged exposure to heat.
- Potential for chemical leaching: PET may release small amounts of chemicals, such as antimony, especially when used for storing acidic or high-temperature liquids.
- Limited chemical resistance: PET is susceptible to damage from certain chemicals, including some solvents and oils.
- Limited UV resistance: PET is not inherently UV resistant and may degrade or become discolored when exposed to prolonged sunlight.

2. Polyethylene (PE)

PE is structurally the simplest plastic. PE produced in three densities produced that are low density polyethylene (LDPE), medium density polyethylene (MDPE), and high-density polyethylene (HDPE). These resins can be created based on the temperature, pressure, and catalyst used during the polymerization process (Harte, 2011).

Advantages

- •Flexibility: Polyethylene (PE) is a very flexible polymer that can be used in products like packaging films and plastic bags where flexibility and durability are crucial.

- Chemical resistance: PE can withstand a wide range of chemicals, such as bases, acids, and solvents, which makes it appropriate for a number of industrial uses.Moisture resistance: PE has excellent moisture barrier properties, making it suitable for packaging applications that require moisture protection.
- Recyclable: PE is widely recyclable and can be transformed into a range of products, including new plastic bags, pipes, and containers.
- Wide availability: PE is one of the most widely produced and used plastics, making it readily available and cost-effective **(**Harte**,** 2011**)**.

Limitations

- Susceptibility to UV degradation: Unless treated with additives, PE can degrade and become brittle when exposed to sunlight, limiting its outdoor use.
- Low heat resistance: PE has a lower melting point compared to some other plastics, which restricts its suitability for high-temperature applications.
- Non-biodegradable: PE is not biodegradable and can persist in the environment for a long time, contributing to plastic waste pollution.
- Limited transparency: PE is generally opaque and not as transparent as other plastics like PET, which can limit its use in certain applications **(**Clara Diago, 2007).

3. **Polypropylene (PP)**

PP has the lowest density and the highest melting point of all the high-volume usage thermoplastics and has a relatively low cost. This versatile plastic can be processed in many ways (Clara Diago, 2007).

- High heat resistance: PP has a relatively high melting point, allowing it to withstand high-temperature applications without deforming or melting.
- Chemical resistance: PP is highly resistant to many chemicals, making it suitable for various chemical and liquid storage applications.

- Lightweight: PP is a lightweight material, which can help reduce transportation costs and energy consumption.
- Impact resistance: PP has good impact strength, making it durable and suitable for applications that require resistance to impacts or rough handling.
- Recyclable: PP is widely recycled and can be turned into a variety of products, including new PP containers, automotive parts, and fibers.

Limitations

The low moisture barrier of polypropylene (PP) is a result of its high coefficient of thermal expansion, which restricts its use in high temperature environments.

• Profound flammability

• Bonding property is poor.

PE and PET plastic materials are chosen for the experimental investigation after data on the physical characteristics, benefits, and drawbacks of each type of plastic has been gathered.**2.14. Main Constituent Material Used for Plastic stabilized Hydra form blocks**

The three main constituent materials used in the production of the blocks are

- Plastic material (for binding the soil particles
- Soil (for the skeletal structure of the block)

2.14.1. Plastic Material for Binding the Soil Particles

Stabilizers are essential for Hydra form blocks to work properly. If not for the use of stabilizers, Hydra form blocks would be no different than typical sun-dried mud blocks, dissolving in contact with water or when subjected to modest impact loads. Depending on the composition of the soil requiring stability, amounts as low as 10% and as much as 25% will be utilized, however, this is not frequently suggested (M Pushpa1, 2019).

2.14.2. Characterization of Soil for Hydra from Block Production

Soil alone constitutes over 75% of the bulk of Hydra form blocks during plastic stabilization. The soil, according to BS 1377 Part 1: 1990, is a collection of distinct particles in the form of a deposit, usually of mineral composition but occasionally of biological origin, that can be separated by gentle mechanical means and contain varying amounts of water and air. (B. P. Kagonbé, 2021)The loose material that results from the long-term change of the underlying parent rock by the simultaneous and evolutionary interaction of climatic conditions and other physicochemical and biological processes is referred to as soil (A.G.Kerali, 2000). Disintegrated rocks, degraded organic matter, and water-soluble mineral salts make up the majority of the soils. These descriptions demonstrate that soil is a complex and varied element in nature. Although soil parameters can be altered to increase performance, not all soils are suitable for stabilization in the manner discovered. Identification of the main constituents in the soil likely to have a direct bearing on its properties and behavior is required to make a suitability decision (Head, 1980).

2.15. Previous Studies

Through numerous investigations, it has been determined that plastic waste qualifies for usage as a soil stabilizer. Studies, including one done in 2010, demonstrated the HDPE (high-density polyethylene) material's potential to operate as a soil reinforcer by improving the qualities of subgrade soil. The soil was mixed with different quantities of HDPE strip length and length from plastic trash before a series of California bearing ratio tests were run on the reinforced soil. According to the test results, adding HDPE strips to the soil to strengthen it is advantageous for use on highways (A.K. Choudhary, 2010).

In 2014, laboratory tests were performed to determine whether the random injection of HDPE strips made from plastic shopping bags increased the shear strength and yielding capacity of locally discovered sand. After conducting the tests and analyses, a visual examination of the plastic material suggested that the tensile stresses mobilized in the reinforcements were the cause of the reinforced soil's increased strength. Some of the elements suggested to affect the effectiveness of the reinforcement material included soil properties (grade, shape, and particle size) and plastic properties (concentration, length, and breadth of the strips) (Chebet, 2014).

In 2015, research was done to determine the technical characteristics of soil by combining it with plastic garbage. The discovered result suggests that the usage of plastic 23 trash bottle chips is a different way to improve the subgrade soil while thinking about building flexible pavements. To determine the value of CBR, plastic trash was blended in different amounts (0.5%, 1%, 1.5%, 2%, and 2.5%) with dry soil. It was determined that adding plastic strip waste to the soil will increase its strength and offer a cost-effective and environmentally responsible way to dispose of the plastic trash (Geyer, 2017).

2.16. Current Application of Plastic stabilized blocks

Earth has been used as a significant building material since the dawn of time, and we can see evidence of this throughout enormous swaths of our world today. In the last 30 years, earth-compressed blocks have become popular not only in third-world countries but also in industrialized countries such as the United States, France, Canada, and Australia. Because of its physical properties and ability to regulate moisture and temperature, it is also the most favored material among Europe's bio-ecological constructors (Tadege,2007).

When compared to sand, and cement-based materials, plastic stabilized blocks produce a truly comfortable living environment in hot areas, and even more so in those with a large thermal variation. When the hydra form blocks have been too firmly connected with low-cost or "cheap" buildings, a social willingness to use the material will arise (Mehmet Serkan Kirgiz, 2022).

Various researchers in India are investigating compressed stabilized earth bricks utilizing various soil stabilization techniques, including plastic stabilization. Plastic stabilized blocks are primarily utilized as pavement blocks in a variety of settings, including schools, stores, offices, and low-cost housing initiatives (Mehmet Serkan Kirgiz, 2022).

Pedestrians in Hyderabad will soon be able to walk on discarded plastic or waste-made tiles, such as polybags, chips packets, and plastic bottles. Shayna Eco Unified India Pvt. Ltd., situated in Delhi, provided the tiles constructed from 30,000 plastic carry bags last month. The installation of paver tiles has already begun. The local corporation is expected to complete the project in a few days, thanks to expert advice from Bamboo House India (Loganayagan, 2021).

Figure 2.4 Plastic stabilized Pavement bricks in India

Picture Source: https://www.home-dzine.co.za/green/green-tiles-from-plastic-waste.html

Due to a significant influx of people from rural areas, African countries such as Zambia, Ghana, Kenya, Uganda, Nigeria, Tanzania, and Southern Africa are experiencing new forms of house development adopting the Hydra form (Loganayagan, 2021).Despite this, the mistaken assumption that hydra form blocks are closely connected with traditional stabilized soil has hampered their use in housing construction. Another disadvantage of stabilized-earth blocks has been the lack of quality control procedures and, in particular, testing equipment for quality control. The absence of evident attempts to solve those issues has been exacerbated by a need for modernity in sand-cement or concrete housing construction technologies (Mehmet Serkan Kirgiz, 2022).

Figure 2.5. Plastic Pavement blocks in Kenya

Picture Source: https://swachhindia.ndtv.com/plastic-choking-planet-save-city-solution-anti-slippery-recyclable-tiles-28972/

The Gjenge Manufacturer's ltd in Kenya has made significant progress in plastic stabilization. Following the construction of a prototype machine that converts spent plastic into paving stones. One day at the factory yields 1,500 churning plastic pavers, valued not only for their quality but also, for their durability (Mehmet Serkan Kirgiz, 2022). Plastic stabilization is now utilized for many different types of road pavements of many styles because of its flexible size and shape. The use of these blocks is encouraging appearing with different shapes and colors is an option that allows for flexibility and aesthetics in design as shown in Figure 2.5 above.

2.16.1. Table Summery

In conclusion, inorder to summerize international case studies on plastic stabilized blocks a table of summery is prepared below.

According to the litrature (Alexander Kumi-Larbi Jnr, 2022), optimum temprature for melting plastic is between 180-295 ^{0}C the temperature range above 300^{0}C is hazardeous category and risky for health.

Table 2.2. Table of summer

No.	Country	Application	Percentage of Plastic Stabilizer	Plastic Types	Compressive Strength result compared to cement based	Water Absorption (%)	Mix Time Interval	Plastic Melting temprature ^{0}C	Reference
1.	India	Pavment blocks	50-80%	PET & PE	4 times higher	1.0-1.5	15-25 min	220-250	(Vasudevan R, 2006)
2	Turkey	Asphalt-concrete mix	4-6% replacement of Bitumen in asphalt	PET & PE	16% higher	5.0-7.0	Not conducted	180-220	(Agar, 2003)
3	Kenya	Pavment blocks	70 %	PET & PE	5-7 times higher	1.5-1.8	12-25min	250-275	(Waita, 2021)
4	Uganada	Walling blocks	25-100%	PET & PE	4 times higher	0.9-1.0	5-12 min	200-220	(Bruce Nuwagaba, 2018)
5	Coloumbia	Walling blocks	100%	PET, PE and, PP	4 times higher	1.0-1.5	10-20min	220-240	(Wadsö, 2019)
6	Nigeria	Hydra form	0-10%	PET & PE	4 times higher	0.9-1.8	10-12min	250-275	(Isaac I. Akinwumi, 2019)
7	Gambia	Pavment blocks	65-75%	PET & PE	5 times higher	1.0-3.2	17-27 min	220-250	(Alexander Kumi-Larbi Jnr, 2022)
8	India	Walling brick	50- 80%	PET & PE	3 times higher	0.9 -1.2	10-15 min	180-200	(S S Chauhan, 2019)

2.17. Local Studies and efforts on soil blocks in Ethiopia

In Ethiopia, the usage of Hydra form as a wall-building material is still in its early stages, owing to a lack of awareness among the population. However, some people presently prefer to utilize Hydra form blocks to build walls for schools, guardhouses, fences, offices, and halls due to the reduced cost and speed of construction, especially in the case of Hydra form blocks using the cement-based stabilization. Yet the use of plastic stabilized Hydra form blocks had never been tried in Ethiopia (Habtemariam Molla, 2012).

2.17.1. Selam Technical and Vocational Center Addis Ababa

The Addis Ababa-based Selam Technical and Vocational Center was founded over 25 years ago. Orphans are cared for, education is provided, vocational training is provided, and appropriate and sustainable technology is developed at the facility. It has evolved into a well-equipped and well-organized training institution, and it is now at the cutting edge of cement-based hydra form production. The firm intends to test a variety of stabilizing techniques in order to improve material performance and gain widespread adoption of cement-based materials. Selam Technical and Vocational center can be mentioned among the companies engaged in mass production of Hydra form blocks (Tadege, 2007).

Hydra form blocks come in a variety of shapes and sizes and are manufactured at their facilities. The hydra form block, with an 8 percent cement content, is the most typically made block. Another form of block features a quarter-circle corner, making it perfect for corners or freestanding columns. Using the electrical press, the blocks were produced at a rate of about 4 blocks per minute, and they were subsequently dried in the shade for 28 days. Hydra form blocks were used to construct the majority of the office buildings and training rooms in the Selam Technical and Vocational Center site (Tekle, 2018).

Figure 2.6- Hydra form blocks from Selam vocational school

2.17.2. Plastic stabilized soil blocks

Several researches have been conducted regarding soil stabilization using plastic among these the research title with ‘‘Stabilization of expansive oil using Plastic Wastes’’, which is conducted Adis Ababa Science and technology university (AASTU).

In-depth research on the behavior and application of waste plastic for extensive soil improvement is presented in this publication. The experimental studies revealed that plastic may be utilized as a reliable stabilizer to deal with waste disposal issues as well as an affordable stabilizing solution **(Tegegn, 2020)**.

PET plastic strips were used to stabilize clay soil, at stepwise concentrations of 0.2%, 0.4%, 0.6%, and 0.8% by dry soil weight. The findings indicate that plastic reinforcement in soil significantly increases maximum dry density, shear strength parameters, and CBR value while decreasing specific gravity, swelling pressure, plasticity index, and ideal moisture content. According to the study, expansive soil's engineering qualities significantly improve at 0.4% plastic concentration (Tegegn, 2020).

2.17.3. Lime and cement stabilized hydra form blocks

Various researches have been conducted regarding partial replacement of cement in the hydra form block production, among these the research titled with ‘‘Study of compressed cement and lime stabilized soil block as an alternative wall making material’’. The research was conducted in Selam technical school, The investigation has shown that the blocks stabilized with cement combined with lime have a higher 56th day compressive strength than the blocks stabilized with cement alone, from the blocks produced at the varying total stabilizer contents from 4% in increments of 2% up to 10% at constant compressive pressure of 10MPa. The blocks stabilized with lime in addition to cement absorb less water than the blocks stabilized with cement alone. Compressive strength has increased with an increase in compaction pressure when the stabilizer content remains the same. (Tekle, 2018).

2.18. Summary of literature review and gap identification

2.18.1. Summary of literature review

The molded earth block's modern descendant is Hydra form blocks. Compacting earth to increase the quality and performance of molded earth bricks is an idea. The materials used to build walls are typically needed to have sufficient compressive strength and erosion resistance. Stabilizing the soil with different stabilizers like cement, lime, plastics, and others might improve its quality. Compaction, which results in higher densities and hence higher compressive strength and better erosion resistance, can improve the strength of stabilized soil blocks (Rebecca Kassa, 2020).

The Hydra form block is a low-cost, sturdy, and long-lasting material for wall construction after stabilization and compacting processes. The advantages of these blocks are their low cost, the use of locally accessible materials, the ability to make them on-site with no transportation costs, and their ease of fabrication. The soil should be carefully and correctly selected for block manufacture, and gradation and plasticity tests should be undertaken and checked against the criteria for compressed earth blocks (A.K. Choudhary, 2010).

Before making the blocks, the soil sample should also undergo a chemical analysis test. The amount of stabilizer in the blocks has an impact on material property. Once the mix has been placed in the mold, it should be carefully compacted to produce the best results. In addition, Curing must be done correctly to avoid rapid drying.

2.18.2. Gap identification

In recent years, extensive research has been conducted to make soil a viable construction material. As a result, technology using soil in the form of rammed earth and unfired bricks known as Hydra form is developed. Stabilizers are used in the manufacturing of Hydra form blocks to provide proper compressive strength and durability, making them suitable for use as building blocks. Though cement is a common stabilizer used in the production of Hydra form blocks, little effort has been put into replacing cement with plastic (H.B. Nagaraja, 2013).

In comparison to cement, however, the use of plastic as a stabilizer in the manufacture of hydra form blocks has not gained traction. As stated in the literature, plastic has been used to stabilize clayey soils and has been found to provide long-term strength gain. Because plastic is recognized to provide long-term strength, its use as a complete replacement for cement becomes more advantageous (H.B. Nagaraja, 2013). This study will attempt to understand how plastic may completely replace cement as a stabilizer in the construction of Hydra form blocks. Any effort to optimize the plastic stabilizer would help to increase the Hydra form block's strength and workability.

Chapter Three: Properties of Material, Mix proportion, and Test

3.1. Introduction

In this chapter, the materials used in the investigation are described with their sources and their physical and chemical properties. All laboratory investigations on materials are carried out in the Selam technical and vocational center in Addis Ababa and the production of the blocks was carried out in the block yard of the center.

3.2. Methodological Approach

This research has involved two methodological approaches: (Tadege, 2007).

1. The theory chapter is mainly based on books, academic reports, and journals that have been found by searching databases such as google scholar. It covered concepts on Hydra form Blocks, plastic, soil stabilization, compressive strength, and water absorption.
2. Develop Experimental prototype to proof the physical property of the material in regards to engineering aspects such as compressive strength and water absorption.

3.4. Properties of Materials

3.4.1. Soil

The soil used in this study came from Kara, a place around 15 kilometers east of Addis Ababa. Drying and screening soil samples to the desired size were used to prepare them. The results of the laboratory tests are used to calculate numerical values for the soil sample parameters.

These figures are then used to determine whether the soil sample is suitable for hydra form blocks. The physical properties of the soil are given in Table 3.1 and Table 3.2 respectively.

Table 3.1 – Physical properties of soil

No.	Physical Properties	Value
1.	Specific gravity	2.59
2.	Clay Content	15.2%
3.	Silt Content	16.3%
4.	Sand Content	68.5%
5.	Plastic Index	9.4%
6.	Plastic Limit	24.4%
7.	Liquid Limit	33.8%
8.	Moisture content	5.33%

Table 3.2 – Chemical composition of soil

No.	Chemical Oxides	Compositions
1.	SiO_2	64.22
2.	Al_2O_3	16.66
3.	CaO	1.3
4.	Fe_2O_3	5.48
5.	MgO	0.42
6.	Na_2O	1.9
7.	MnO	0.1
8.	K2O	2.84
9.	P2O5	0.03
10.	H_2O	1.82
11.	TiO_2	0.24
12.	LOI	4.95
13.	CI	<0.01
14.	SO3	0.22
15.	PH	7.44

3.4.2. Plastic Material

Polyethylene terephthalate is a member of the polyester family of polymers, which is one of the largest and most diversified. The common trait of this family of polymers is the presence of an ester (-COO-) link in the main chain, but the diversity of polyester materials is likely the widest of all the polymer families. Furthermore, PET's chemical structure consists of only three atomic species: carbon, hydrogen, and oxygen. As a result, melting PET does not produce harmful fumes, and its characteristics indicate that a melting temperature of 260 ^{o} C is necessary. It is also clear from the PET's qualities that it has high chemical resistance as well as greater UV resistance (M Pushpa1, 2019).

When PET is burned, only water and carbon dioxide are generated. As a result, even though PET melting was all that was required in this circumstance, there is no risk of inflicting harm through gas emissions. The physical property of PET is described in the following table (M Pushpa1, 2019).

Table 3.3 – Physical properties of PET (Poly-ethylene terephthalate)

S.No	Particular	Value
1.	Coefficient of Thermal Expansion	7 x 10-3/ºC
2.	Water Absorption	0.07 – 0.10%
3.	Melting Point	260ºC
4.	Long-Term Service Temperature	115 - 170ºC
5.	Specific Gravity	1.3-1.4
6.	Elasticity Modulus	9
7.	Tensile creep strength	8
8.	Bending creep Modulus	1
9.	Elongation at break (%)	>600
10.	Thermal Conductivity	0
11.	Ignition Temperature	3

3.5. Mix Proportion

Four mix series will be created in order to examine the effects of the cement, Plastic, and soil contents. The mix proportions are chosen based on recommendations from the literature (S S Chauhan, 2019), and (Tekle, 2018). The mixes are prepared and casted in the workshop of Selam Technical and Vocational Center. To this result, the following mix proportions are presented.

1. The first series of mixes (3 in number), are conducted to compare the variation in compressive strength values with age, and the rate of strength development of the PET (Poly-ethylene terephthalate) and PE (Poly ethylene) block created using soil. They are also employed to study how the presence of plastic affects the stabilized block's compressive strength and water absorption. They contain variable amounts of plastic, with a total stabilizer level 50%, 70% and 80% weight of soil. 33 blocks were produced as sampling and testing according to ASTM C140 (ASTM Standards, 2008).

Table 3.4 Mix Proportion of 1st series

Mix Code	Soil	Plastic	Water
A	50%	50%	0%
B	30%	70%	0%
C	20%	80%	0%

2. The second series of mix are conducted to compare the variation in strength values with age, and the rate of strength development of the block produced using Portland pozzolana cement and soil mix Hydra form block. It contains 90% soil and 10% cement as a stabilizer. (Ahmed, 2015).11 blocks were produced as a sampling and testing according to ASTM C140 (ASTM Standards, 2008).

Table 3.5 Mix Proportion of 2nd series

Mix Code	Soil	Plastic	Water	Cement
D	90%	0%	20%	10%

3.6 Specimen preparation

One of the most crucial steps in handling the experiments was getting the specimen ready, and special attention had to be paid to the samples' soil, Cementous material mix, moisture content, compression, curing, and size (Tekle, 2018).

A set amount of time had to pass before the laboratory testing could be finished. The process used to prepare the sample includes the basic ingredients utilized, the proportioning of the mix, the addition of moisture, and any other steps designed to pass a certain set of tests. Accuracy, reliability, and repeatability were the three main criteria that were attempted to be met by all laboratory tests' outcomes. For the creation of hydra form Blocks, only conventional techniques were employed (Tekle, 2018).

3.6.1 Pulverization

To ensure that the components were evenly mixed, the earth was first ground up. The soil was broken up into smaller bits by being crushed between two surfaces. Stones and gravel are homogeneous grains that are left whole and isolated from the soil (Ahmed, 2015).

3.6.2 Screening

When the pulverization has been insufficient and there are huge particles in the soil, this step is crucial to the process. A fixed screen was hung or set up at an angle to separate them from the earth. Even though this task can be accomplished mechanically, it was readily accomplished manually. A shovel was used to dump unprepared earth towards the fixed screen's top. The bigger unscreened material was then discarded while the screened soil was carried into a wheelbarrow and prepared to be blended with the other components. It may be put to other uses or further ground and pulverized before being screened.

3.6.3. Mould Preparation

A wooden mold with the dimensions 210mmx220mmx110mm will be made as it can been seen in the figure 3.1. A variety of mixed proportions were used to create the bricks, with the needed amount of plastic added to each brick along with about 3 kg of laterite soil (Manjula, 2022).

Figure 3.1. Mould Preparation

3.6.4. Mix Proportion

The success of the product and the structure itself is ensured by proper mixing. If the component proportions are optimized, it also ensures that the blocks are constructed inexpensively. The soil raw material and stabilizer were mixed in the proper proportions. As follows: 80%, 70%, and 50 % of stabilizer, by percentage weight of soil ranging from 20 to 50 percent (Manjula, 2022). After melting the plastic at 260 C and mix it with the soil according to the mix series listed above (Manish Kumar Sahu, 2017).

After the mix is prepared it will be poured into the brick mold and crushed using a steel rod or tamping rod. To quickly demolish the mold after casting, the faces must be thinly coated with lubricant. Oil will be used to polish the surface (Manjula, 2022).The sides of the mould are greased before the liquid is added to make removing the bricks easier. After 24 hours, the cast block will be taken off. The mould is utilized to prepare brick in a standardized shape. After being put together, the mould will be set on the base plate and compacted with vibration. Air-dried for a period of 24hr for proper heat dissipation (M Pushpa1, 2019).

3.7 Tests on Blocks

The research on the effects of stabilization and molding pressure on the strength and performance of blocks was the focus of several independent tests and experiments, all of which were chosen and carried out. Wet and dry compressive strength tests as well as a water absorption test are among the testing. Although the water absorption test and the wet and dry compressive strength tests are now both widely used and touted as standard performance tests for stabilized soils, they were initially created for concrete blocks and burned bricks (Tadege, 2007).

3.8 Compressive strength

The compressive strength machine is used to calculate the wet compressive strength value of blocks. The dry compressive strength is employed for the structural design because the wet compressive strength was lower. A common test is the compressive strength test, which is based on (ASTM C140 Standards, Test Method for Compressive Strength of Masonry Prisms,2014).

The blocks were measured and weighed after being dried for intervals of 7, 14, and 28 days, with an average block size.

$$\text{Compressive Strength} = \frac{\text{Compressive force on the specimen}}{\text{Area of specimen}} \qquad \text{Eq. (1)}$$

3.10 Water Absorption

Wet water absorption tests were conducted on three blocks in each category with variable plastic content (from 50% in increments of 70% up to 80% of the same soil). Each block was given 24 hours soak in plain water. The samples were taken out and set aside to allow the surface water to dry for 20 minutes. The samples were then carefully inserted into the machine's set marking pins to determine each block's weight, these tests were conducted according to the ASTM C140 (ASTM Standards, 2008).

Chapter Four: Laboratory Test and Discussion on soil suitability for making the Hydra form blocks

4.1. Introduction

For Hydra form blocks to be successfully produced, adequate soil must be used. Since Hydra form blocks are made from soil from a specific place called Kara a neighborhood near Addis Ababa. The focus of the inquiry and testing was on this area. The procedure of choosing soil for the creation of Hydra form blocks was investigated in the study that followed. Next, soil that is ideal for producing Hydra form blocks is examined from the perspective of particle grading and plasticity, taking into account the underlying mechanisms responsible for strength and durability.

The literature on soil testing often outlines a number of significant tests yet does not provide a rational schedule of execution. In the following section, the laboratory outcomes regarding soil tests for suitability are discussed and further analyzed. The main reason behind this is to create an understanding of the need for various soil testing while reading this topic. the laboratory study includes the necessary tests like chemical composition, soil grading, and plasticity. The soil from the Kara area is taken as a sample for the laboratory test and all the necessary tests have been carried out.

Sample blocks are made using various plastic types and content based on the results of soil testing, and the blocks are evaluated for compressive strength and water absorption capacity at various time intervals, including 7, 14 and 28 days.

4.2. Laboratory Test Result on Soil Sample

Laboratory tests were conducted to provide more precise information on the gradation and plasticity of the soil. This information helps in deciding whether the soil satisfies the selection criteria given in earlier sections.

In this research work, only a few characteristics that are important for producing compressed plastic stabilized soil blocks are taken into consideration. When making plastic stabilized hydra form soil blocks, the physical properties are more crucial because they affect the material's porosity, permeability, shrinkage, dry strength, bulk density, and ease of mixing, forming, and placement. Particle size analysis and plasticity index are the two main metrics used to describe soil samples in general. The plasticity index indicates the cohesiveness of the fines, while the particle size analysis provides information on the soil's capacity to pack into a compact structure and the number of fines present (combined silt and clay percentage). The laboratory tests were performed to aid in determining numerical values for the properties of the soil sample, particularly the percentage distribution of the various soil particle sizes present and the plasticity limitations. These numbers are then used to determine whether the soil sample is suitable for block manufacture.

I. Particle Size Distribution

The soil sample's various size fractions were divided into distinct portions by the combined sieving and hydrometer tests, providing information about the particle grading of the soil. Figure 4.1 below shows a plot of the outcomes of these tests. In Appendix A, detailed raw data and test results are provided in Appendix A.

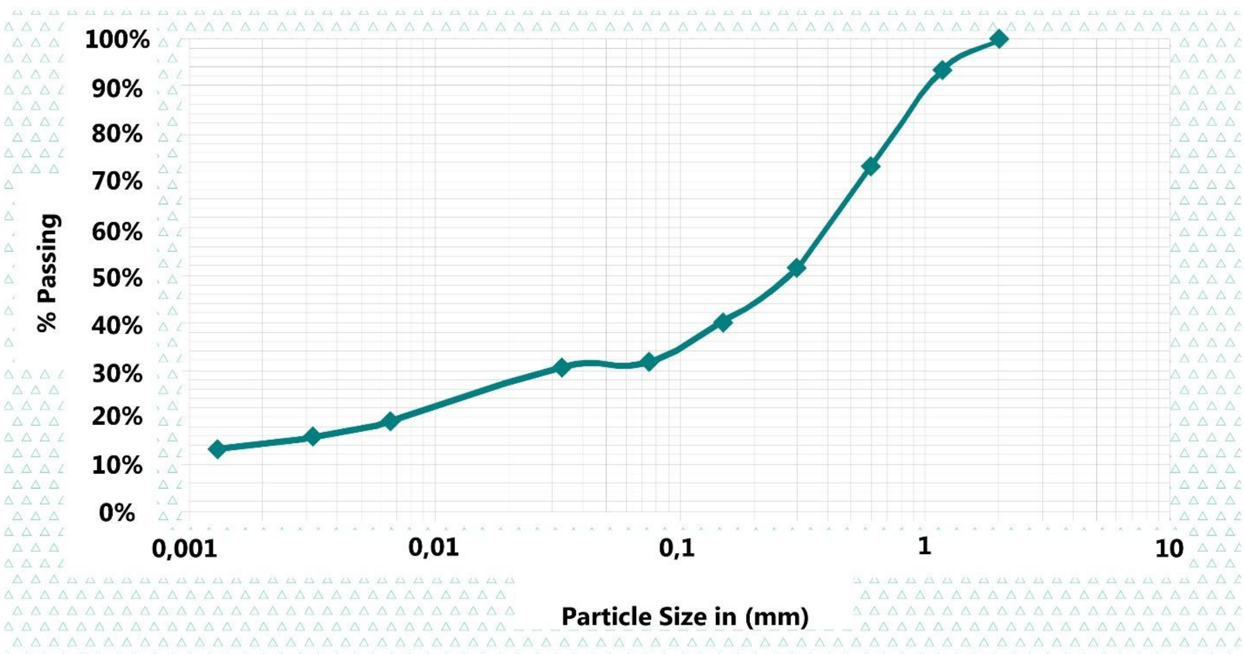


Figure 4.1. Distribution of Particle size in the soil used.

Based on the aforementioned curve, the following groups represent the actual soil composition utilized to create compressed stabilized earth blocks: Silt, at 16.3%, Silt, at 16.3%, and Clay, at 15.2%. To assess soil feasibility and appropriateness of the soil the African Regional Standards

(ARS) were referred. In accordance with ARS 680:1996 Code of practice for the manufacturing of compressed earth blocks (CDI, 1996).

When the soil's granular composition falls inside the shaded area of the textural diagram given in Figure 4.2. the outcome is good. As seen in Figure 4.1 on the previous page, the gradation curve of the soil sample utilized for the research perfectly fits inside the shaded region of the texture diagram, as illustrated in Figure 4.2 below. It follows that the sample soil selected satisfies this criterion.

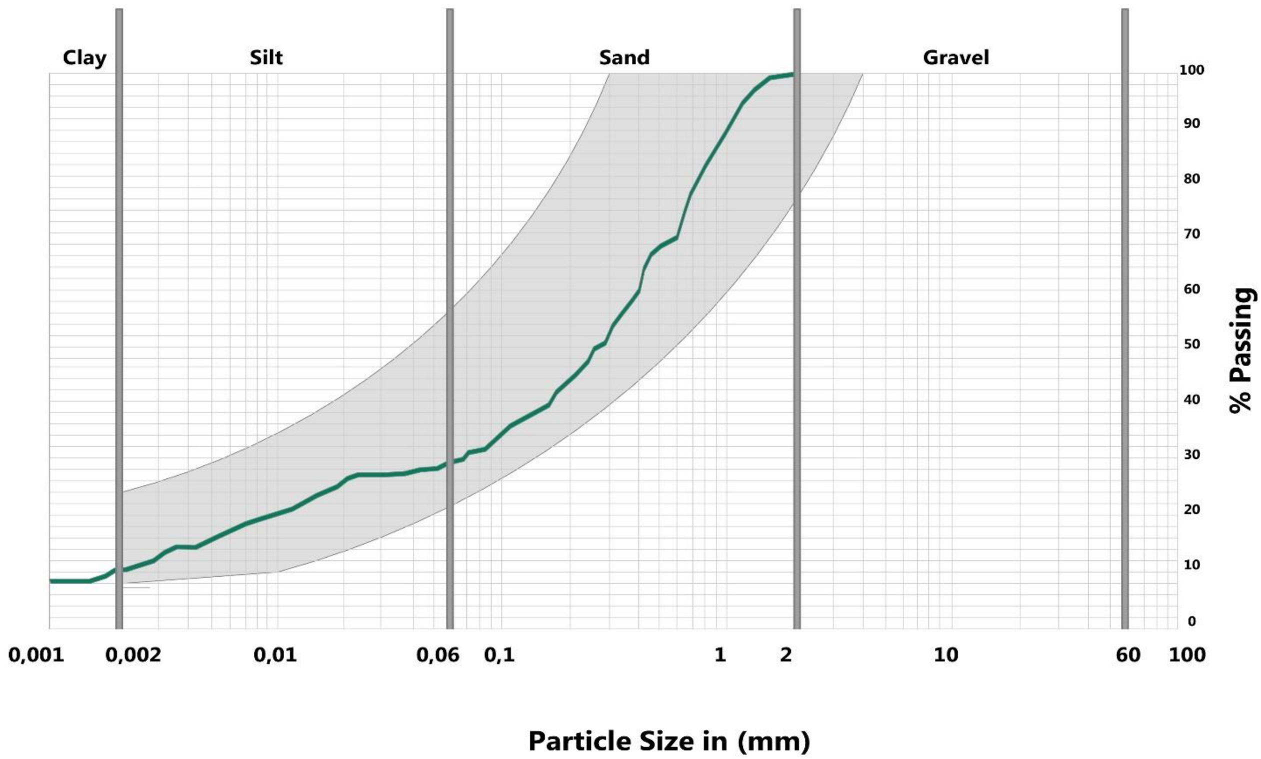


Figure 4.2 Particle size distribution of the test soil seen on the texture diagram.

II. Atterberg's Limit

The liquid and plastic limits, respectively, are determined by the Atterberg's or plasticity tests, which also determine the moisture content at which the soil transitions from a liquid to a plastic state and from a plastic state to a solid one. The plastic limit and liquid limit tests in appendix A are created using the ASTM D 2216-92 method, which enables the soil plasticity characteristics to be matched to the appropriate soil selection criteria listed above in section 2.9.4. The findings of the soil sample's Atterberg limit test is shown in Table 4.1 on the following page, although Appendix A has a description of all test measurements and data records.

Table 4.1 Atterberg's limit test results of soil used in the study

Atterberg Limit	%
Plasticity Index	9.4%
Plastic Limit	24.4%
Liquid Limit	33.8%

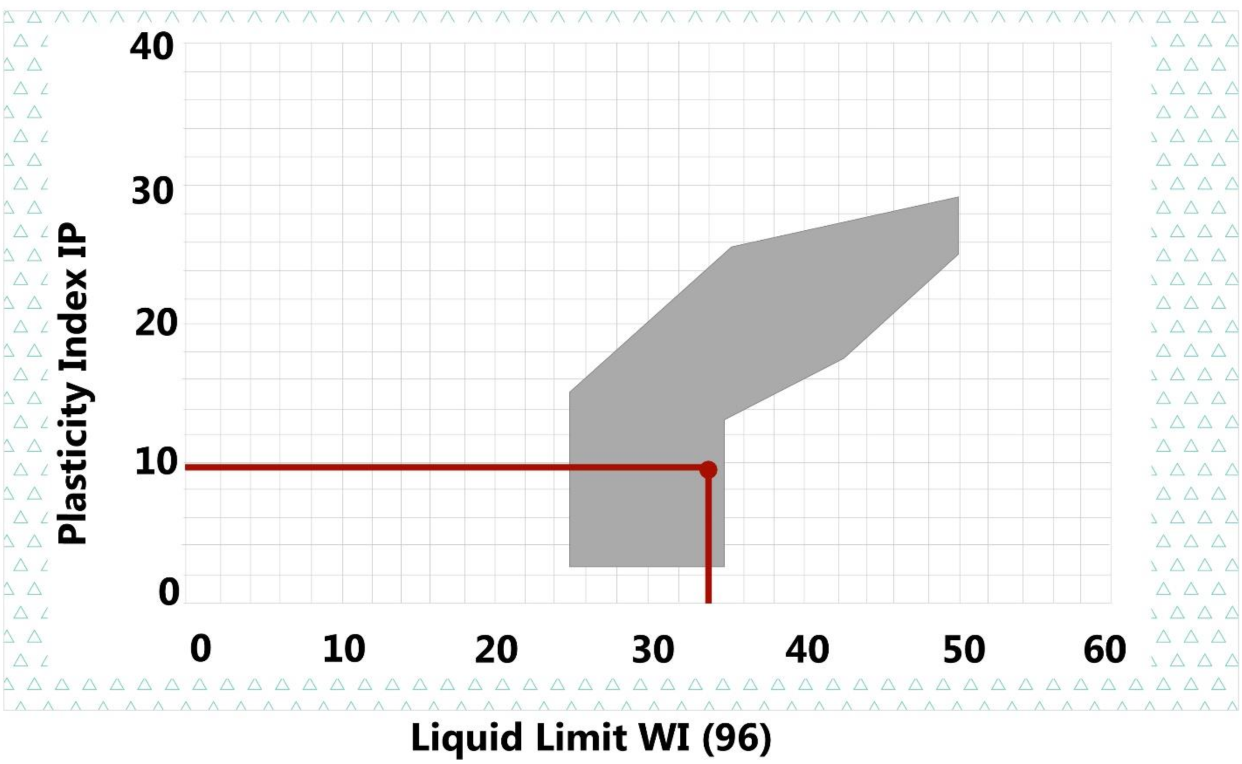


Figure 4.3 Soil Plasticity chart

The red point located in the shaded region indicates the suitability of the KARA soil for the production of Hydra form.

III. Soil Compaction Test

The suitability of the soil sample for the liquid limits and plasticity index has been evaluated, and since the soil is deemed suitable, further tests will be conducted on it.

Compaction tests are performed on the soil samples. The air spaces between the soil particles can be removed by compacting the soil particles closer together. This is a practical and affordable method of enhancing the soil's qualities. The dry unit weight (dry density) of the compacted soil can be used to express the qualities of the soil. (Ahmed, 2015)

The standard proctor test, a common compaction test carried out in a lab, is typically decided by the ideal moisture content and maximum dry density of the soil samples.

The findings of the BS1377: 1975 Test 12 & 13 method used to determine the standard proctor tests for the soils from the Kara area are represented in graph 4.4 below. Additionally, Appendix A, provide the precise measurements and the raw data.

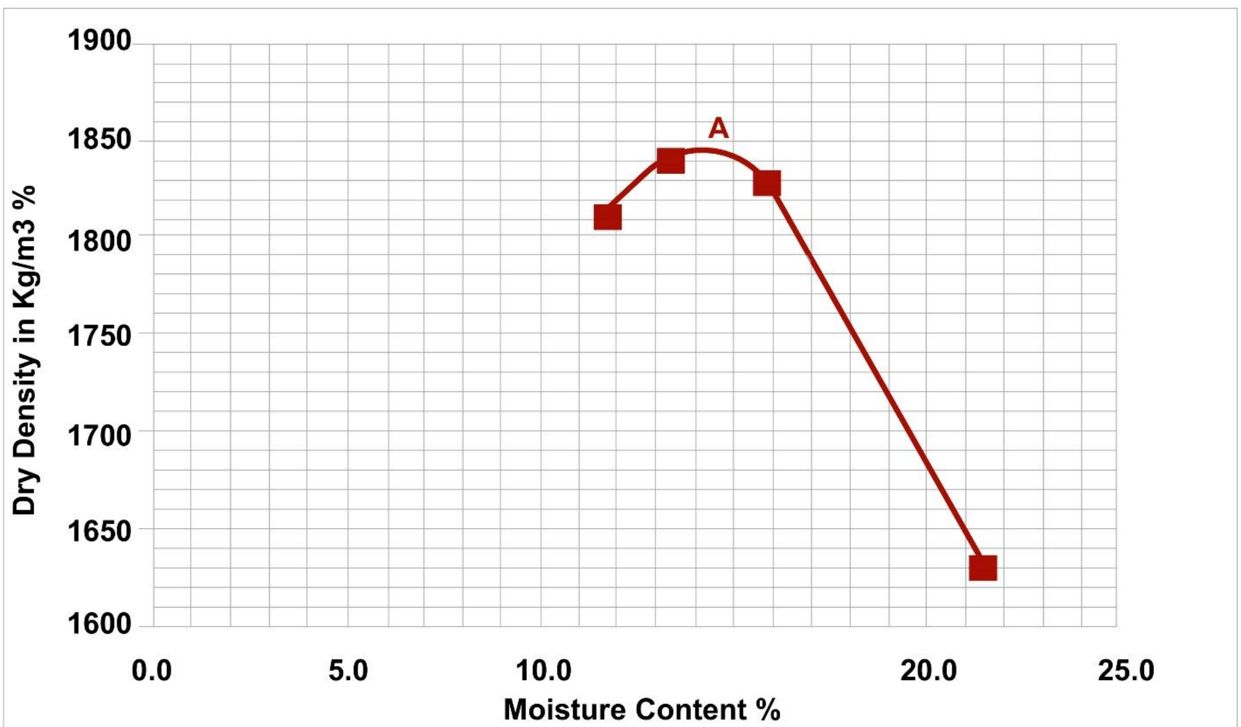


Figure 4.4 Proctor compaction curve test for Kara Soil

The soil sample's ideal moisture content (OMC) and maximum dry density (MDD) are displayed in the graph above at point "A". The soil's MDD and OMC were 1840 kg/m3 and 14%, respectively.

The degree of compaction is the primary factor affecting the optimal moisture content and maximum dry density for a particular soil type. In this case, soil samples were manually compacted on a wooden mould. The correct moisture content was calculated using the ideal block length for a particular soil type. It is expected that the amount of moisture used to produce this ideal block length corresponds to the optimum moisture content.

IV. Chemical Analysis

According to the literature review, it is important to consider the soil's chemical qualities, particularly when a chemical additive is being utilized. These factors include composition, mineral content, metallic oxides, PH levels, and sulfates. The chemical study of soil from the Kara area was carried out at the Geochemical Laboratory of the Geological Survey of Ethiopia because plastic waste is used as a stabilizer.

The ultimate goal was to determine the chemical make-up of the soil and to gain further insight into the interactions that occur in stabilized soil mixtures. Chapter 3 provides the results of the inquiry of the research soil. The amount of SiO_2 (64.22%), we can infer from the chemical constituents, is a reflection of the type of sand in the soil. The silica and alumina in soil react with a stabilizer to produce a cementing agent. Earth's SiO_2 and Al_2O_3 react with polypropylene from plastic materials. This shows that control occurs when PET and soil conditions are suitable. The amount of silica in the soil determines how reactive and active it is.

Consideration of the soil as an excellent responding soil is aided by its PH level of 7.44. Because soil with a PH below 5.3 often reacts abnormally when exposed to cement and lime. Another significant aspect is the PH level; soil with a PH level below 4.5 or above 10 should be avoided. The soil's tiny amount of SO_3 (0.22%), which is crucial to lowering the number of sulfates that are created, is another significant characteristic.

Chapter Five: Test Result and discussion on the production of Hydra form blocks

5.1 Introduction

Building materials including cement blocks, bricks, and Hydra form blocks must undergo tests that require assessing the block's durability-related characteristics, such as strength and water absorption, as well as monitoring the block's performance in the event of degradation.

The comparison criteria for the outcome is based on the experimental findings and data that have been linked to regional and global trends. The experiments would offer the chance for existing beliefs to be compared to reality, prove the research's hypothesis, and increase production, performance, and awareness of the use of locally available materials in the development of their housing standard and quality, thereby resolving the issue with Ethiopia's housing system.

5.2. Compressive Strength Test

The Hydra form blocks have been produced from the soil stabilized with plastic waste which has been used soil, and plastic waste. In general, this material property affects the overall performance of the block produced. The other things that have been affecting the block performance were compaction pressure and curing conditions. In this experiment, all other variables decided to be fixed except the plastic contents since it was the stabilizer. According to the literature on stabilized soils, the stabilizer was significantly responsible for the improvement in strength, dimension stability, and durability of blocks. The test samples were given time to strengthen before being air-dried for two days at 125 °C, followed by three hours of cooling time. The samples were put in the crushing machine to be checked for strength once the cooling period had passed. The compressive strength was determined using the formula in Eq. (1)

$$\text{Compressive Strength} = \frac{\text{Compressive force on the specimen}}{\text{Area of specimen}} \qquad \text{Eq. (1)}$$

5.3. Effects of Plastic on the Compressive Strength

The 7th, 14th, and 28th days mean compressive strength values of Hydra form blocks stabilized with Plastic waste contents of 50%, 70%, and 80% are shown in Table 5.1 below and all the raw data of cube compressive strength test results are presented in a tabulated form in Appendix D,E , and F and in a graphical form in Figure 5.1.

Tables 5.1 Mean Compressive Result

Days test was conducted	Mix Content	Mean Compressive Strength (MPa)
7th day	MIX A (50% Plastic)	0.98
	MIX B (70% Plastic)	1.55
	MIX C (80% Plastic)	1.33
	Mix D (10% Cement)	0.78
14th day	MIX A (50% Plastic)	2.93
	MIX B (70% Plastic)	3.76
	MIX C (80% Plastic)	3.34
	Mix D (10% Cement)	1.85
28th day	MIX A (50% Plastic)	3.39
	MIX B (70% Plastic)	4.77
	MIX C (80% Plastic)	3.81
	Mix D (10% Cement)	3.46

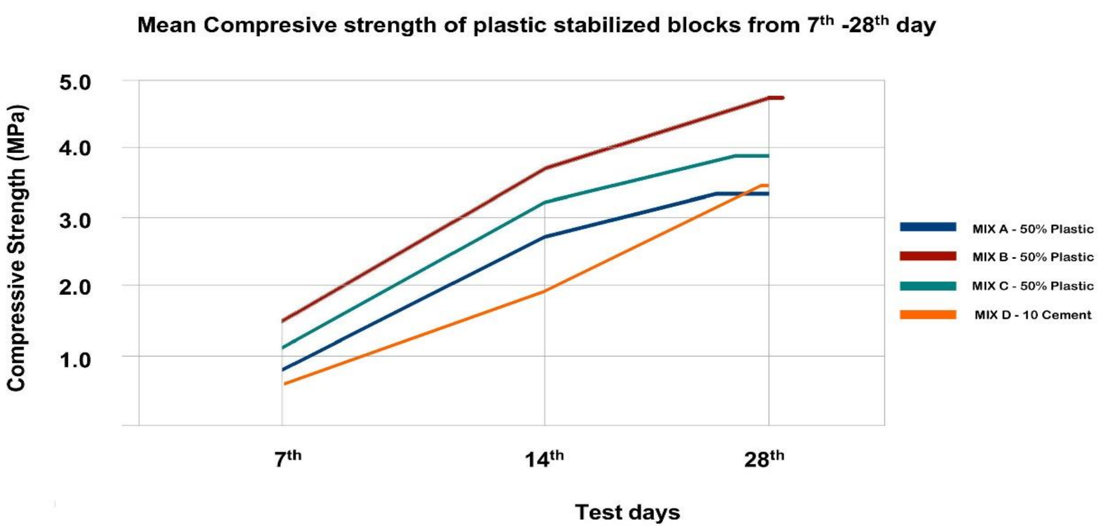


Figure 5.1 Mean compressive strength of plastic stabilized blocks from 7th – 28th day performance

Effect of compaction pressure on the 28th day compressive strength of blocks stabilized with plastic material.

The proposed and locally available trends can be noticed and identified from these test findings in general. It may be concluded from the tabulated data in Appendices C, D, and E that an increase in plastic waste content can lead to a decrease in absolute compressive strength for a given constant compaction pressure. While balancing ration to soil with the plastic waste increase the absolute compressive strength. The soil particles are bound together by the plastic waste gel layer between them, which also strengthens the blocks. The results also show that all of the blocks have 28-day wet compressive strength values well above the majority of the recommended minimum values for use in structural work according to the literature (Alexander Kumi-Larbi Jnr, 2022), with plastic contents ranging from 50% in increments of 70% up to 80% at constant mixing time.

The literature suggests a number of possible minimum values for 28-day wet compressive strength, all above 1.0MPa, which are all determined to be higher than the suggested minimum.

5.4. Water Absorption

The main factor contributing to the deterioration of earth blocks is water absorption. The quick decomposition of earth blocks is facilitated by the high-water absorption. The strength, which is more correlated with the material's porosity, decreases as the moisture content rises. The key factor affecting earth block durability is water absorption. The fundamental idea of stabilization is to stop water attacks in order to create a strong material (A.G.Kerali, 2000).

When the earth is not saturated, earth blocks are resilient. When brick material is exposed to saturated and wet circumstances, durability issues develop. Due to their high-water absorption value, earth bricks deteriorate quickly (A.G.Kerali, 2000). For instance, the issue of rain penetration into buildings must be fixed in order to boost durability. By using appropriate soil and employing effective stabilizing techniques, it is possible to increase the durability of earth blocks and decrease the amount of water that they absorb (C. Egenti, 2013).

The degree of compaction pressure employed, the quantity and kind of stabilizer, and the type of soil used are the main variables impacting the water absorption of hydra form blocks. Stabilizers work to lower the number of interstitial voids, fill empty spaces, and strengthen the bonding between soil grains. (C. Egenti, 2013) Numerous types of stabilizers are employed for different types of soil in order to obtain better mechanical qualities, decreased porosity, limited dimensional changes, and greater resilience to normal and severe exposure conditions. (Tadege, 2007) By mechanically densifying the soil particles in close proximity, compacting the soil will enable the trapped air to be released from the soil mass. The amount of water absorption will be reduced as a result of raising the density of the hydra form blocks through compacting. (A.G.Kerali, 2000)

The soil particle size distribution and the soil's origin determine how much water is absorbed by the blocks that the soil forms. Less water is absorbed in well-graded soil because the grains are tightly packed and occupy the bulk of the spaces. Organic particles in the soil make the soil unsuitable for growing blocks because they will absorb more water. (Tekle, 2018)

The purpose of the water absorption test was to determine how much moisture the block samples could absorb on a percentage basis. Block samples were weighed in a dry lab environment, immersed in water for 24 hours, and then taken out to be weighed again. For the block water absorption test, the ASTM C140 - Standard test methodologies for sampling and testing concrete masonry units and related units - served as the foundation.

5.4.1 Water Absorption Test Result for Plastic Stabilized Hydra Form Blocks

According to the results in Figure 5.4 below, the mean water absorption values of samples A (50% Plastic and 50% Soil), B (70% Plastic and 30% soil), and C (80% plastic and 20% Soil), are 1.5%, 1.0%,1.0% and 1.3% respectively. Compared to mix A, mix B and C show a 0.2 %- 0.5% reduction in block water absorption.

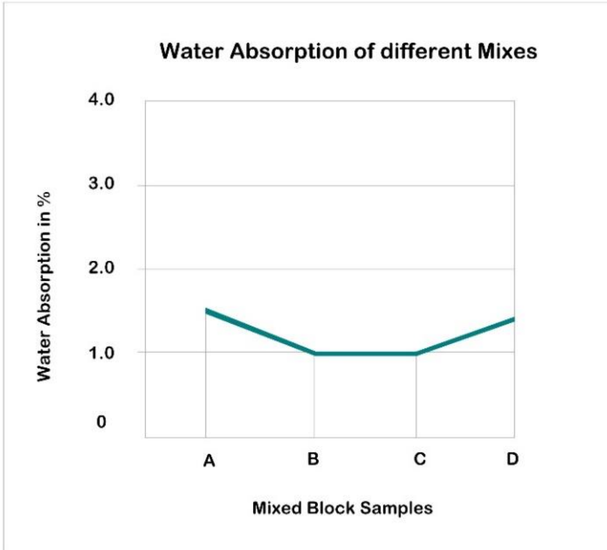


Figure 5.4 – Effects of Plastic stabilizer in the water absorption property of Hydra form Blocks

5.5. Summary

The performance qualities of soil blocks are improved by stabilizing the soil before the production of hydra-form blocks. In this study, polyethylene terephthalate (PET) and polyethylene (PE) are utilized as stabilizers of three different series of mixes that were prepared, and 33 plastic stabilized blocks and 11 cement based blocks were produced from the Kara soil according to the ASTM standard (ASTM Standards, 2008).

According to (ASTM Standards, 2008) sample taking for the compressive strength 3 blocks prepared for each day of testing that's is for 7th, 14th and 28th day compressive day testing and 2 blocks were prepared for water absorption property test. The Selam Technical and Vocational Center in Addis Abeba conducted many standard performance tests using these tests. On the performance of hydra form blocks, the effects of compaction pressure on the quality of soil blocks, the effects of using plastic as a stabilizer in place of cement, and the effects of stabilizer content on the soil blocks' ability to absorb water were also looked at. The conclusions drawn below are based on the findings.

- While increases in stabilizer content increase the compressive strength up to 70%.

Chapter Six: Production Cost

6.1. Production Cost of Hydra form blocks

Selam Technical and Vocational center provided pertinent information on the working circumstances used in this research project for the manufacturing cost calculation of hydra form block. Additionally, the pricing of the raw materials required to make the blocks are based on what materials are currently selling on the market.

6.2. Factors that affect the price of producing hydra form

A. Daily/Annual Production

Depending on the data from the center the size of the block affects the production. The daily production rate for 220*140*115 mm blocks is 1300 blocks. 272 days working annually. They work 24 days of the month, there are 21 days of holiday in Ethiopian Calander.

Days off calculation = 6 days*12 month

= 72 days + 21 days of holiday

Days of calculation = 93 day, subtracting this number from the whole year we get 272 days of working. In this study, the annual production is 353,600 blocks.

For the Plastic stabilized blocks daily production using 2 laborers is 64 blocks/day which is 8 blocks /hour. In the cement based to produce 1300 blocks, 20 laborers are required. Thus, the estimated daily production of plastic blocks with 20 laborers will be 576 blocks with total 8 hours of working hours manually without any hydraulic press. This will give us 156,672 blocks annually.

B. Machine Performance

The machine used for cement-based hydra form block is M7E380, the machine needs a proper maintenance yearly with the replacement of steel pads. This reflects the maximum number of blocks that the Hydra form block forming machine is capable of producing. With proper maintenance.

The machine's annual repairs as well as daily upkeep are included in the maintenance cost. In this study, the machine's annual maintenance costs are estimated to be 2% of the machine's initial purchase price. Thus, the Machine is expected to be maintained yearly.

C. Labor

The per diem cost of daily laborers is estimated at 300ETB/day based on the current market. In addition, 15 workers are needed to produce the daily output.

D. Equipment Cost

The Hydra form block-making machine, soil mixer, soil sieve, wheelbarrow, water can, and plastic sheet are the primary tools and machinery used for producing compressed stabilized earth blocks. The machine costs $14,810 convert this into Ethiopian birr it is 814,550birr, we use the current exchange rate that is 1 USD = 55 ETB.

Depreciation of equipment is determined based on the lifespan, where a major parts substitution needs every 10 years. As a result, the depreciation can be calculated at 6% annually. The computation approach was straight-line depreciation. The salvage value of the machine is 6,000 USD, (Alibaba, 2022)which is 330,000 ETB.

Straight depreciation Formula= (asset cost – salvage value) / useful life Eq.(1)

Depreciation = (814,550 ETB – 330,000 ETB)/ 10years

Depreciation = 48,455, which is 6%

E. Stabilizer content

Various stabilizer contents were utilized as the optimal stabilizer contents. The 28th-day compressive strength of hydra form blocks stabilized by plastic stabilizer alone is more than 2.5 MPa, which is higher than the specified 28th compressive strength of 1 MPa to 2 MPa. (A.G.Kerali, 2000)

F. Soil

The cost of the dirt, which includes the expense of excavating the soil from the source, loading, and unloading, and transportation charges, is estimated at 3 ETB/kg of soil based on the current market price.

G. Profit Margin

Since these bricks are not for sale 20% profit margin is taken for this research work so as to set price.

6.3. Unit Price

Table 6.1 below provides a summary of the data that was utilized to determine unit costs. In Tables 6.2 and 6.3, respectively, the unit cost calculation for the production of hydra form blocks with and without plastic stabilizer are displayed. Since, Mix type B with 70% plastic content shows a better material property it is taken for cost calculation due to the estimation for future market competence.

Table 6-1: Factors affecting Unit Cost

	Production	**Units**
Daily Production	800	Blocks
Annual Production	228,800	Blocks
Items	**Cost**	**Units**
1. Equipment Cost		
Equipment cost with accessories		100,000/year
Maintenance cost		20,000/year
2. Labor Cost		
Laborers Cost/day	300	ETB/day
Forman Salary	6,600	ETB/Month
3. Material Cost		
Soil Price	3	ETB/kg
Cement	100	ETB/kg
Plastic Bottle	5	ETB/Kg

Wood (Fuel)	150	ETB/ day

Table 6-2: Unit Cost of a block with 70% Plastic Content

Fixed Cost			
Fixed	**Initial Cost**	**Percentage**	**Cost/Block**
Equipment depreciation	814,550 ETB	6% per year	1.55
Investment cost (interest)	85,000 ETB	4% per year	0.55
Site duration	200,000 ETB	5% per year	3.54
Miscellaneous		5%	1.55
Profit margin		20%	0.85
Over Head		20%	4.00
Total			**12.04 ETB**
Variable Cost			
Variable	**Cost**	**Amount**	**Cost in ETB**
Daily Cost	2 laborer/day	300 ETB/day/person	10.00
Soil Cost	1kg/ block (30%)	3/kg	55.00
Plastic Material (50%)	22 kg/total blocks (11)	5 ETB/ Kg	10.00
Wood /Fuel	150ETB	150ETB/day	150
Maintenance cost			0.15
Total ETB			**226.15 ETB**

Then we use Unit cost Analysis method to get a unit cost,

Unit Cost = Variable costs + fixed costs /Total number of units produced

Unit Cost= 12.04ETB+ 226.15 ETB/ 11

Unit Cost= 21.6ETB

Table 6.3: Unit Cost of a block with cement and soil

Fixed Cost			
Fixed	**Initial Cost**	**Percentage**	**Cost/Block**
Equipment depreciation	814,550 ETB	6% per year	1.55
Investment cost (interest)	85,000 ETB	4% per year	0.55
Site duration	200,000 ETB	5% per year	3.54
Miscellaneous		5%	1.55
Profit margin		20%	0.85
Over Head		20%	4.00
Total			**12.04 ETB**
Variable Cost			
Variable	**Cost**	**Amount**	**Cost /Block in ETB**
Daily Cost	2 laborer/day	300 ETB/day/person	4.00
Soil Cost	9 kg/ block (90%)	3/kg	264
Cement Cost	0.5 kg/total blocks (11)	100 ETB/ Kg	50
Maintenance cost			0.15
Total ETB			**318.15 ETB**

Then we use Unit cost Analysis method to get a unit cost,

Unit Cost = Variable costs + fixed costs /Total number of units produced

Unit Cost= 12.04ETB+ 318.15 ETB/ 11 blocks

Unit Cost=30 ETB

6.5. Cost Comparison between Cement stabilized and plastic stabilized Hydra forms

The first thing a potential customer would inquire about is whether a structure made of Hydra form block is more cost-effective than one made of any other material. The type of construction must be taken into account first. The cost of the materials used to build walls makes up a very small portion of the overall cost of a luxurious house (Tadege, 2007). However, the price of the blocks makes up a significant portion of the overall cost in the case of low-cost homes, such as those covered by social housing programs.

In Ethiopia, the use of cement-stabilized hydra form is expanding quickly. However, the price is heavily influenced by cement supply and local fees. Even though, both cement-stabilized and plastic bricks are eco-friendly substitutes for conventional bricks. Plastic stabilized bricks are much lighter and more durable than ordinary hydra form due to the plastic's fiber composition. On the other hand, the typical hydra form is heavier and more compact due to the manufacturing process using hydraulic press.

In most African nations, improper plastic trash disposal is turning into a serious environmental problem. Currently, they are engulfing water and landfills, clogging sewage systems, upsetting the natural balance, and destroying an aesthetically pleasing environment. As a result, the life of animals, plants, and people are seriously harmed. More than a century is needed for trash PET bottles to degrade in the natural environment. With its enormous consumption potential, the construction industry is suitable for recycling and using these plastic bottles to stabilize expanding clay soil. Additionally, recycling plastic conserves the fossil fuels used in its production and lowers its carbon footprint (Rebecca Belay Kassa, 2020).

Chapter Seven: Conclusion and Recommendations

7.1. Conclusion

The following conclusions are made as a result of the investigations conducted:

1. The soil from Kara exhibits favorable physical and chemical characteristics for the production of plastic Hydra form blocks as an alternative walling material.
2. This experimental study on PHFBs has shown the effectiveness of using plastic in combination with soil improved 28th-day compressive strength and reduced block water absorption than using cement and soil. A better development has been recorded during the experimental study.
3. Using the same compaction pressure, a higher plastic content can lead to a higher compressive strength. Our research demonstrates that it is possible to create Hydra-form blocks with enough compressive strength by raising compaction pressure and adding Plastic materials to the permitted percentage.
4. The Polyethylene (PE) and Polyethylene terephthalate (PET) used for the stabilization shows more or less equal technical performance on the 28th day, regardless of their chemical composition. The combination of soil and plastic is mutually beneficial in imparting strength to the blocks in a better way because plastic has taken care of stabilizing the sand portion with hydration products obtained from plastic material to stabilize the clay fraction present in the mix.
5. The cost of a hydra form blocks with a combination of cement is 30% more expensive than using a plastic stabilized one, according to a cost comparison between hydra form block prepared using plastic stabilization as a fully replacement to cement and cement stabilized hydra form block prepared. This is brought on by the rising cost of cement and the increased use of soil in cement stabilized blocks.

7.2. Recommendation

Based on the research's findings the following suggestions are made:

1. The findings of this study have shown that plastic-stabilized hydra form blocks can be utilized as an alternative wall-making material. Low-cost housing developments, particularly those in remote and town houses can be benefited from the cost and quality of the material. Any concerned body can use the Kara soil for plastic stabilized hydra form blocks.
2. Since the plastic stabilized hydra form block machine is not applicable in Ethiopia a better manual press machines should be designed and planted locally in terms of preparation and providing also by giving appropriate training to the community so as to improve the housing problem in our context.
3. Due to the quantity and diversity of soil types, particularly in Ethiopia, further research on many types of soils, including clay, sandy clay, and sandy silt soils is crucial.
4. Additional research is needed to better understand the chemical and organic components of soil that impede hydration reactions as well as how the material affects thermal comfort.
5. Using stabilizers as a replacement for cement would help in reducing the consumption of cement. This has significant benefits for the decrease of energy used in the construction of blocks, Especially, when it's done on a bigger scale. In Addition to that, maximizing the utilization of recycling resources, lowering energy use, and reducing environmental pollution, would also aid in the sustainable expansion of society.

BIBLIOGRAPHY

A.G.Kerali, 2000. *Destructive Effects of Moisture on the Long-termDurability of Stabilised Soil Blocks.* India: Development Technology UnitSchool of Engineering, University of Warwick .

A.K. Choudhary, J. J. a. d. K. G., 2010. A study on cbr behavior of waste plastic strip reinforced soil. *Emirates Journal for Engineering Research,* Volume 15 (1), 51-57 (2010), p. 7.

AASHTO, A. A. o. S. H. a. T., 2001. *A policy on geometric design of highway and streets.* Washington, D.C.:

Adam, D. E., 2001. Compressed. In: United Nations Educational, Scientific and Cultural Organization.

Afkari, A., 2010. *Sustainable Low-Cost Housing in, Ethiopia,.* 1 ed. Halmstad University .

Agar, S. H. a. E., 2003. *Use of waste high density polyethylene as bitumen modifier in asphalt concrete mix.* Turkey.

Ahmed, A. B., 2015. Production possibility of hydraform block as walling material for affordable housing in. 1 ed. Jigjiga:

Ahmed, I., 2020. *Usage of plastic bags as soil stabilizer.* 4 ed. Delhi.

Alexander Kumi-Larbi Jnr, 2022. Reuse of Waste Plastics in Developing Countries: Properties of Waste Plastic-Sand Composites. *Springer*, p. 14.

Alibaba, 2022. *Alibaba.* [Online]
Available at: https://www.alibaba.com/showroom/used-hydraform-machine-for-sale.html
[Accessed 2022].

Assefa, M. G., 2019. Investigation of stabilization of expansive soil with plastic bottle strip waste. 1 ed. Addis Ababa.

ASTM Standards, A., 2008. Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units.

Ayele, E., 2001. Policy Impacts on Housing Sector,The Case of Addis Ababa. *Urban Planner,Ministry of Works and Urban Development, Ethiopia* , p. 10.

B. P. Kagonbé, 2021. *Mineralogical, Geochemical and Physico-Chemical Characterization of Clay Raw Materials from Three Clay Deposits in Northern Cameroon.*

Baba Shehu Waziri, 2013. Properties of Compressed Stabilized Earth Blocks (CSEB) For Low-Cost Housing Construction: A Preliminary Investigation. *International Journal of Sustainable Construction Engineering & Technology,* Volume vol 4, No. 2, p. 7.

Boniface Chidi Okoro, 2007. Quality Assessment of Groundwater Sources of Potable Water in Owerri, Imo State, Nigeria. *Arora, K.R. (2007) Irrigation, Water Power and Water Resources Engineering. 4th Edition, Standard Publishers Distributors, Delhi.*

Bruce Nuwagaba, 2018. *Recycling Plastics and steel waste to produce Low Cost sustainable building units.* Kampala.

BSI, B. s., 2016. *A standard for standards –Principles of standardization.*

C. Egenti, 2013. Analysis of expansion and water absorption of composite compressed earth block. 1st ed. United Kingdom,

CDI, 1996. *ARS, Compressed earth blocks standards.*

Chebet, F 2014. Laboratory investigation on re-using polyethylene.

Civeira, G., 2019. Introductory Chapter, Soil Moisture.

Clara Diago, 2007. *Assesment of environmental advantages and drawbacks of existing and emerging polymers recovery process.*

Ernawati Mustafa Kamal,2020. The low-middle income housing challenges in malaysia. *Journal of the Malaysian Institute of Planners,* volume 18 (ISSUE 1), p. 16.

Geyer, R.\ 2017. *Production, use, and fate of all plastics ever.* 3 ed

H.B. Nagaraja, M.V. Sravana, T.G. Aruna, K.S. Jagadish, 2013. Role of lime with cement in long-term strength ofCompressed Stabilized Earth Blocks. *International Journal of Sustainable Built Environment*, p. 7.

Habtemariam Molla, 2012. *Study of stablized mud block as an alternative building material and development of models.* Addis Ababa: Addis Ababa Institute of Technology,.

Harte, D. T. a. B., 2011. *Food and Beverage Packaging Technology.* Second ed.

Head, K., 1980. *Manual of Soil Laboratory Testing.* Wiley, 1980.

Hoog, C., 2021. *PET recycling - Material chemistry and performance aspects.*

Humphrey Danso, 2015. *Influence of compacting rate on the properties of compressed earth.* Accra, Ghana.

Isaac I. Akinwumi, A. H. D.-S. A. S., 2019. Marine plastic pollution and affordable housing challenge Shredded waste plastic stabilized soil for producing compressed earth bricks. *Elsevier* , p. 8.

Jai Prakash, K. 2017. Stabilization of Soil Using Rice Husk Ash. *International Journal of Innovative Research in Science,Engineering and Technology*, 6(7), p. 7.

Jean-Claude Morel, 2007. Compressive strength testing of compressed. *Construction and Building Materials · February 2007*, p. 19.

krishna, B. 2021. A study on time, cost, quality (tcq) and risk management in scheduling of various constrution projects. *IJCRT,* Volume 9, p. 8.

Loganayagan, K. A. a. A. V., 2021. Study on plastic pet bottles characteristics to develop eco-friendly plastic paver blocks. *IOP Conference Series: Materials Science and Engineering,*, Volume 1059, p. 10.

M Pushpa1, M. M. 2. S. K. V. B. 4., 2019. Utilization of waste plastic in manufacture of plastic soil. *International Research Journal of Engineering and Technology (IRJET)* , Volume 06, p. 5.

Makusa, G. P., 2012. *Soil Stabilization Methods and Materials.* Sweden.

Manish Kumar Sahu, L. S., 2017. Critical review on types of bricks type 14: PLASTIC. *International Journal of Mechanical And Production Engineering,* Volume 5, p. 5.

Manjula, A. 2022. Reuse of Waste Plastics in Developing Countries: Properties of Waste. *Waste and Biomass Valorization (,* Volume 1, p. 14.

Mehmet Serkan Kirgiz, P. O. A., 2022. Transforming of Plastic Waste and Ceramic Waste into Construction Material. *Journal of Advanced Composite Materials, Construction, Environment, and Nano Technology,* Volume 1.

MoFED, 2006. *Ethiopia: Building on Progress A Plan for Accelerated and Sustained Development to End Poverty (PASDEP).* Volume I: Main Text ed. Addis Ababa.

Morton, B. L. a. T., 2001. *Building with earth in scotland:.* Scotland: Scottish Executive Central Research Unit.

Programme, N. R. S., 2021. Plastic consumption and recycling in addis ababa,. *Natural Resources Stewardship Programme,* p. 4.

Rebecca Kassa, T. 2020. Soil Stabilization Using Waste Plastic Materials. *Open Journal of Civil Engineering,* Volume 10, p. 14.

Report, W. B., 2007. *Development and Next generation.* Washington Dc.

Rigassi, V. a. C.-E., 1985. *Compressed Earth: Manual OF Production.* 1 ed. Germany: The Deutsches Zentrum fur Entwicklungtechnologien-Gate.

Roland Geyer, J 2017. *Production, use, and fate of all plastics ever.* 3 ed.

S S Chauhan, B. 2019. *Fabrication and Testing of Plastic Sand Bricks.* India: IOP Conference Series: Materials Science and Engineering.

Spon.E.&F.N. Ltd, L., 1985. *Appropriate Building Materials for Low Cost Housing African region, proceedings of a symposium held in Nairobi Kenya from 7 to 14.* 1 ed. Kenya.

Staff, S. S. D., 2017. *Soil Survey Manual.* 3rd ed. s.l.:United States Department of Agriculture.

Tadege, A., 2007. Study of compressed cement stabilised soil. Addis Ababa.

Tegegn, M., 2020. *Stabilization of Expansive Soil Using Plastic Wastes.* Adis Ababa.

Tekle, G., 2018. Study of compressed cement and lime stabilized soil. Addis Ababa.

UN-Habitat, 2021. SDG indicator metadata. Volume 7.

Vasudevan R, N. A., 2006. *Utilization of waste plastics for flexible pavement, Indian Highways Indian RoadCongress,*. Vol. 34, ed. India.

Wadsö, E. S. a. O., 2019. *Material, A survey of recycled plastic waste as an alternative building.* 1 ed. Sweden: E-husets trycker.

Waita, E., 2021. *Kenyan recycles plastic waste into bricks stronger than concrete,* Kenya: https://www.reuters.com/.

World Bank, B., 2007. *Introducing the Adequate Housing Index.* Washington Dc.

World Bank, Group., 2015. *Stocktaking of the Housing Sector in Sub-Saharan Africa Challenges and Opportunities.*

Yang H 2006. *Water absorption behavior and mechanical properties of lignocellulosic filler–polyolefin bio-composites. Composite Structures.*

Yazew, S., 2015. *Study of plastic soil cement for flooring application.* Addis Ababa: Addis Ababa University.

APPENDIX A: Publication

ABSTRACT

Cement is a common stabilizer used in the production of hydra form blocks (HFBs), but limited studies has been done to use plastic as a replacement for cement. This study is intended to investigate the technical and cost of plastic stabilized hydra form blocks to use as an alternative wall-making material. The results of laboratory tests on the soil utilized for the research demonstrated the soil's appropriateness for block manufacturing by providing thorough information on the soil's plasticity, grading, and chemical composition. The investigation has revealed that blocks produced at varying total stabilizer contents from 50% in increments up to 80% at constant compressive pressure, the blocks stabilized with 70% plastic have an increased 28th-day compressive strength than that of the blocks stabilized with cement only. The water absorption of the blocks stabilized with plastic is lower than that of the blocks stabilized with cement. An increment of compaction pressure with the same stabilizer content has shown an increased compressive strength. Two types of plastic material were used in this research, Polyethylene (PE) and the other type is Polyethylene Terephthalate (PET). The cost of hydra-form blocks stabilized with cement is higher than the plastic stabilized hydra-form blocks since the current price of cement is higher than that of plastic material. The cost comparison with the cement-stabilized hydra form has revealed that PHFBs are preferred because it is an economical walling material and permits the use of economical building techniques. This experimental study on PHFBs prepared using plastic as a total replacement to cement has demonstrated the effectiveness of plastic material in enhancing the 7^{th}*,* 14^{th} *, and 28th-day compressive strength than using cement alone. The research findings indicate the need to review the grading of the number and quality of stabilizers to produce high-quality building blocks. It is also advised that hydraulic machinery be used to strengthen the material and reduce air voids by compaction pressure. The experimental research result concludes that it is possible to produce plastic stabilized hydra form blocks using Kara soil to fulfill the compressive strength, which uses no cement, contributes sustainable activity by recycling plastic material, and is adaptable to the environment as walling material for low-cost housing.*

Key Words: Hydra form blocks, Polyethylene Terephthalate (PET), Polyethylene (PE), Soil stabilization, Material property.

INTRODUCTION

Shelter is one of the most essential needs of human life and plays an essential role in creating a sense of belongingness, reduction of vulnerability, and building resilience. Housing refers to a safe physical space with socially, and economically acceptable viable living environments. (UN-Habitat, 2021) In developing nations, most of the population are without adequate housing facilities. (MoFED, 2006)

According to a 2007 identified World Bank report on 152 developing countries, one in three people is without adequate shelter. To address these issues, stakeholders should focus on the provision of low-cost, long-lasting, and technologically advanced materials. While also recognizing the importance of providing adequate shelter for all, access to basic services, safe and healthier shelter is essential to physical, socioeconomic, and psychological well-being, as well as helping to reduce statistics. (World Bank, 2007)

According to (World Bank, 2015), Housing informality is the result of both economic factors that limit household and commercial investment in housing, which limit the production of affordable housing units at a scale to meet needs. Due to a discrepancy between the cost of an affordable housing unit and households' capacity to pay for it, formal housing makes up a very small portion of housing production and consumption in Sub-Saharan Africa, in contrast to developed economies where formality is the norm in both supply and demand. In order to solve the shortage, more efforts are being made to provide more serviceable, cost-effective, energy-efficient sustainable soil construction materials such as, interlocking soil blocks, adobe blocks and sun-dried soil blocks. (Tadege, 2007)

Housing is a major problem in Ethiopian context. The obstacle to the economic development of Ethiopia is related to the access to adequate and affordable housing for the urban poor. Even the existing housing units are categorized as slums due to poor standards, lack of basic services, sanitation, and infrastructure problems (Habtemariam Molla, 2012). In the scheme of poverty reduction providing adequate housing for low and middle-income groups is the major component of urban development. (Ayele, 2001)

The housing situation is the manifestation of demographic factors related to urbanization. An increase in population rate and migration towards urban areas creates overcrowding and squatter settlements. Inadequate housing production has become a distinctive characteristic of most cities. In addition, the extent of such housing problems varies from one urban area to the other due to various constraints like unsafe living condition, sanitation, high density, and insecurity that are common in such urban areas (UN-2 NUN-Habitat, 2008).

According to (Tadege, 2007), there is a need to provide a sustainable low-cost dwelling for the community. It's significantly important to use existing technologies and easily implement them with available resources in different regions.

Hydra form blocks are among these technologies (Baba Shehu Waziri, 2013). In this research, Hydra form blocks (HFB) are considered as an alternative walling material. Stabilizers play a vital role in the production of Hydra form blocks (HFB) so as to provide adequate compressive strength and durability (Ahmed, 2015). As a result, this experimental study on HFB will be performed by using plastic stabilization as a full replacement for cement to stabilize the blocks based on cost and material property efficiency value.

RESEARCH METHODOLOGY

All laboratory investigations on materials are carried out in the Selam Technical and vocational center in Addis Ababa and the production of the blocks was carried out in the block yard of the center.

This research has involved two methodological approaches:

1.The theory chapter is mainly based on books, academic reports, and journals that have been found by searching databases such as google scholar. Hydra form Blocks, plastic, soil stabilization, compressive strength, and water absorption.

2.Develop an Experimental prototype to prove the physical property of the material in regard to engineering aspects such as compressive strength, water absorption, and others.

2.2 Materials Preparation

The soil used in this study came from Kara, a place around 15 kilometers east of Addis Ababa. Drying and screening soil samples to the desired size were used to prepare them. The results of the laboratory tests are used to calculate numerical values for the soil sample parameters. These figures are then used to determine whether the soil sample is suitable for compressed stabilized earth blocks. The physical properties of the soil are given in the table below (Tekle, 2018).

Table 1: Physical Properties of Soil

No.	Physical Properties	Value
1.	Specific gravity	2.59
2.	Clay Content	15.2%
3.	Silt Content	16.3%
4.	Sand Content	68.5%
5.	Plastic Index	9.4%
6.	Plastic Limit	24.4%
7.	Liquid Limit	33.8%
8.	Moisture content	5.33%

Polyethylene terephthalate is a member of the polyester family of polymers, which is one of the largest and most diversified. The common trait of this family of polymers is the presence of an ester (-COO-) link in the main chain, but the diversity of polyester materials is likely the widest of all the polymer families. Furthermore, PET's chemical structure consists of only three atomic species: carbon, hydrogen, and oxygen. As a result, melting PET does not produce harmful fumes, and its characteristics indicate that a melting temperature of 260 o C is necessary. It is also clear from the PET's qualities that it has high chemical resistance as well as greater UV resistance (M Pushpa1, 2019).

PET is made up of three elements: carbon, oxygen, and hydrogen. When PET is burned, only water and carbon dioxide are generated. As a result, even though PET melting was all that was required in this circumstance, there is no risk of inflicting harm through gas emissions. The physical property of PET is described in the following table (M Pushpa1, 2019).

Table 2: Physical Properties of Plastic

No.	Chemical Oxides	Compositions
1.	SiO_2	64.22
2.	Al_2O_3	16.66
3.	CaO	1.3
4.	Fe_2O_3	5.48
5.	MgO	0.42
6.	Na_2O	1.9
7.	MnO	0.1
8.	K2O	2.84
9.	P2O5	0.03
10.	H_2O	1.82
11.	TiO_2	0.24
12.	LOI	4.95
13.	CI	<0.01
14.	SO3	0.22
15.	PH	7.44

2.3 Methods

Some of the geotechnical properties of the natural soil were investigated. The tests conducted include sieve analysis, specific gravity, Atterberg limits, and compaction. Moisture Content of Soil was carried out in accordance with ASTM D 2216, Plastic Limit Determination was used according to ASTM D 2216 -92 Sieve and hydrometer analyses were carried out in accordance with ASTM D422-63, while the specific gravity was done in accordance with ASTM D854-00. Atterberg limits tests were conducted in accordance with ASTM D4318-00, while the standard Liquid Limit Determination was done in accordance with ASTM D 2216 -92. The soil with varying percentages of waste plastic (50, 70, and 80%) was proportioned by mass and mixed at optimum moisture content. The bricks were formed using a manual mould.

Compressive Strength Test

The Hydra form blocks have been produced from the soil stabilized with plastic waste which has been used soil, and plastic waste. In general, this material property affects the overall performance of the block produced. The other things that have been affecting the block performance were curing conditions. In this experiment, all other variables decided to be fixed except the plastic contents since it was the stabilizer. According to the literature on stabilized soils, the stabilizer was significantly responsible for the improvement in strength, dimension stability, and durability of blocks.

The test samples were given time to strengthen before being air-dried for two days at 125 °C, followed by three hours of cooling time. The samples were put in the crushing machine to be checked for strength once the cooling period had passed.

$$\text{Compressive Strength} = \frac{\text{Compressive force on the specimen}}{\text{Area of specimen}}$$

The blocks were measured and weighed after being dried for intervals of 7, 14, and 28 days, with average block size. A compression test apparatus with a 2000 KN maximum load was used to test it. The machine has been approved and calibrated by Ethiopian Standard and Quality Control Agency for the duration of the test.

Water Absorption Test

The main factor contributing to the deterioration of earth blocks is water absorption. The quick decomposition of earth blocks is facilitated by high-water absorption. The strength, which is more correlated with the material's porosity, de-creases as the moisture content rises. The key factor affecting earth block durability is water absorption. The fundamental idea of stabilization is to stop water attacks in order to create a strong material (A.G.Kerali, 2000).

The soil particle size distribution and the soil's origin deter-mine how much water is absorbed by the blocks that the soil forms. Less water is absorbed in well-graded soil because the grains are tightly packed and occupy the bulk of the spaces. Organic particles in the soil make the soil unsuitable for growing blocks because they will absorb more water (Tekle, 2018).

LABORATORY TESTS

Soil that is ideal for producing Hydra form blocks is examined from the perspective of particle grading and plasticity, considering the underlying mechanisms responsible for strength and durability. The literature on soil testing often outlines a number of significant tests yet does not provide a rational schedule of execution. In the following section, the laboratory outcomes regarding soil tests for suitability are discussed and further analyzed. The main reason behind this is to create an understanding of the need for various soil testing while reading this topic. the laboratory study includes the necessary tests like chemical composition, soil grading, and plasticity. The soil from the Kara area is taken as a sample for the laboratory test and all the necessary tests have been carried out.

Sample blocks are made using various plastic types and content based on the results of soil testing, and the blocks are evaluated for compressive strength and water absorption capacity at various time intervals, including 7, 21and 28 days (Rebecca Belay Kassa, 2020).

In this research work, only a few characteristics that are important for producing compressed plastic stabilized soil blocks are taken into consideration. When making compressed plastic stabilized soil blocks, the physical properties are more crucial because they affect the material's porosity, permeability, shrinkage, dry strength, bulk density, and ease of mixing, forming, and placement. Particle size analysis and plasticity index are the two main metrics used to describe soil samples in general. The plasticity index indicates the cohesiveness of the fines, while the particle size analysis provides information on the soil's capacity to pack into a compact structure and the number of fines present (combined silt and clay percentage). The laboratory tests were per-formed to aid in determining numerical values for the properties of the soil sample, particularly the percentage distribution of the various soil particle sizes present and the plasticity limitations. These numbers are then used to determine whether the soil sample is suitable for block manufacture (Ahmed, 2015).

Particle Size Distribution

The soil sample's various size fractions were divided into distinct portions by the combined sieving and hydrometer tests, providing information about the particle grading of the soil. Figure 3 below shows a plot of the outcomes of these tests.

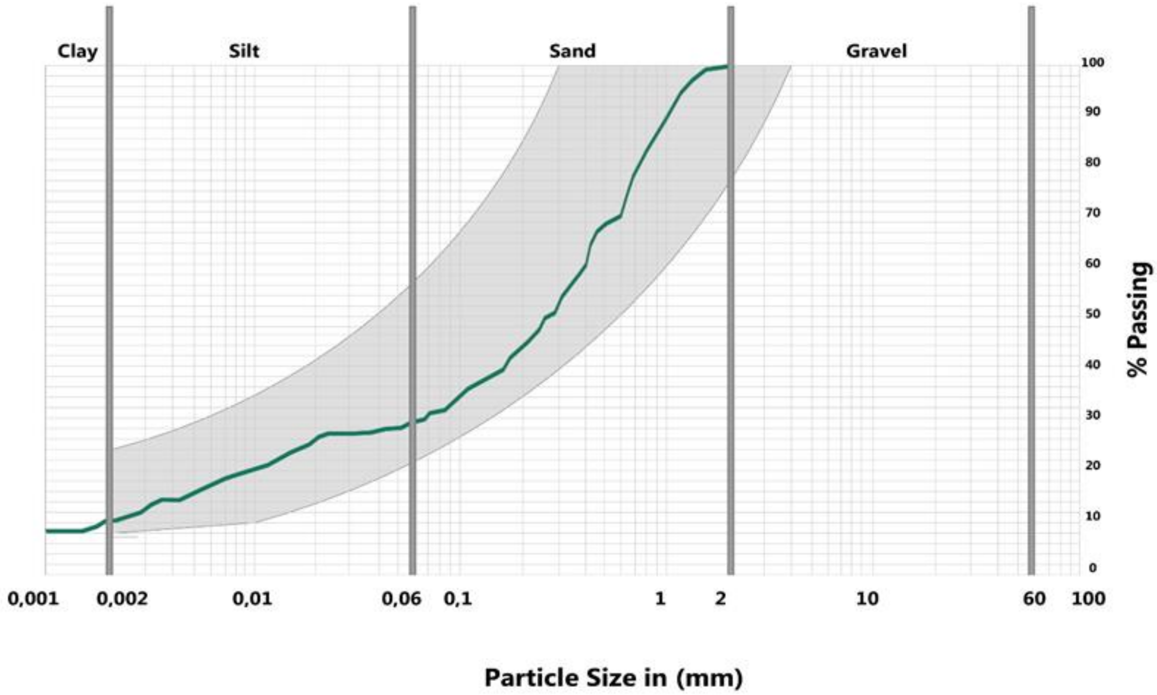


Figure 3 Distribution of Particle size in the soil used

Based on the aforementioned curve, the following groups represent the actual soil composition utilized to create com-pressed stabilized earth blocks: Silt, at 16.3%, Silt, at 16.3%, and Clay, at 15.2%. Now that this conclusion has been obtained, it is feasible to assess the soil's appropriateness. based on regional standards for Africa (ARS). in accordance with ARS 680:1996 Code of Practice for the manufacturing of com-pressed earth blocks (Humphrey Danso, 2015).

When the soil's granular composition falls inside the shaded area of the textural diagram given in Graph 4.2. the outcome is good. As seen in Figure 3 on the previous page, the gradation curve of the soil sample utilized for the research perfect-ly fits inside the shaded region of the texture diagram, as illustrated in Figure 4 below. It follows that the sample soil selected satisfies this criterion.

Atterberg's Limit

The liquid and plastic limits, respectively, are determined by Atterberg's or plasticity tests, which also determine the moisture content at which the soil transitions from a liquid to a plastic state and from a plastic state to a solid one. The findings of the soil sample's Atterberg limit test are shown in Table 3.

Table 3 Atterberg's limit test results of soil used in the study

Atterberg Limit	%
Plasticity Index	9.4%
Plastic Limit	24.4%
Liquid Limit	33.8%

Liquid Limit

The liquid and plastic limits, respectively, are determined by Atterberg's or plasticity tests, which also determine the moisture content at which the soil transitions from a liquid to a plastic state and from a plastic state to a solid one. The plastic limit is created using the ASTM D 2216-92 method, the red point located in the shaded region indicates the suitability of the KARA soil for the production of Hydra form.

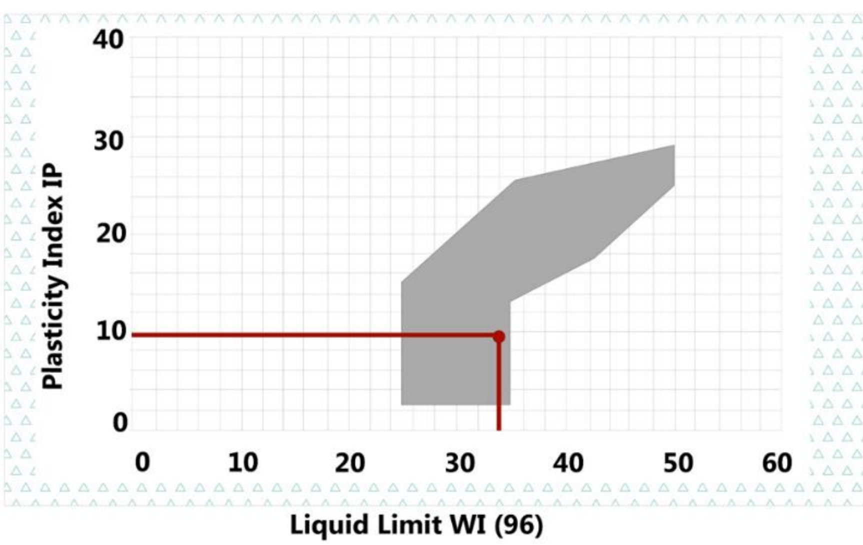


Figure 4 Distribution of Particle size in the soil used

Soil Compression

The suitability of the soil sample for the liquid limits and plasticity index has been evaluated, and since the soil is deemed suitable, further tests will be conducted on it. compression tests are performed on the soil samples. The air spaces between the soil particles can be removed by compacting the soil particles closer together. This is a practical and affordable method of enhancing the soil's qualities. The dry unit weight (dry density) of the compacted soil can be used to express the qualities of the soil (Ahmed, 2015).

The standard proctor test, a common compaction test carried out in a lab, is typically decided by the ideal moisture con-tent and maximum dry density of the soil samples. The soil sample's ideal moisture content (OMC) and maxi-mum dry density (MDD) are displayed in the graph above at point "A". The soil's MDD and OMC were 1840 kg/m3 and 15%, respectively.

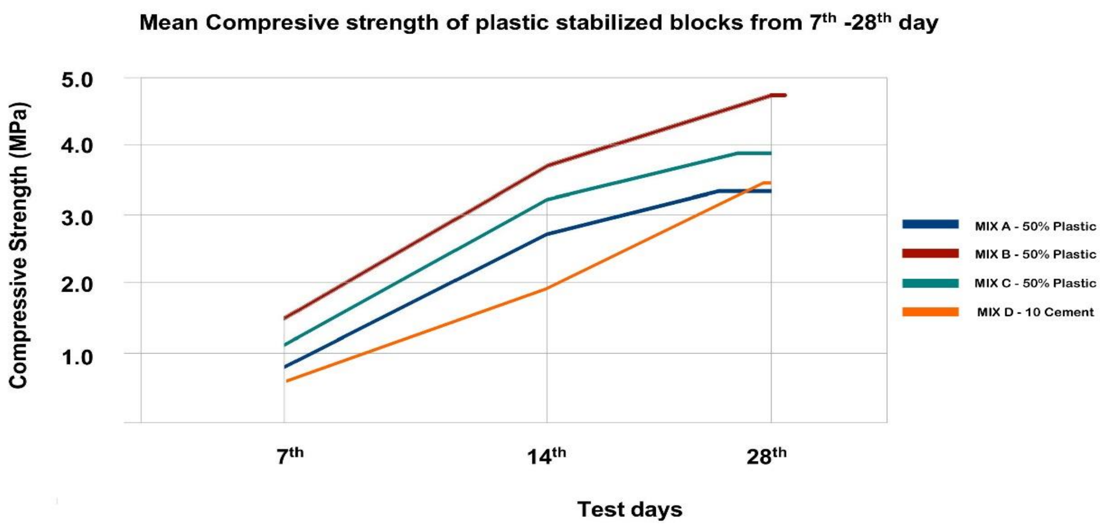
RESULTS AND DISCUSSION

Building materials including cement blocks, bricks, and Hydra form blocks must undergo tests that require assessing the block's durability-related characteristics, such as strength and water absorption, as well as monitoring the block's performance in the event of degradation. The comparison criteria for the outcome are based on the experimental findings and data that have been linked to regional and global trends. The experiments would offer the chance for existing beliefs to be compared to reality, prove the research's hypothesis, and in-crease production, performance, and awareness of the use of locally available materials in the development of their housing standard and quality, thereby resolving the issue with Ethiopia's housing system.

Effects of Plastic and Soil on the compressive strength of blocks

The 7th, 14th, and 28th days mean compressive strength values of Hydra form blocks stabilized with Plastic waste contents of 50%, 70%, and 80% are shown in Table 3 below and all the raw data of cube compressive strength test results are presented in a tabulated and graphical form in Table 4.

Table 4 Mean Compressive Result



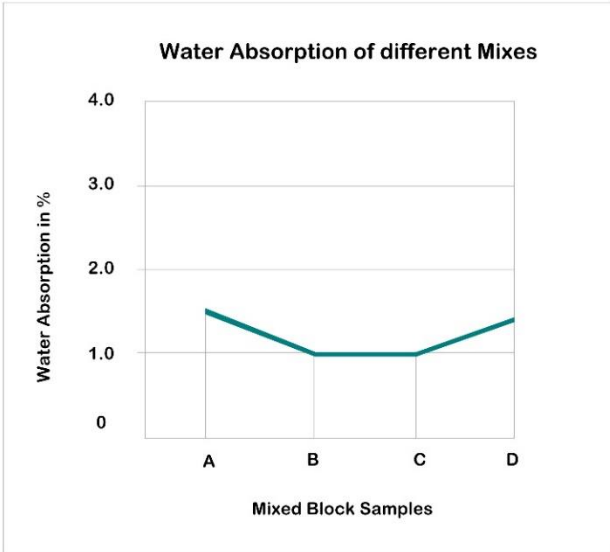
The proposed and locally available trends can be noticed and identified from these test findings in general. It may be concluded from the tabulated data in Appendices D, E, and F that an increase in plastic waste content can lead to a decrease in absolute compressive strength for a given constant compressive pressure.

While balancing the ratio of topsoil with plastic waste in-creases the absolute compressive strength. The soil particles are bound together by the plastic waste gel layer between them, which also strengthens the blocks. The results also show that all of the blocks have 28-day wet compressive strength values well above the majority of the recommended minimum values for use in structural work according to the literature, with plastic contents ranging from 50% in increments of 70% up to 80% at constant compressive pressure. The literature suggests a number of possible minimum values for 28-day wet compressive strength, all above 1.0MPa, which are all determined to be higher than the suggested minimum.

4.2. EFFECTS OF WATER ABSORPTION

According to the results in Table 6 below, the mean water absorption values of samples A (50% Plastic and 50% Soil), B (70% Plastic and 30% soil), and C (80% plastic and 20% Soil), are 1.5%, 1.0%, and 1.0% respectively. Compared to mix A, mix B and C show a 0.5% reduction in block water absorption

Table 5: Mix Proportion



CONCLUSION

The performance qualities of soil blocks are improved by stabilizing the soil before the production of hydra-form blocks. In this study, polypropylene (PP) and polyethylene (PE) are utilized as stabilizers of three different series of mixes that were prepared and 10 soil blocks were produced from the Kara soil.

The Selam Technical and Vocational Center in Addis Ababa conducted many standard performance tests using these tests. On the performance of hydra form blocks, the effects of compaction pressure on the quality of soil blocks, the effects of using plastic as a stabilizer in place of cement, and the effects of stabilizer content on the soil blocks' ability to absorb water were also looked at. The conclusions drawn below are based on the findings.

- Increases in compaction pressure improve the compressive strength of hydra form blocks.
- while increases in stabilizer content increase the compressive strength and reduce water absorption capacity.

- Additions of plastic combined with soil show less block water absorption than those made with cement and soil.

The following Conclusions are drawn based on the results obtained from the study.

1. The soil from Kara exhibits favorable physical and chemical characteristics for the production of plastic Hydra form blocks as an alternative walling material.
2. This experimental study on hydra-form blocks has shown that using plastic is more successful than using cement in improving 28th-day compressive strength and reducing block water absorption.
3. This experimental study on PHCBs has shown the effectiveness of using plastic in combination with soil improved 28th-day compressive strength and reduced block water absorption than using cement and soil. A better development has been recorded during the experimental study.
4. Using the same compaction pressure, a higher plastic content can lead to a lower compressive strength. Our research demonstrates that it is possible to create Hydra-form blocks with enough compressive strength by raising compaction pressure and adding Plastic materials to the permitted percentage.
5. The Polypropylene (PP) and Polyethylene (PE) used for the stabilization shows more or less equal technical performance on the 28th day, regardless of their chemical composition. The combination of soil and plastic is mutually beneficial in imparting strength to the blocks in a better way because plastic has taken care of stabilizing the sand portion with hydration products obtained from plastic material to stabilize the clay fraction present in the mix.
6. The cost of a compressed stabilized soil block with a combination of cement is 1.5% more expensive than using a plastic stabilized one, according to a cost comparison between hydra form block prepared using plastic stabilization as a replacement to cement in certain proportions and cement stabilized hydra form block prepared. This is brought on by the rising cost of cement and the increased use of soil.

APPENDIX B

Physical Property of Soil

Table 1 Moisture Content of Soil

Method – ASTM D 2216

Determination	**1**	**2**	**3**
Weight of Can + moist soil, W1(g)	197.65	197.4	197.42
Weight of Can + dry soil, W2(g)	190.55	190.2	190.33
Weight of can, Wc(g)	64.93	62.51	63.45
Weight of water, Ww(g)	7.1	7.2	7.09
Weight of dry soil, Ws(g)	125.62	127.69	126.88
Moisture Content	5.35%	5.34%	5.29%
	5.33%		

Table 2 Plastic Limit Determination

Method – ASTM D 2216 -92

Determination	**1**	**2**	**3**
Weight of Can + moist soil, W1(g)	21.4	21.07	21.1
Weight of Can + dry soil, W2(g)	20.63	20.27	20.3
Weight of can, Wc(g)	17.5	17	17
Weight of water, Ww(g)	0.77	0.8	0.8
Weight of dry soil, Ws(g)	3.13	3.27	3.3
Plastic Limit (%)	24.6%	24.5%	24.2%
	24.4%		

Table 3 Liquid Limit Determination

Method – ASTM D 2216 -92

Determination	**1**	**2**	**3**	**4**
Number of Drops	150	210	235	245
Weight of Can + moist soil, W1(g)	44.2	37.1	36.537	37.8
Weight of Can + dry soil, W2(g)	41.9	35.3	34.1	35.3
Weight of can, Wc(g)	35	30	27	28
Weight of water, Ww(g)	2.3	1.8	2.4	2.5
Weight of dry soil, Ws(g)	6.9	5.3	7.1	7.3
Plastic Limit (%)	33.3%	34.0%	33.8%	34.2%
	33.8%			

Table 4 Specific Gravity Test

Method – ASTM D 854

Determination	**1**	**2**	**3**
Weight of pycnometer+ Soil+ Water(m^3)	80.35	84.42	82.55
Weight of pycnometer+ Soil+ Water(m^4)	75.86	79.12	77.42
Weight of pycnometer+ Soil (m^2)	33.29	37.91	36.52
Weight of pycnometer (M1)	25.98	29.25	27.62
Temperature	23	23	23
Specific Gravity	2.59	2.58	2.6
Average Specific Gravity	**2.59**		

Table 5 Sieve Analysis

Method – ASTM D 422

Sieve Size (mm)	Weight retained (gm)	% retained	Cumulative Retained	Cumulative Passing
2	0	0.00%	0.00%	100%
1.18	13	6.50%	6.50%	93.50%
0.6	41	20.50%	27.00%	73.00%
0.3	43	21.50	48.50%	51.50%
0.15	23	11.50%	60.00%	40.00%
0.075	17	8.50%	68.50%	31.50%
PAN	63	31.50%	100.00%	0.00%

Table 6 Hydrometer Analysis

Method – ASTM D 422

Time Elapsed (min)	Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Temperature (^oC)	Finer
2	1.018	0.002	1.016	21	30.5
5	1.017	0.002	1.015	21	29.1
15	1.015	0.002	1.013	21	24.3
30	1.013	0.002	1.011	21.5	21.8
60	1.012	0.002	1.01	21.5	19.1
250	1.011	0.002	1.009	20	15.8
1440	1.01	0.002	1.008	20	13.1

APPENDIX C

Chemical Composition of Plastic materia

S.No	Particular	Value
1.	Coefficient of Thermal Expansion	7 x 10-3/ºC
2.	Water Absorption	0.07 – 0.10%
3.	Melting Point	260ºC
4.	Long-Term Service Temperature	115 - 170ºC
5.	Specific Gravity	1.3-1.4
6.	Elasticity Modulus	9
7.	Tensile creep strength	8
8.	Bending creep Modulus	1
9.	Elongation at break (%)	>600
10.	Thermal Conductivity	0
11.	Ignition Temperature	3

APPENDIX D

7th Day Compressive Strength Test Result

Mix A (50% Soil and 50% Plastic material)										
Marking	**Casting Date**	**Testing Date**	**Age**	**Mass (Kg)**	**L**	**W**	**H**	**Unit Weight**	**Compressive Strength**	**Average Compressive Strength (Mpa)**
A1	10/06/2023	16/06/2023	7	3.2	22.0	22.4	11.5	2.5	0.95	**0.98**
A2	10/06/2023	16/06/2023	7	3.15	22.0	22.4	11.5	2.2	0.99	
A3	10/06/2023	16/06/2023	7	3.2	22.0	22.4	11.5	2.1	0.98	

Mix B (30% Soil and 70% Plastic material)										
Marking	**Casting Date**	**Testing Date**	**Age**	**Mass (Kg)**	**L**	**W**	**H**	**Unit Weight**	**Compressive Strength**	**Average Compressive Strength (Mpa)**
B1	10/06/2023	16/06/2023	7	3.2	22.0	12.0	11.5	2.5	1.58	**1.57**
B2	10/06/2023	16/06/2023	7	3.15	22.0	12.0	11.5	2.2	1.55	
B3	10/06/2023	16/06/2023	7	3.2	22.0	12.0	11.5	2.1	1.59	

Mix C(20% Soil and 80% Plastic material,										
Marking	**Casting Date**	**Testing Date**	**Age**	**Mass (Kg)**	**L**	**W**	**H**	**Unit Weight**	**Compressive Strength**	**Average Compressive Strength (Mpa)**
C1	10/06/2023	16/06/2023	7	3.2	22.0	12.0	11.5	2.5	1.32	**1.33**
C2	10/06/2023	16/06/2023	7	3.15	22.0	12.0	11.5	2.2	1.33	
C3	10/06/2023	16/06/2023	7	3.2	22.0	12.0	11.5	2.1	1.35	

APPENDIX E

14th Day Compressive Strength Test Result

Mix A (50% Soil and 50% Plastic material)										
Marking	**Casting Date**	**Testing Date**	**Age**	**Mass (Kg)**	**L**	**W**	**H**	**Unit Weight**	**Compressive Strength**	**Average Compressive Strength (Mpa)**
A1	10/06/2023	23/06/2023	14	3.2	22.0	22.4	11.5	2.5	2.90	**2.95**
A2	10/06/2023	23/06/2023	14	3.15	22.0	22.4	11.5	2.2	2.98	
A3	10/06/2023	23/06/2023	14	3.2	22.0	22.4	11.5	2.1	2.97	

Mix B (30% Soil and 70% Plastic material)										
Marking	**Casting Date**	**Testing Date**	**Age**	**Mass (Kg)**	**L**	**W**	**H**	**Unit Weight**	**Compressive Strength**	**Average Compressive Strength (Mpa)**
B1	25/10/2022	23/06/2023	14	3.2	22.0	12.0	11.5	2.5	3.77	**3.75**
B2	10/06/2023	23/06/2023	14	3.15	22.0	12.0	11.5	2.2	3.76	
B3	10/06/2023	23/06/2023	14	3.2	22.0	12.0	11.5	2.1	3.74	

Mix C (20% Soil and 80% Plastic material,)										
Marking	**Casting Date**	**Testing Date**	**Age**	**Mass (Kg)**	**L**	**W**	**H**	**Unit Weight**	**Compressive Strength**	**Average Compressive Strength (Mpa)**
C1	10/06/2023	23/06/2023	14	3.2	22.0	22.4	11.5	2.5	3.34	**3.34**
C2	10/06/2023	23/06/2023	14	3.15	22.0	22.4	11.5	2.2	3.35	
C3	10/06/2023	23/06/2023	14	3.2	22.0	22.4	11.5	2.1	3.34	

APPENDIX F

28th Day Compressive Strength Test Result

Mix A (50% Soil and 50% Plastic material)										
Marking	**Casting Date**	**Testing Date**	**Age**	**Mass (Kg)**	**L**	**W**	**H**	**Unit Weight**	**Compressive Strength**	**Average Compressive Strength (Mpa)**
A1	10/06/2023	07/07/2023	28	3.2	22.0	12.0	11.5	2.5	3.43	**3.41**
A2	10/06/2023	07/07/2023	28	3.2	22.0	12.0	11.5	2.2	3.40	
A3	10/06/2023	07/07/2023	28	3.2	22.0	12.0	11.5	2.1	3.42	

Mix B (30% Soil and 70% Plastic material,)										
Marking	**Casting Date**	**Testing Date**	**Age**	**Mass (Kg)**	**L**	**W**	**H**	**Unit Weight**	**Compressive Strength**	**Average Compressive Strength (Mpa)**
B1	10/06/2023	07/07/2023	28	3.2	22.0	12.0	11.5	1.5	4.70	**4.77**
B2	10/06/2023	07/07/2023	28	3.15	22.0	12.0	11.5	1.6	4.79	
B3	10/06/2023	07/07/2023	28	3.2	22.0	12.0	11.5	1.5	4.82	

Mix C (20% Soil and 80% Plastic material,)										
Marking	**Casting Date**	**Testing Date**	**Age**	**Mass (Kg)**	**L**	**W**	**H**	**Unit Weight**	**Compressive Strength**	**Average Compressive Strength (Mpa)**
C1	10/06/2023	07/07/2023	28	3.2	22.0	12.0	11.5	1.5	3.80	**3.81**
C2	10/06/2023	07/07/2023	28	3.15	22.0	12.0	11.5	1.6	3.85	
C3	10/06/2023	07/07/2023	28	3.2	22.0	12.0	11.5	1.5	3.79	

APPENDIX G

7th-28th Day Compressive Strength Test Result

Mix D (90% Soil and 10% Cement)										
Marking	**Casting Date**	**Testing Date**	**Age**	**Mass (Kg)**	**L**	**W**	**H**	**Unit Weight**	**Compressive Strength**	**Average Compressive Strength (Mpa)**
D1	09/06/2023	15/06/2023	07	10	22.0	12.0	11.5	-	0.70	**0.78**
D2	09/06/2023	15/06/2023	07	10	22.0	12.0	11.5	-	0.80	
D3	09/06/2023	15/06/2023	07	10	22.0	12.0	11.5	-	0.85	

Mix D (90% Soil and 10% Cement)										
Marking	**Casting Date**	**Testing Date**	**Age**	**Mass (Kg)**	**L**	**W**	**H**	**Unit Weight**	**Compressive Strength**	**Average Compressive Strength (Mpa)**
D1	09/06/2023	22/06/2023	14	10	22.0	12.0	11.5	-	1.90	**1.85**
D2	09/06/2023	22/06/2023	14	10	22.0	12.0	11.5	-	1.85	
D3	09/06/2023	22/06/2023	14	10	22.0	12.0	11.5	-	1.80	

Mix D (90% Soil and 10% Cement)										
Marking	**Casting Date**	**Testing Date**	**Age**	**Mass (Kg)**	**L**	**W**	**H**	**Unit Weight**	**Compressive Strength**	**Average Compressive Strength (Mpa)**
D1	09/06/2023	06/07/2023	28	10	22.0	12.0	11.5	-	3.43	**3.46**
D2	09/06/2023	06/07/2023	28	10	22.0	12.0	11.5	-	3.50	
D3	09/06/2023	06/07/2023	28	10	22.0	12.0	11.5	-	3.45	

APPENDIX H

Water absorption

Type	**Sample**	**Absorbed Water**	**Mean Absorbed**
A	1	1.42	**1.5%**
	2	1.55	
B	1	1.0	**1.0%**
	2	1.2	
C	1	1.2	**1.0%**
	2	1.0	
D	1	1.3	**1.3%**
	2	1.4	

APPENDIX I

Production Process

Soil

Melting process

Collected Plastic Bottle

APPENDIX J

Produced Blocks

Produced Brick with 110mm sizes

APPENDIX K

Physical Property Evaluation