Jimma University

School of Graduate Studies

Jimma Institute of Technology

School of Civil and Environmental Engineering

Construction Engineering and Management Stream

# Comparative Study on Compressive Strength of Locally Produced Fired Clay Bricks And Stabilized Clay Bricks With Cement And Lime In Jimma Town.

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Construction Engineering and Management Stream)

By: **Miskir G/hiwot**

September, 2016

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Advisor**: Prof. Emer T. Quezon**

Co- Advisor: **Engr. Getachew Kebede**

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**SCHOOL OF GRADUATE STUDIES**

**JIMMA INSTITUTE OF TECHNOLOGY**

**SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**

**CONSTRUCTION ENGINEERING AND MANAGEMENT CHAIR**

# Comparative Study on Compressive Strength of Locally Produced Fired Clay Bricks and Stabilized Clay Bricks with Cement and Lime in Jimma Town.

By: MISKIR G/HIWOT

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# Declaration

I, the undersigned, declare that this thesis entitled **"Comparative Study On Compressive Strength Of Locally Produced Fired Clay Bricks And Stabilized Clay Bricks With Cement And Lime In Jimma Town."** is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for these have been dually acknowledged.

Candidate:

**Ms. Miskir G/hiwot**

Signature : _________________________

As Master research Advisors, we here by certify that we have read and evaluate this Msc research prepared under our guidance, by Ms. Miskir G/hiwot entitled: "**Comparative Study On Compressive Strength Of Locally Produced Fired Clay Bricks And Stabilized Clay Bricks With Cement And Lime In Jimma Town.**"

We recommend that it can be submitted as fulfilling the MSc Thesis requirements.

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# Abbreviations

| | |
|---|---|
| AASHTO | American association of state highway and transportation |
| ASTM | American society for testing and materials |
| BS | British standard |
| CSCB | Cement stabilized clay brick |
| ES | Ethiopian standard |
| FCB | Fired clay brick |
| IS | Indian Standard |
| JIT | Jimma institute of technology |
| LSCB | Lime stabilized clay brick |
| MDD | Maximum dry density |
| Mpa | Mega Pascal |
| OMC | Optimum moisture content |
| OPC | Ordinary Portland Cement |
| PCA | Portland cement association |
| $P_L$ | Plastic limit |
| SCB | Stabilized clay bricks |
| $W_L$ | Liquid limit |

# Abstract

*Housing is one of the basic needs of human beings. The local fired brick production technique is the known method of brick making especially in Jimma town. Firing of bricks in local brick production method is conducted by burning of much amount of woods. But this method of firing bricks by burning of woods will affect the environment. Additionally the locale firing technique is difficult to control firing temperature which will result in non-uniform burnt bricks.*

*The major objective of this experimental study was to compare the compressive strengths of locally fired clay bricks and the local unfired cement and lime stabilized clay bricks. And specifically to determine the index properties of soil used for brick production, to determine the compressive strength of locally fired clay bricks and stabilized clay bricks and to compare the determined compressive strength of local fired and stabilized clay bricks with different standards.*

*The index properties of the soil used for local brick production were determined in the laboratory. The contents of the stabilizers were 10%, 12% and 14% lime and cement. The mix ratio was 1:9, 1:7 and 1:6 by volume of stabilizer to clay for 10%, 12% and 14% respectively.*

*Based on the 28$^{th}$ day mean compressive strength test results, the 10%,12% and 14% cement Stabilized clay bricks have compressive strengths of **2.91Mpa, 3.28Mpa** and **3.79Mpa** respectively which are better than the mean compressive strength of the locally fired clay bricks which is **2.73Mpa**. The 28th day mean compressive strengths of the lime stabilized clay bricks were **2.19Mpa**, **2.51Mpa** and **2.69Mpa** respectively. The Fired Clay Brick fails the minimum mean compressive strength requirement of ES, ASTM and IS standards. But the Stabilized Clay Bricks fulfills the minimum compressive strength requirements of IS standard for stabilized bricks.*

*Finally the cement stabilized clay bricks were better in quality than both locally fired and lime stabilized bricks. Therefore, concerned government bodies, small and micro brick production enterprises and users of local bricks shall adopt the stabilization technique.*



**Keywords: Cement, Compressive Strength, Fired clay bricks, Index properties, Lime and Stabilization,**

# CHAPTER ONE
# INTRODUCTION

## 1.1. Background

Construction industry is one of the biggest industries in Ethiopia. This industry comprises housing construction, road construction, industrial construction etc. Construction materials are the major requirement for the achievement of the paper work of construction industry in to real. They are different construction materials in building construction. Among these the locally produced fired clay bricks are the most abundant construction material in area of large availability of clay material.

The housing problems in Ethiopia is a very critical issue that not only its poor condition and level of affordability but also its critical degradation of the environment. Because in the pastoral areas villages as well as most of the towns are using wood for the construction of the houses, which lead to the environmental degradation and for high contribution of global warming. Ethiopia is like in many other developing countries; especially African countries have critical shortage and poor condition of housing which have significant effect on the environment. These problems can be solved through the application of engineering knowledge that the country need to stands for the whole development (A.w. Hendry, 1991)

Due to inadequate resources in developing countries, cost reduction seems to be the best way forward, especially in housing for the economically weaker section. This can be achieved by innovating, manufacturing, and utilizing low cost but durable construction materials from locally available resources .Traditional earth construction techniques such as compressed earth blocks are experiencing a new popularity, taking in to account that they constitute green building materials, becoming economically competitive (M.C.N Villamizar, 2012)

The techniques of firing clay to produce bricks and tiles for building construction is more than 5000 years old and their utilization are preferable especially in areas of harsh environment due to its resistance to cold and moist weather conditions (Osinubi *et al.*,2007).

In the United States, the compressive strength of bricks produced ranges between 7 and 105N/mm$^2$depending on the usage of the bricks. Modification of compressive strength of bricks produced from locally available lateritic soils, through additives in order to enhance their utilization in Nigerian construction industry is also desirable (O.S.oladejiand A.F.Akinrinde,2013).

Clay brick is the first man made artificial building material and one of the oldest building materials known. Its wide spread use is mainly due to the availability of clay in most countries. Its durability and aesthetic appeal also contribute to its extensive application in both load bearing and non-load bearing structures. The properties of clay units depend on the mineralogical compositions of the clays used to manufacture the unit, the manufacturing process and the firing temperature (A.W.hendry, 1991).

Soil requires to be stabilized because the materials found in its natural state are not durable for long-term use in buildings. By properly modifying the properties of soil, its long term performance can be significantly improved (Mitchell .JK, 1963).Soil stabilization processes focus on altering its phase structure, namely the soil–water-air interphase. The general goal is to reduce the volume of interstitial voids, fill empty voids ,and improve bonding between the soil grains.in this way better mechanical property ,reduced porosity, limited dimensional changes, and enhanced resistance to normal and sever exposure conditions can be achieved (Gooding & Thoma,1995).

Soil stabilization is the process of mixing additives with soil to improve its volume stability, strength, permeability, and durability (Bell,1993).

Lime stabilization reactions result in the formation of inter-particle cementation bonds that improves strength and reduce compressibility of clay soils. Though several studies in the past have focused on the impact of lime stabilization on the strength behavior, few studies have examined the impact of lime stabilization on the compressibility behavior of clay soils. Cementation bonds formed during the lime stabilization reactions imparted yield stress in the range of 3900–5200kPa to the artificially cemented specimens (sudhakar et, al, 2004).

Cement stabilized bricks compared favorably with hollow sandcrete blocks in terms of engineering properties and the compressive strength of cement stabilized bricks is slightly higher than that of the hollow sand Crete blocks and also all the blocks produced and tested, meet the minimum required compressive strength for use as a wall component in building (Ogunbiyi.M, et al., 2014).

## 1.2. Statement of the Problem

The production process of Fired clay bricks in Jimma town consists of preparing the clay materials from quarry, tempering, molding, drying and firing. Among these processes firing is the most important for the hardening of the brick.. The firing process in locally produce fired clay bricks is by using heat from burning of woods. But this has an adverse impact on the environmental condition due to high deforestation of tress.

Traditional brick and tile production requires a great deal of fuel during firing. This excess fuel consumption increases air pollution. If wood is used as a fuel, excess consumption often contributes to deforestation and associated environmental impacts (USAID, 2013).

The priciest thing that we all living things have is our environment. Keeping our environment today is keeping our generation and our country tomorrow. Global warming is becoming the hottest issue now a day. The only solution that can keep our environment safe is keeping our trees. Jimma town is a beautiful town surrounding with a green area of different types of trees and coffee.in Jimma town there are around three locally fired clay brick production enterprises which are now actively participating in the market. These enterprises consume much amount of woods for the firing of the bricks.

In addition to the environmental effect, firing by a traditional way also affects the quality of the produced fired clay bricks. When Clay soil react with water it becomes plastic and can be molded with different shapes. But for structural use of the produced product in addition of drying it should also be fired with a suitable temperature. The hardening process by firing of the bricks cannot be controlled in traditional way of production of bricks. This uncontrolled burning process results over burning or under burning of the bricks with lower qualities in both cases. This study applied the concept of stabilizing the clay soil with cement and lime to give the hardness of the bricks by chemical action instead of firing. This then replace the firing process and reduce deforestation for firing.

Firing the bricks creates a ceramic bond in a specific temperature (900 ºc -1200ºc) which increases the strength of brick making it water resistant. Using the right amount of fuel is very important not only for fuel and cost efficiency but also to provide the right temperature for bonding. Low temperature results in poor quality /bonding while high temperature would either slump or melt the bricks (Arman H. and Heather C., 2015).

## 1.3. Research Questions

The research questions that this study attempted to clarify was as follows:

1. What are the index properties of soil used for brick production in Jimma town?
2. What is the difference in compressive strength of locally fired clay bricks and stabilized clay bricks with cement and lime?
3. Does the compressive strength of locally fired clay bricks and stabilized clay bricks attain the required compressive strength of available standards?

## 1.4. Objectives

## 1.4.1. General objective

- The general objective of this study is to compare the compressive strength of locally produced fired clay bricks and stabilized bricks in Jimma town.

### 1.4.2. Specific Objectives

- To determine the index properties of soil used for brick production.
- To determine the compressive strength of locally fired clay bricks and stabilized clay bricks.
- To compare compressive strength of local fired and stabilized bricks with available standards.

## 1.5. Significance of the study

Jimma town is rich in clay soil which is suitable for the production of bricks. The local firing process takes place by building up a stock of dried bricks which takes around two or three months to dry. The firings of the clay bricks using trees have an adverse effect on our environment and also the quality of the bricks produced. The outcomes of this study show an alternative method of producing bricks by stabilizing within short period of time without firing.

Additionally as a research this paper would be used as a reference for further studies regards to stabilization of clay soil in brick production.

## 1.6. Scop and Limitation of the study

The study was conducted by selecting a quarry site among the actively available small and micro enterprises participating in traditional brick making in Jimma town. The production process of the stabilized clay bricks was conducted manually without any molding or mixing machine.. The wooden mold used for the production of locally fired clay bricks in Jimma town has 24cmx12cmx6cm inside dimension; this mold was also applied for the production of stabilized clay bricks.

The limitation of this study was that, cost. Due to budget constraint the molding is done with hand molding which in turn affects the quality of the brick.

# CHAPTER TWO
# LITERATURE REVIEW

## 2.1 Introduction

Soil has been one of the primary components of construction since ancient times, finding applications in a variety of forms like mud plaster, adobe blocks, and rammed earth to name a few. With the development of technology, fired brick came in to existence which improved the performance of soil and made them more water resistant and durable. Other forms of soil utilizations lowly faded into oblivion due to their inability to resist damage due to water ingress in moist environments. Thus, fired bricks have been the primary building material for construction for a long time. However, in the recent years there has been a shift away from the utilization of fired bricks towards eco-friendly building materials (Jijo James,*et.al*,2016).

Earth is one of man's oldest building materials and most ancient civilizations used it in some form. It was easily available, cheap, and strong and required only simple technology. In Egypt the grain stores of Ramasseum built in adobe in 1300BC still exist; the Great Wall of China has sections built in rammed earth over 2000 years ago. Iran, India, Nepal, Yemen all have examples of ancient cities and large buildings built in various forms of earthen construction. It is significant that the oldest surviving examples of this building form are in the most arid areas of the world. The strength of unsterilized earth walls comes from the bonding effect of dried clay (Sruthi G S 2013).

Clay for brickmaking is prepared differently in a rural environment manually in small brick yards and near towns and urban areas mostly in large-scale factories employing heavy-duty machinery and equipment. Since modern clay works quite often cannot satisfy the demand for bricks and tiles, rural brick makers are increasingly playing an important role as suppliers and thus, are confronted with the demand for good quality fired clay products (Basin,1999).

## 2.2. Soil as a building material

Building material is any material which is used for a construction purpose. Many naturally occurring substances, such as clay, sand, wood and rocks, even twigs and leaves have been used to construct buildings ( M.Adinarayana, 2011).

Soil is one of the natural building materials, which is absolutely different from wood, rock, and cement or metal. Mud can be formed for our shelters and it can be reformed or recycling ease back to nature, to be simple soil on earth. Moreover, mud can match with all environments and good for being a passive air-conditioning system. Reusability of mud creates tremendous reduction in environmental impact, energy use and capital expenditure. Mud house from earth or soil is one of the most widely used traditional building materials throughout the world. Currently, one-third of world population stills live in mud house. It can be found mostly in hot-dry and arid area such as some parts of India, Nepal, China, African continent and even in the West Side of North and South American continent (Asmamaw T., 2007)

## 2.3. Index properties of soils

The tests required for determination of engineering properties are generally elaborate and time-consuming. Sometimes the geotechnical engineer is interested to have some rough assessment of the engineering properties without conducting elaborate tests .this is possible if index properties are determined. The properties of soils which are not of primary interest to the geotechnical engineer but which are indicative of the engineering properties are called index properties. Simple tests which are required to determine the index properties are known as classification tests; the soils are classified and identified based on the index properties .the main index properties of coarse grained soils are particle size and the relative density. For fine grained soils the main index properties are atterrberg limits and the consistency (K.R.Arora .2004)

Index properties are the properties of soil that help in identification and classification of soil. Water content, Specific gravity, Particle size distribution, In situ density (Bulk Unit weight of soil), Consistency Limits and relative density are the index properties of soil. These properties are generally determined in the laboratory ( S. K. Prasad,2008).

### 2.3.1. Water content

Water content is defined as the ratio of weight of water present in a given soil mass by the weight of dry soil. Water content is usually expressed in percent. Most natural soils, which are sandy and gravelly in nature, may have water contents up to about 15 to 20%. In natural fine-grained (silty or clayey) soils, water contents up to about 50 to 80% can be found. However, peat and highly organic soils with water contents up to about 500% are not uncommon (Brajam .D, 2002).

### 2.3.2. Specific gravity

The specific gravity of a given material is defined as the ratio of the weight of a given volume of the material to the weight of an equal volume of distilled water. In soil mechanics, the specific gravity of soil solids (which is often referred to as the specific gravity of soil) is an important parameter for calculation of the weight-volume relationship (Brajam .D, 2002).

Table 2.3.2.1.General range of Specific gravities for various soil types (Brajam .D, 2002)

| Soil type | Range of specific gravity |
|---|---|
| Sand | 2.63-2.67 |
| Silt | 2.65-2.7 |
| Clay and silty clay | 2.67-2.9 |
| Organic soil | Less than 2 |

### 2.3.3. Particle size distribution

Soil in nature exists in different sizes, shapes and appearance. Depending on these attributes, the soil at a site can be packed either densely or loosely. Hence, it is important to determine the percentage of various sized soil particles in a soil mass ( S. K. Prasad,2008).

Table 2.3.3.1.Types of soils and their average grain sizes and shapes ( S. K. Prasad,2008).

| Soil type | Description | Average grain size |
|---|---|---|
| Gravel | Rounded and/or angular bulky hard rock | Coarse: 80 mm to 20 mm<br>Fine: 20 mm to 4.75 mm |
| Sand | Rounded and/or angular bulky hard rock | Coarse: 4.75 mm to 2 mm<br>Medium: 2 mm to 0.425 mm<br>Fine: 0.425 mm to 0.075 mm |
| Silt | Particles smaller than 0.075 mm, exhibit little or no strength when dried | 0.075 mm to 0.002 mm |
| Clay | Particles smaller than 0.002 mm, exhibit significant strength when dried; water reduces strength | <0.002 mm |

### 2.3.4. Consistency Limits

Consistency is the relative ease with which soil can be deformed. It is applicable to fine grained soils whose consistency depends on water content. Relative consistency can be expressed as very stiff, stiff, medium stiff, soft, very soft with increasing water content. Atterberg, a Swedish agriculturist in 1911 observed four states of consistency, namely Liquid state, Plastic state, Semi solid state and Solid state in clayey soil with changing water content. He set arbitrary limits for these states called consistency or atterberg limits ( S. K. Prasad,2008).

**1 .Liquid Limit ($W_L$)**: It is the water content corresponding to an arbitrary limit between liquid and plastic states of consistency of a soil. It is minimum water content at which soil is still in liquid state, but possessing small shear strength and exhibiting some resistance to flow.

**2. Plastic limit ($W_P$):** It is the water content corresponding to an arbitrary limit between plastic and semi-solid states of consistency of a soil. It is a minimum water content at which soil will just begin to crumble when rolled  minimum water content at which soil will just begin to crumble when rolled  minimum water content at which soil will just begin to crumble when rolled in to a thread of approximately 3 mm diameter .

Clay& silt content of 40%-65% and plasticity index of 7%-16% are soils which are suitable for brick making (TARA ,2014)

**3. Shrinkage limit (Ws) :** It is the water content corresponding to an arbitrary limit between semi-solid and solid states of consistency of a soil. It is the lowest water content at which soil is fully saturated. It is also the maximum water content at which any reduction in water content will not reduce volume of the soil mass ( S. K. Prasad,2008).

**4. Linear shrinkage:** The linear shrinkage of a soil for the moisture content equivalent to the liquid limit is the decrease in one dimension, expressed as a percentage of the original dimension of the soil mass, when the moisture content is reduced from the liquid limit to an oven-dry state Shrinkage due to drying is significant in clays, but less so in silts and sands. If the drying process is prolonged after the plastic limit has been reached, the soil will continue to decrease in volume, which is also relevant to the converse condition of expansion due to wetting. The linear shrinkage value is a way of quantifying the amount of shrinkage likely to be experienced by clayey material. Such a value is also relevant to the converse condition of due to wetting (CTM 228 -A4 )

## 2.4. Soil classification methods

Soil is a broad term used in engineering applications which includes all deposits of loose Material on the earth’s crust that are created by weathering and erosion of underlying rocks. Although weathering occurs on a geologic scale, the process is continuous and keeps the soil in constant transition. The physical, chemical, and biological processes that form soils vary widely with time, location and environmental conditions and result in a wide range of soil properties (Mitchell J. K., 1993).

Soil classification systems divide soils into groups and subgroups based on common engineering properties such as grain-size distribution, liquid limit, and plastic limit. The two major classification systems presently in use are (Brajam .D, 2002).

(1) AASHTO (American Association of State Highway and Transportation Officials)

(2) Unified Soil Classification System

### 2.4. 1. AASHTO soil classification system

This system is presently used by federal, state, and county highway departments in the United States. In this soil classification system, soils are generally placed in seven major groups: *A-i*, *A-*

*2, A-3, A-4, A-5, A-6* andA-7. *GroupA-1* is divided into two subgroups: *A-1-a* and *A-1-b*. Group *A* -2 is divided into four subgroups: *A-2-4, A-2-5, A-2-6* andA-2-7. Soils under group *A-7* are also divided into two subgroups: *A-7-5* andA-7-6. This system is also presently included in ASTM under test designation D-3284 (Brajam .D, 2002).

**2.4. 1. 1. Procedure for soil classification**

1. Determine the percentage of soil passing through U.S. No. 200 sieve (0.075 mm opening). If 35% or less passes No. 200 sieve, it is a coarse-grained material .Proceed to Steps 2 and 4. If more than 35% passed No. 200 sieve, it is a fine-grained material (i.e., silty or clayey material). For this, go to Steps 3 and 5.
2. For coarse-grained Soils, determine the percentage passing U.S. sieve Nos. 10, 40 and 200 and, additionally, the liquid limit and plasticity index. Then proceed to Table 2.3.1.1.1.Start from the top line and compare the known soil properties with those given in the table (Columns 2 through 6). Go down one line at a time until a line is found for which all the properties of the desired soil matches. The soil group (or subgroup) is determined from Column I.
3. For fine-grained soils, determine the liquid limit and the plasticity index. Then go to Table .2.3.1.1.2.Start from the top line. By matching the soil properties from Columns 2, 3 and 4, determine the proper soil group (or subgroup).
4. To determine the group index (Gl) of coarse-grained soils, the following rules need to be observed [22].

   A. GI for soils in groups (or subgroups) A-I-a, A-I-b, A-2-4, A-2-5 and A-3 is Zero.

   B. For GI in soils of groups A-2-6 and A-2-7, use the following equation:

GI = 0.01 (F200 - 15) (PI - 10)

Where F200 = percent passing No. 200 sieve

PI = plasticity index

If the GI comes out negative, round it off to zero. If the GI is positive, round it off to the nearest whole number.

Table 2.4.1.1.1.ASSHTO classification for coarse grained soils (Brajam .D, 2002).

| Soil group(1) | | Grain size | | | Liquid Limit (5) | Plasticity Index (6) | Material Type (7) |
|---|---|---|---|---|---|---|---|
| | | Passing No 10 Sieve(2) | Passing No 40 Sieve(3) | Passing No 200 Sieve(4) | | | |
| A-1 | A-1-a | 50max | 30max | 15max | | 6max | Stone fragment gravel &sand |
| | A-1-b | | 50max | 25max | | 6max | |
| A-3 | | | 51min | 10max | | Non plastic | Fine sand |
| A-2 | A-2-4 | | | 35max | 40max | 10max | Silty &clayey Gravel &sand |
| | A-2-5 | | | 35max | 41min | 10max | |
| | A-2-6 | | | 35max | 40max | 11min | |
| | A-2-7 | | | 35max | 41min | 11min | |

Table 2.4.1.1.2. ASSHTO classification for fine grained soils (Brajam .D, 2002).

| Soil type (1) | | Pass no. 200 sieve(2) | Liquid limit (3) | Plasticity index(4) | Material Type(5) |
|---|---|---|---|---|---|
| A-4 | | 36min | 40max | 10max | Silty soil |
| A-5 | | 36min | 41min | 10max | Silty soil |
| A-6 | | 36min | 40max | 11min | Clayey soil |
| A-7 | A-7-5 | 36min | 41min | 11min& PI≤LL-30 | Clayey soil |
| | A-7-6 | 36min | 41min | 11min& PI>LL-30 | Clayey soil |

### 2.4.2. Unified soil classification system

This classification system was originally developed in 1942 by Arthur Casagrande for airfield construction during World War II. This work was conducted on behalf of the U.S. Army Corps of Engineers. At a later date, with the cooperation of the United States Bureau of Reclamation, the classification was modified. More recently, the American Society of Testing and Materials (ASTM) introduced a more definite system for group name of soils. In the present form, it is widely used by foundation engineers all over the world. Unlike the AASHTO system, the Unified system uses symbols to represent the soil types and the index properties of the soil (Brajam .D, 2002).

Table 2.4.2.1. Unified soil classification (Brajam .D, 2002).

| Symbol | Soil | Symbol | Index property |
|---|---|---|---|
| G | Gravel | W | Well graded (for grain size distribution) |
| S | Sand | P | Poorly graded(for grain size distribution) |
| M | Silt | L | Low to medium plasticity |
| C | Clay | H | High plasticity |
| O | Organic silt & clay | | |
| $P_t$ | Highly organic soil & peat | | |

## 2.5. Techniques of using soil as a building material

### 2.5. 1. Mud as a building material

Mud, a mixture of earth and water, is economical, practical, functional and attractive. It is easy to work with, and it takes decoration as well. Mud is especially useful in humid and hot climates. Mud is a natural building material that is found in abundance, especially where other building materials such as bricks, stone or wood are scarce due to affordability and or availability. Depending on the characteristics of the mud available, availability of supporting materials and technology used, different manifestations of mud are used. These include Adobe or Sun-dried bricks, Cob, Rammed earth, Pressed brick, Wattle and Daub etc. (Sruthi G S , 2013).

#### 2.5.1.1 Cob

The word cob comes from Old English root meaning "a lump mass". It's a traditional of rounded building technique using hand formed lumps of earth mixed with sand and straw. Cob is easy to learn and inexpensive to build. It dries to hardness similar to lean concrete.

This ancient technology doesn't contribute to deforestation, pollution or mining, nor depend on manufactured materials or power tools. Cob is non-toxic and completely recyclable. Regular working windows are embedded in the cob along with their lintels while the layers are building up. If fixed window is needed we can use any kind of glass embedded into the cob. Cob houses have been known to last for centuries.

#### 2.5. 1.2. Adobe

Adobe is a natural building material made from sand, clay, water and some kind of fibrous or Organic material (sticks, straw and or manure), which the builders shapes into bricks using frames and dry in sun. Adobe buildings are similar to cob and mud brick buildings. Adobe structures are extremely durable, and account for some of the oldest existing building in the world. In hot climates, compared with wooden buildings offer significant advantage due to their greater thermal mass, but they are known to be particularly susceptible to earthquake damage. Buildings made up of sun-dried earth are common in the West Asia, Northern Africa, West Africa, South America, Spain, Eastern Europe and East Anglia.

#### 2.5. 1.3. Rammed earth

Rammed earth is an ancient building method that has seen a revival in recent years as people seek more sustainable building materials and natural building methods. Rammed earth walls are simple to construct, incombustible to water damage. Traditionally, rammed earth buildings are found in every continent except Antarctica, from the temperate and wet regions of Northern Europe to semi-dry deserts, mountain areas and the tropics.

Rammed earth, consists of moist, loose sub-soil compacted between shuttering in layers. Coarser soils are sometimes sieved prior to compaction to remove larger aggregate. The shuttering is struck immediately and then moved along or upwards to form the next section of wall. Recent technological advances in rolling and climbing formwork, together with the use of mechanical compaction, have aided this process. The exact composition of the soil and the right amount of water content are critical for the success of this method (Kerali .A.G., 2001).

The compressive strength of rammed earth can be up to 4.3 MPa. This is less than that of a similar thickness of concrete, but more than strong enough for use in domestic buildings. Indeed, properly built rammed earth can withstand loads for thousands of years, as many still-standing ancient structures around the world attest. Rammed earth using re-bar, wood or bamboo reinforcement can prevent failure caused by earthquakes or heavy storms (Sruthi G S , 2013).

#### 2.5.1.4. Wattle and Daub

Wattle and daub is a building material used for making walls, in which a woven lattice of wooden strips called wattle is daubed with a sticky material usually made of some combination of wet soil, clay, sand, animal dung and straw. It is an important construction Material in many parts of the world. The wattle is made by weaving thin branches or slats between upright stakes. The wattle may be made in place to form the whole of a wall. Daub is generally created from a mixture of certain ingredients from three categories: binders, aggregates and reinforcement. Binders hold the mix together and can include clay, lime, chalk dust and limestone dust Aggregates give the mix its bulk and dimensional stability through materials such as earth, sand, crushed chalk and crushed stone. Reinforcement is provided by straw hair, hay or other fibrous material and helps to hold mix together as well as to control shrinkage and provide flexibility. The daub may be mixed by hand or by treading either by humans or livestock it is then applied to the wattle and allowed to dry and often then whitewashed to increase its resistance to rain (Sruthi G S , 2013).

#### 2.5. 1.5. Compressed Earth Blocks

This type of block is produced in a manually operated press, which exerts a large amount of pressure on the soil in the mold. Blocks are thus produced in standard sizes. The soil requirements are similar to those for rammed earth (Asmamaw T,  2007).

The soil, raw or stabilized, is slightly moistened, poured into a steel press and then compressed either with a manual or motorized press. It is developed from traditional rammed earth. The input of soil stabilization allowed building higher with thinner walls, which have a much better compressive strength and water resistance (Sruthi G S , 2013).

### 2.5.2. Fired clay bricks

Originally, bricks were hand-moulded from moist clay and then sun-baked, as is still the practice in certain arid climates. The firing of clay bricks dates back well over 5000 years, and is now a sophisticated and highly controlled manufacturing process; yet the principle of burning clay, to convert it from its natural plastic state into a dimensionally stable, durable, low-maintenance Ceramic material remains unchanged (Arthur Lyons, 2010).

#### 2.5.2.1. Classification of Fired clay bricks

**A. On basis of field practice**

Clay bricks are classified as first class, second class, third class and fourth class based on their physical and mechanical properties (S.K.Duggal,2008)

**1. First class bricks**

1. These are thoroughly burnt and are of deep red, cherry or copper color.

2. The surface should be smooth and rectangular, with parallel, sharp and straight edges and square corners.

3. These should be free from flaws, cracks and stones.

4. These should have uniform texture.

5. No impression should be left on the brick when a scratch is made by a finger nail.

6. The fractured surface of the brick should not show lumps of lime.

7. A metallic or ringing sound should come when two bricks are struck against each other.

8. Water absorption should be 12–15% of its dry weight when immersed in cold water for

24 hours.

9. The crushing strength of the brick should not be less than 10 N/mm2.This limit varies with different Government organizations around the country.

**Uses**: First class bricks are recommended for pointing, exposed face work in masonry Structures, flooring and reinforced brick work.

**2. Second class bricks**

Are supposed to have the same requirements as the first class ones except that

1. Small cracks and distortions are permitted.

2. A little higher water absorption of about 16–20% of its dry weight is allowed.

3. The crushing strength should not be less than 7.0 N/mm2

**Uses:** Second class bricks are recommended for all important or unimportant hidden masonry Works and centering of reinforced brick and reinforced cement concrete (RCC) structures.

**3. Third class bricks**

This bricks are under burnt. They are soft and light-colored producing a dull sound when struck against each other. Water absorption is about 25 per cent of dry weight.

**Uses:** It is used for building temporary structures.

- 4. Fourth class bricks

Are over burnt and badly distorted in shape and size and are brittle in nature.

**Uses:** The ballast of such bricks is used for foundation and floors in lime concrete and road metal.

**B. On the basis of Use**

**Common bricks:** is a general multi-purpose unit manufactured economically without special reference to appearance. These may vary greatly in strength and durability and are used for filling, backing and in walls where appearance is of no consequence (S.K.Duggal,2008).

Common bricks have no visual finish, and are therefore usually used for general building work especially where the brickwork is to be rendered, plastered or will be unseen in the finished work (Arthur Lyons, 2010).

**Facing bricks:** are made primarily with a view to have good appearance, either of color or texture or both. These are durable under severe exposure and are used in fronts of building walls for which a pleasing appearance is desired (S.K.Duggal,2008).

Facing bricks are manufactured and selected to give an attractive finish. The particular colour, which may be uniform or multicoloured, results from the blend of clay used and the firing conditions. Additionally, the surface may be smooth, textured or sand-faced as required. A slightly distressed appearance, similar to that associated with reclaimed bricks, is obtained by tumbling either unfired or fired bricks within a rotating drum. Facing bricks are used for most visual brickwork where a pleasing and durable finish is required (Arthur Lyons, 2010).

**Engineering bricks:** are strong, impermeable, smooth, table molded, hard and conform to defined limits of absorption and strength. These are used for all load bearing structures (S.K.Duggal,2008).

Engineering bricks are dense and vitreous, with specific load-bearing characteristics and low water absorption. Engineering bricks are used to support heavy loads, and also in positions where the effects of impact damage, water absorption or chemical attack need to be minimised. They are generally reds or blues and more expensive than other machine-made facing bricks because of their higher firing temperature (Arthur Lyons, 2010).

**C. On the basis of finish**

- Sand -faced brick: has textured surface manufactured by sprinkling sand on the inner surfaces of the mould.
- Rustic brick: has mechanically textured finish, varying in pattern.

**D. On the basis of manufacture**

- Hand-made: These bricks are hand moulded.
- Machine-made: Depending upon mechanical arrangement, bricks are known as
- wire-cut bricks—bricks cut from clay extruded in a column and cut off into brick sizes by wires;
- pressed-bricks—when bricks are manufactured from stiff plastic or semi-dry clay and pressed into moulds;
- moulded bricks—when bricks are moulded by machines imitating hand mixing.

**E. On the basis of burning**

- Kiln fired brick

Kiln-fired brick production requires a high capital investment and a significant amount of infrastructure to support production. A greater degree of material selection must be employed, staff needs to be highly skilled, spares and servicing is highly specialized and energy requirements are considerable. Production output is very high, typically 10,000 - 30,000 bricks per day and needs to be continuous if to achieve high efficiency and to achieve the greatest return on investment (DE Montgomery,2001).

- Clamp fired brick

Can be inexpensive in monetary terms because the raw materials are dug from the ground and the energy required firing the brick could come from collected firewood. Thorough burning is necessary to fire all the blocks properly and this takes several days to achieve. The finished blocks can be quite badly misshapen and this requires a thick layer of mortar between the blocks, sometimes as thick as 20mm. Furthermore, if the blocks are poorly fired then in order to achieve adequate durability they may need to be rendered as well. Fired blocks are considered attractive and so they are not generally rendered unless necessary (DE Montgomery,2001).

#### 2.5.2.2. Manufacturing of fired clay bricks

There are five main processes in the manufacture of clay bricks: these are extraction of the raw material; forming processes; drying; firing; packaging and distribution (Arthur Lyons, 2010).

**1. Extraction of the raw material**

The process begins with the extraction of the raw material from the quarry and its transportation to the works, by conveyor belt or road transport. Top-soil and unsuitable overburden are removed first and used for site reclamation after the usable clay is removed.

The raw material is screened to remove any rocks, and then ground into fine powder by a series of crushers and rollers with further screening to remove any over- size particles. Small quantities of pigments or other clays may be blended in at this stage to produce various colour effects; for example, manganese dioxide will produce an almost black brick and fireclay gives a teak brown effect. Occasionally, coke breeze is added into the clay as a source of fuel for the firing process. Finally, depending on the subsequent brick forming process, up to 25% water may be added to give the required plasticity (Arthur Lyons, 2010).

The soil used for making building bricks should be processed so as to be free of gravel, coarse sand (practical size more than 2 mm), lime and kankar particles, organic matter,etc. About 20 cm of the top layer of the earth, normally containing stones, pebbles, gravel,roots, etc., is removed after clearing the trees and vegetation (S.K.Duggal,2008).

2. **Forming processes**

According to ( Arthur Lyons, 2010) the forming methods used in brick production are handmade process, soft mud process and pressing method.

- **Handmade process**: The handmade process involves the throwing of a suitably sized clot of wet clay in to a wooden mould on a bench. The surplus clay is struck off with a framed wire and the green brick removed. The bricks produced are irregular in shape with soft arises and interestingly folded surfaces .
- **Soft mud process**: The handmade process has now been largely auto-mated, with the clay being mechanically thrown in to pre-sanded moulds; the excess clay is then removed and the bricks released from the mould. These soft mud process bricks retain much of the individuality associated with true handmade bricks, but at lower cost .
- **Pressed bricks**: In the semi-dry process used for Fletton bricks the appropriate quantity of clay is subjected to a sequence of four pressings within steel moulds to produce the green brick. These bricks usually have a deep frog on one bed face. For facing bricks, texturing on both headers and one stretcher may be applied by a series of rollers. A water spray to moisten the surface, followed by a blast of a sand/pigment mixture, produces the sand-faced finish .

**3. Drying**

To prevent cracking and distortion during the firing process, green bricks produced from wet clays must be allowed to dry out and shrink. Shrinkage is typically10%on each dimension depending upon the moisture content. The green bricks, laid in an open chequer-work pattern to ensure a uniform loss of moisture, are stacked in, or passed through, drying chambers which are warmed with the waste heat from the firing process. Drying temperatures and humidity levels are carefully controlled to ensure shrinkage without distortion ( Arthur Lyons, 2010)

Green bricks contain about 7–30% moisture depending upon the method of manufacture. Theobject of drying is to remove the moistre to control the shrinkage and save fuel and time during burning.The drying shrinkage is dependent upon pore spaces within the clay and the mixing water. The addition of sand or ground burnt clay reduces shrinkage, increases porosity and facilities drying. The moisture content is brought down to about 3 per cent under exposed conditions within three to four days. Thus, the strength of the green bricks is increased and thebricks can be handled safely (S.K.Duggal,2008).

5. **Firing**

**Clamps:** The basis of clamp firing is the inclusion of coke breeze into the clay, which then acts as the major source of energy during the firing process. In the traditional process, alternate layers of unfired bricks and additional coke breeze are stacked up and then sealed over with waste bricks and clay. The clamp is then ignited with kindling material and allowed to burn for two to five weeks. After firing, the bricks are hand selected because of their variability from under- to over-fired. Currently some handmade bricks are manufactured in gas-fired clamps which give a fully controlled firing process but still produce bricks with the characteristic dark patches on their surfaces due to the burnt breeze content (Arthur Lyons, 2010).

The bricks and fuel are placed in alternate layers. The amount of fuel is reduced successively in the top layers. Each brick tier consists of 4–5 layers of bricks. Some space is left between bricks for free circulation of hot gasses. After 30 per cent loading of the clamp, the fuel in the lowest layer is fired and the remaining loading of bricks and fuel is carried out hurriedly. The top and sides of the clamp are plastered with mud. Then a coat of cowdung is given, which prevents the escape of heat. The production of bricks is 2–3 lacs and the process is completed in six months. This process yields about 60 per cent first class bricks (S.K.Duggal,2008).

**Tunnel kiln**: In the tunnel kiln process the bricks are loaded 10 to14 high on kiln cars which are moved progressively through the preheating, firing and cooling zones. A carefully controlled temperature profile within the kiln and an appropriate kiln car speed ensure that the green bricks are correctly fired with the minimum use of fuel, usually natural gas. The maximum firing temperature within the range 940◦C to 1200◦C depends on the clay, but is normally around 1050◦C, with an average kiln time of three days. The oxygen content within the atmosphere of the kiln will affect the colour of the brick products. Typically a high temperature and low oxygen content are used in the manufacture of blue bricks. Higher oxygen content will turn any iron oxide within the clay red ( Arthur Lyons, 2010).

The kiln used for burning bricks may be underground, e.g. Bull's trench kiln or overground, e.g. Hoffman's kiln. These may be rectangular, circular or oval in shape. When the process of burning bricks is continuous, the kiln is known as continuous kiln, e.g. Bull's trench and Hoffman's kilns. On the other hand if the process of burning bricks is discontinuous, the kiln is known as intermittent kiln (S.K.Duggal,2008).

**5. Packaging and distributing**

Damaged or cracked bricks are removed prior to packing. Most bricks are now banded and shrink-wrapped into packs of between 300 and 500, for easy transportation by forklift truck and specialist road vehicles. Special shapes are frequently shrink-wrapped onto wooden pallets (Arthur Lyons, 2010)

#### 2.5.2.3. Standard specifications for clay bricks

Different specifications which are used to classify burnt clay soils used mainly their mean compressive strength and other quality properties such as water absorption. According to ASTM C 216, clay bricks are classified based on their compressive strength, water absorption and Saturation coefficients, British Standard Specification for Clay bricks (BS 3921:1985) also classifies clay bricks based on their compressive strength and water absorption and Ethiopian standard specification for Clay Bricks- also uses these physical requirements for classifying solid fired clay bricks.

**A. Ethiopian standard specification**

Bricks are classified based on laboratory test results of mean compressive strength, water absorption and saturation coefficients according to ES 86:2001.

Table 2.5.2.3 A.1. Minimum compressive strength of solid clay-bricks (ES 86, 2001).

| Class | Minimum compressive strength | |
|---|---|---|
| | Average of 5 bricks | Individual brick |
| | $N/mm^2$ | $N/mm^2$ |
| A | 20 | 17.5 |
| B | 15 | 12.5 |
| C | 10 | 7.5 |
| D | 7.5 | 5.0 |

Table.2.5.2.3.A.2. Maximum water absorption of solid clay bricks in (%)(ES 86, 2001)

| Class | After 24hr immersion | | After 5hr boiling | |
|---|---|---|---|---|
| | Average of 5 bricks | Individual brick | Average of 5 bricks | Individual brick |
| A | 21 | 23 | 22 | 24 |
| B | 22 | 24 | 23 | 24 |
| C,D | No limit | No limit | No limit | No limit |

Table. 2.5.2.3. A 3. Maximum saturation coefficient of solid clay bricks (ES 86, 2001)

| Class | Average of 5 bricks | Individual brick |
|---|---|---|
| A,B | 0.96 | 0.99 |
| C,D | No limit | No limit |

**B. British Standard Specification for Clay bricks (BS 3921:1985)**

Table.2.5.2.3.B.classification of clay bricks by compressive strength &water absorption (BS 3921, 1985)

| No | Class of clay bricks | Compressive strength($N/mm^2$) | Water absorption (% by mass) |
|---|---|---|---|
| 1 | Engineering A | >70 | <4.5 |
| 2 | Engineering B | >50 | <7.0 |
| 3 | Damp-proof course 1 | >5 | <4.5 |
| 4 | Damp-proof course 2 | >5 | <7.0 |
| 5 | All others | >5 | No limit |

**C. ASTM Standard Specification for Building Bricks (ASTM C 216-10)**

Grades classify brick according to their resistance to damage by freezing when saturated at a moisture content not exceeding the 24-h cold water absorption. Two grades of facing brick are covered and the requirements are given (ASTM C 216, 2010).

- Grade SW (Severe Weathering)—Brick intended for use where high resistance to damage caused by cyclic freezing is desired.
- Grade MW (Moderate Weathering)—Brick intended for use where moderate resistance to cyclic freezing damage is permissible.

**Note:** The saturation coefficient is the ratio of absorption by 24-h submersion in cold water to that after 5-h submersion in boiling water (ASTM C 216 ,2010).

Table 2.5.2.3.C. ASTM Standard Specification for Building Bricks (ASTM C 216, 2010)

| designation | Minimum compressive Strength (Mpa) | | Maximum water absorption by 5hr boiling (%) | | Maximum saturation coefficient | |
|---|---|---|---|---|---|---|
| | Average of 5 bricks | individual | Average of 5 bricks | individual | Average of 5 bricks | Individual |
| Grade SW | 20.7 | 17.2 | 17.0 | 20.0 | 0.78 | 0.80 |
| Grade MW | 17.2 | 15.2 | 22.0 | 25.0 | 0.88 | 0.90 |

### 2.5. 3. Stabilized clay blocks

#### 2.5. 3. 1. Clay Soil stabilization

The modification of clay soils to improve their engineering properties is well recognized and widely practiced. Through stabilization, the plasticity of soil is reduced, it becomes more workable, and its compressive strength and load bearing properties are improved. Such improvements are the result of a number of chemical processes that take place in the presence of a stabilizer (Sanker.B & Javed I.,2003).

Clay alone is not suitable for making sustainable blocks. Earth construction suffers from shrinkage cracking and should be reduced with good stabilizer. Stabilizing decreases the blocks shrinkage due to the cohesive property of clay which is required as natural binder for composite block (Abdulrahman, 2009),

Soil stabilization can be accomplished by several methods. All these methods fall into two broad categories namely (Gregory.P, 2012).

- Mechanical stabilization: under this category, soil stabilization can be achieved through physical process by altering the physical nature of native soil particles by either induced vibration or compaction or by incorporating other physical properties such as barriers and nailing.

- Chemical stabilization: under this category, soil stabilization depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect. Chemical stabilization involves mixing or injecting the soil with chemically active compounds such as Portland cement, lime, fly ash, calcium or sodium chloride or with viscoelastic materials such as bitumen.

#### 2.5. 3. 2. Soil stabilizing agents

**A. cement**

Cement is the oldest binding agent since the invention of soil stabilization technology in 1960's. It may be considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required (Sherwood, 1993). Cement reaction is not dependent on soil minerals, and the key role is its reaction with water that may be available in any soil .This can be the reason why cement is used to stabilize a wide range of soils. Numerous types of cement are available in the market; these are ordinary Portland cement, blast furnace cement, sulfate resistant cement and high alumina cement. Usually the choice of cement depends on type of soil to be treated and desired final strength (Gregory.P, 2012).

Clay consists of the finest particles in the soil, in same way that cement does, the cement coat the other particles when mixed with water and cause a significant cohesion after the mixture is dried. Indeed this is how the majority of earth bricks are made today (kerali G.,2001).Cement stabilization involves the addition of small amount of cement to modify the soil properties. The amount of cement needed to stabilize soil may range from 3 to 16% by dry weight of soil, depending on the soil type and properties required. Any type of cement may be used for soil stabilization but ordinary Portland cement is mostly used ( Bell ,1993).

Soils with AASHTO classifications A-2 and A-3 are ideal for stabilization with cement, but certainly cement can be successfully used to stabilize A-4 through A-7 soils as well (Oglesby C,1963). The Portland cement Association (PCA) established guidelines for stabilizing a wide range of soils from gravels to clays (PCA, 1992).

Table 2.5.3.2 Estimated amounts of cement content for stabilization (PCA, 1992)

| AASHTO soil group | Usual range in cement requirement | |
|---|---|---|
| | Percent by volume | Percent by weight |
| A-1-a | 5-7 | 3-5 |
| A-1-b | 7-9 | 5-8 |
| A-2 | 7-10 | 5-9 |
| A-3 | 8-12 | 7-11 |
| A-4 | 8-12 | 8-13 |
| A-5 | 8-12 | 8-13 |
| A-6 | 10-14 | 9-15 |
| A-7 | 10-14 | 10-16 |

According to the study of (Ogumbiya M., 2014), on comparative study of cement stabilized clay brick and sandcrete blocks, the result indicate that the compressive strength of the cement stabilized clay bricks for different mix ratios ranges from 1.14N/mm$^2$-1.49N/mm$^2$ as curing age increase from 7 to 28 days considering cement/clay mix ratio of 1:12.Cement /clay ratio of 1.5:12 gives a compressive strength of 1.2N/mm$^2$-1.47N/mm$^2$ for the same 7 to 28 days. result also indicates that the compressive strength of 225mm and 150mm sand crete hollow blocks vary from 0.85 N/mm to 1.33N/mm for cement/ sand mix ratio 1:12 and 0.92N/mm to 1.39 N/mm for mix ratio 1.5:12 respectively, for curing period of 7 to 28 days .

**B. Lime**

Pure lime, generally called quick lime, is a white oxide of calcium. Much of commercial quick lime, however, contains more or less magnesium oxide, which gives the product a brownish or grayish tinge. Quick lime is the lime obtained after the calcination of limestone. It is also called caustic lime. It is capable of slaking with water and has no affinity for carbonic acid. The specific gravity of pure lime is about 3.40.Lime provides an economical way of soil stabilization. Lime modification describes an increase in strength brought by cation exchange capacity rather than cementing effect brought by pozzolanic reaction (Sherwood, 1993).

Lime stabilization refers to the process of adding burned limestone products either calcium oxide (i.e. quicklime) or calcium hydroxide ($Ca(OH)_2$) to soil in order to improve its properties. This process is similar to cement stabilization except that according to (Bell, 1993); lime stabilization is suitable for soils with high clay contents. Lime was used throughout the world by the ancient civilization as a binding agent for brick and stone .

#### 2.5. 3. 3. Step of production of stabilized blocks

**A. Material preparation**

The laterite samples were air–dried for seven days in a cool, dry place. Air drying was necessary to enhance grinding and sieving of the laterite. After drying, grinding was carried out using a punner and hammer to break the lumps present in the soil **(**A.A. Raheem et al ,2010).

**B. Mixing**

The materials used for the production of lateritic interlocking blocks were measured by volume batching. For the 5% cement stabilization adopted, ninety five (95) parts of laterite with five (5) parts of cement i.e. ratio 19:1 (laterite: cement) was used. A four liter plastic container was used as the gauge box. The mixing was done on an impermeable surface made free from all harmful materials which could alter the properties of the mix, by sweeping and brushing or scraping. The measured laterite sample was spread using a shovel to a reasonably large surface area. Cement was then spread evenly on the laterite and the composite material thoroughly mixed with the shovel. The dry mixture was spread again to receive water which was added gradually while mixing, until the optimum moisture content of the mixture was attained **(**A.A. Raheem et al ,2010).

The optimum moisture content of the mixture was determined by progressively wetting the soil and taking handful of the soil, compressing it firmly in the fist, and then allowing it to drop on a hard, flat surface from a height of about 1.10m.When the soil breaks into 4 or 5 parts, the water is considered right (National Building Code, 2006)

**C. Forming**

According to the study of (Habtemariam M., 2012) the prepared mixture was compacted manually by hands into wood formworks of internal dimensions (14 × 21 × 9) cm.

Fig 2.5. 3.3 C. Wooden formworks used for molding (Habtemariam M., 2012)

A.A. Raheem, O.A. Bello, and O.A. Makinde, (2010) ,on their study about the comparative study of cement and lime stabilized lateritic interlocking blocks states about the forming of the blocks that ,''The interior of the mould were lubricated so as to prevent the laterite interlocking block from sticking to the sides of the mould and also to give the block a smooth surface. The wet mixture was filled into the mould and then compacted with hydraulic press''.

**D. Drying**

After removing the blocks from the machine, they were first allowed to air dry under a shade made with polythene sheet for 24 hours (Akeem Ayinde, et al,2012).

**E. Curing**

Curing was continued by sprinkling of water morning and evening and covering the blocks with polythene sheet for one week to prevent rapid drying out of the blocks which could lead to shrinkage cracking. The blocks were later stacked in rows and columns with maximum of five blocks in a column until, they were ready for compressive strength test (Akeem Ayinde, et al,2012)

## 2.6. Quality control Tests on bricks

Bricks to be used for any quality construction work such as residential, office, commercial or industrial buildings, etc should have smooth and good appearance. They should be of uniform sizes and shapes and should appear reddish in color. They should be well burnt. That is, they should neither be over-burnt nor under-burnt. Over-cooked and under-cooked ones won't appear uniformly reddish. They would show shades of blue and sometimes even black or so. Usually, they won't be of uniform shape as well.

Now, about the quality tests: Four simple tests usually performed on common clay bricks in quality control laboratories at construction sites are (M.C.N. villamizar, 2012)

- Water absorption test
- Efflorescence test
- Test of compressive strength
- Test of dimensions

**Water absorption test:** Five bricks are picked at random from a stack of bricks intended to be used. They are then dried thoroughly in a laboratory oven at a temperature between 105¤C to 110¤C. Thereafter they are cooled and weighed separately. Then they are kept immersed in water ($27^0$C or – $2^0$C). After 24 hours the bricks are taken out of water and excess surface water is wiped off using a damp fabric. Immediately after, they are weighed again separately.

Supposing that the dry weight of a brick is Wd and the wet weight of the same brick is Ww, the water absorption capacity of the brick expressed in percentage of its dry wt. is = (Ww – Wd)/Wd X 100. Upon calculating the same for each of the 5 bricks the average is found out which is considered as the water absorption capacity for the bricks. The water absorption capacity of first class bricks should not exceed 20% when calculated as described above. The same for 2nd and 3rd class bricks are not to exceed 22% and 25% respectively. For any superior quality brickwork, first class bricks only are recommended while 2nd & 3rd class clay bricks are advised for moderate to low quality work.

**Efflorescence test:** Brick are not required to be tested for efflorescence to comply with this specification unless requested by the specfier or purchaser. When the efflorescence test is requested by the specifier or purchaser, the brick shall be sampled at the place of manufacture, and tested in accordance with Test Methods ASTM C67.

Ten specimens shall be sorted into five pairs so that both specimens of each pair will have the same appearance as nearly as possible Set one specimen from each of the five pairs, on end, partially immersed in distilled water to a depth of approximately 1 in. (25.4 mm) for 7 days in the drying room. When several specimens are tested in the same container, separate the individual specimens by a spacing of at least 2 in. (50.8 mm) (ASTM C67, 2002).

**Compressive strength:** Five specimens shall be tested and If the surface which will become bearing surfaces during the compression test are recessed or paneled, fill the depressions with a mortar composed of 1 part by weight of quick-hardening cement conforming to the requirements for Type III cement of Specification C 150, and 2 parts by weight of sand. Age the specimens at least 48 h before capping them (ASTM C67, 2002).

**Test of dimensions**: Detail like tolerances in the dimensions of bricks will depend on the type of brick to be used in a particular work. There are conventional (commonly used) bricks and modular bricks in use for various works. Both have different dimensions. The conventional clay bricks too come in several sizes. Hence, corresponding (specific) requirements may be referred to while conducting dimension test for a particular variety of brick (M.C.N. Villamizar, 2012)

Table 2.6.1.ASTM standards on dimension tolerance of bricks (ASTM C 216,2010)

| Specified dimension or average brick size(mm) | Maximum permissible variation in (mm) plus or minus from | | | | |
|---|---|---|---|---|---|
| | Column A(for specified) | | Column B(for average bricks size in job lot sample) | | |
| | Type FBX | Type FBS | Type FBX | Type FBS(smooth) | Type FBS (rough) |
| 76 and under | 1.2 | 2.4 | 1.6 | 1.6 | **2.4** |
| 76 to102 | 2.4 | 3.2 | 1.6 | 2.6 | 3.2 |
| 102 to 152 | 3.2 | 4.8 | 2.4 | 2.4 | **4.8** |
| 152 to 203 | 4.0 | **6.4** | 2.4 | 3.2 | 6.4 |
| **203 to 305** | 5.6 | **7.9** | 3.2 | 4.8 | **7.9** |
| 305 to 406 | 7.1 | 9.5 | 4.8 | 6.4 | 9.5 |

FBS and FBX stands for brick for general use in masonry and brick for general use in masonry here a high degree of precision and lower permissible variation in size than permitted for type FBS, respectively as described in ASTM C 216.

## CHAPTER THREE

## MATERIALS AND METHODOLOGY

### 3.1. Study area

This study has been conducted in Jimma town. Jimma is located at about 346 km in the South West of Addis Ababa, capital city of Ethiopia and has total surface area of 4,623 hectares. The town is divided in to 3 Woreda and 13 Kebeles.

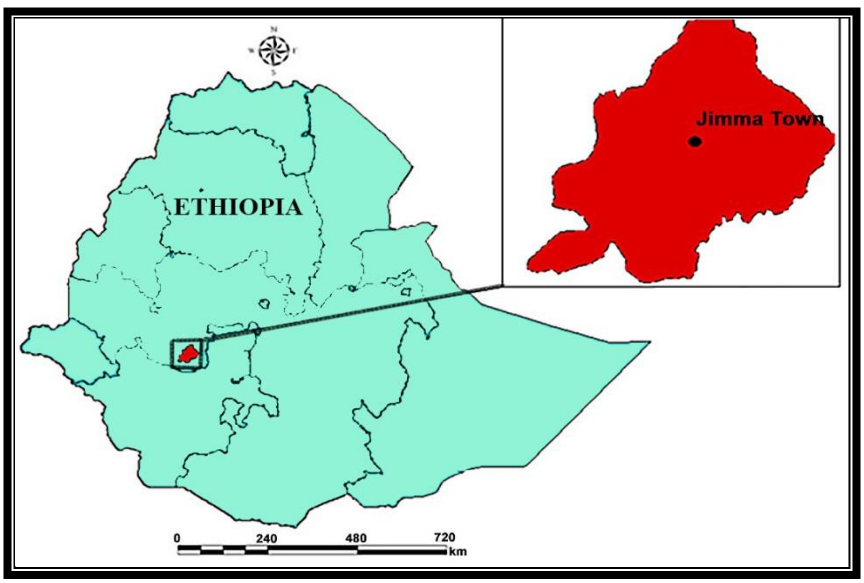


Fig 3.1.1.Map of the study area Jimma town

### 3.2. Sampling techniques and sample size

Selection of samples for this study is purposive sample selection. For the determination of the index property of the soil, samples was taken based on the required amount of soil for the type of test and from the total number of fired and stabilized clay brick the samples for each experimental laboratory tests was selected based on the requirement of the test procedure.

The main objective of this study is to compare the compressive strength of locally produced fired clay bricks with cement- clay and lime-clay stabilized bricks by altering the contents of the stabilizing agents applied based on the type of soil. The compressive strength for all types of bricks was tested in 7, 14 and 28 days of curing. Other quality tests were conducted on the bricks after the 28th day of curing.

Table 3.2.number of samples for different laboratory tests

| Types bricks | Compressive strength | | | Absorption test | Dimension tolerance and efflorescence | Total sample |
|---|---|---|---|---|---|---|
| | 7th day | 14th day | 28th Day | | | |
| Locally fired clay bricks | 5 | | | 5 | 10 | |
| Total sample | 5 | | | 5 | 10 | **20** |
| Cement–clay stabilized | | | | | | |
| 10% | 5 | 5 | 5 | 5 | 10 | **30** |
| 12% | 5 | 5 | 5 | 5 | 10 | **30** |
| 14% | 5 | 5 | 5 | 5 | 10 | **30** |
| Lime–clay stabilized | | | | | | |
| 10% | 5 | 5 | 5 | 5 | 10 | **30** |
| 12% | 5 | 5 | 5 | 5 | 10 | **30** |
| 14% | 5 | 5 | 5 | 5 | 10 | **30** |
| Total sample number | | | | | | **200** |

**Note:** the sample for locally fired clay bricks was taken randomly from bottom, middle and top part of the firing stock of bricks

The total numbers of sample clay bricks for this study are 200 bricks as shown in table 3.3. 20 bricks from locally fired bricks, 30bricks from 10% cement stabilized bricks, 30 bricks from 12% cement stabilized bricks, 30 bricks from14 %cement stabilized bricks, 30 bricks from 10%

lime stabilized bricks, 30 bricks from12%lime stabilized bricks and 30 bricks from 14 % lime stabilized bricks were taken as a sample for the compressive strength and other quality tests of the brick.

## 3.3. Materials

The materials used in this study are soil, cement and lime. Based on the index property tests, clay soil (A-7) is used for the production of fired clay brick in MURTESA small and micro locale brick producer. And for this study the soil was stabilized with both cement and lime separately with 10%,12% and 14% stabilization contents taken from the estimated amounts by PCA based on the type of soil.

### 3.3.1. Soil

#### 3.3.1.1. Quarry site selection and determining index properties of soil

Locally fired clay brick production is the known production method of building units in jimma town due to the availability of clay soil. **kito site**, **frustale site** and **boye site**, are actively available quarry sites which are hold by small and micro enterprises which are now actively participating in the market of locally FCB in the town. To select one quarry site among the above, 15 green (unfired) bricks were produced by taking soil samples enough for 5 bricks production from each quarry site. Then 15 bricks were produced with a uniform method of production and let them to dry for two weeks. Then the site with higher mean compressive strength result of green bricks, **frustale** which is owned by **MURTESA small and micro enterprise** was selected to conduct this study.

Table 3.3.1.1.quarry or production site selection

| Quarry (brick production) site in Jimma town | Mean compressive strength of 5green bricks(Mpa) |
|---|---|
| Boye | 0.65 |
| **Frustalle** | **0.82** |
| Kito | 0.79 |

Once the quarry site was selected the next step was determining the index properties of the soil from the quarry site to decide the content of stabilizer based on the soils class in AASHTO soil classification. Index properties of the soil determined were moisture content, grain size, Atterberg's limits, optimum moisture content and maximum dry density and the specific gravity. The standard test methods for the laboratory tests are summarized in table 3.3.1.2**.**The tests were conducted at JIT soil laboratory.

Table.3.3.1.2. Standards to conduct index properties of soil

| **Index property of soil** | **Test method used** |
|---|---|
| Natural moisture content | ASTM D 2216 |
| Grain size | ASTM D 422 |
| Liquid limit | ASTM D 4318 |
| Plastic limit | ASTM D 4318 |
| Plasticity index | ASTM D 4318 |
| Maximum dry density and OMC | ASTM D 698 |
| Linear Shrinkage | CTM 228 -A4 |
| Specific gravity | ASTM D 854 |
| AASHTO class | AASHTO M145 or ASTM D3282 |

The physical properties of the soil were determined following the given test methods on Table.33.1.2.and the data of each test was collected on a data sheet which is attached on appendix A. AASHTO classification of the soil was determined by using the properties of the soil which are percent passed sieve no 200, liquid limit, plastic limit and plasticity index. Then the content of stabilization were determined from the estimated amount of cement stabilization for different AASHTO class soils based on PCA.

**3.3.2. Cement:** Cement used in the stabilization process in this research is "Dangote 42.5R "ordinary Portland cement.

**3.3.3. Lime:** Type of lime used for stabilization in this study was hydrated lime ($Ca(OH)_2$), from Dire dawa cement and lime factory.

**3.3.4. Water:** The water used in this study was a potable tap water from MURTESA small and micro enterprise water supply system.

## 3.4. Preparation of materials

Clay soil was excavated by using hand tool and collected on plastic cover and air dried for one week. This was done to remove the moisture and to make it easy for grinding. After air drying the grinding was done using a shovel to break the lumps in the soil. Any coarser materials were again grinded in to fine by hands and any vegetation roots and stones were removed. This is done to make it easy to mix with the stabilizing agents.

Fig.3.5.1. Sample clay soil prepared for production

The materials used for stabilization, which are cement and lime were bought from market and transported to the production site.

## 3.5. Production of clay bricks

### 3.5.1. Fired clay bricks

The fired clay bricks for the comparison of the compressive strength and other quality tests with stabilized clay bricks were purchased from “MURTESA local brick production small scale enterprise”. Production of fired clay bricks in Jimma town is done first by mudding the soil by foot and then molding by hand. After that the green bricks will be dried about one month if it is sunny season and 2-3 months if it is rainy. The last step of production is firing. The firing process takes place by building up a rectangular wall like structure with 40,000-50,000 dried green bricks as shown in figure 3.5.1. The bottom part has openings to facilitate firing process which will last for up to 3 days. Generally the local FCB production will need at least 35 days if we consider 40,000-50,000 bricks can be molded per day which is not possible.

Fig.3.5.1. local firing process of bricks

### 3.5.2. Stabilized bricks

The production of stabilized bricks in this research was conducted by the following steps.

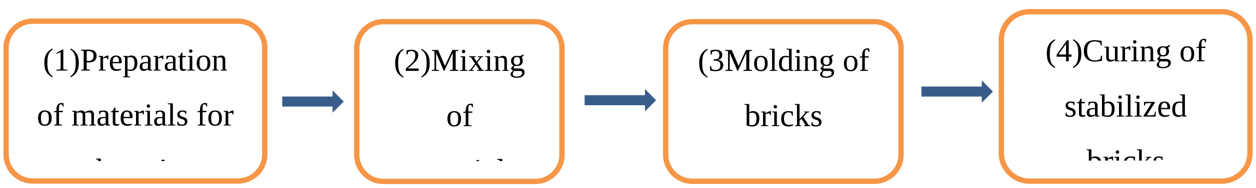


Fig 3.5.2.1.schematic diagram of production process of stabilized bricks

**1. Preparation of materials**

This is the first step which involves proportioning of the stabilizing agents (cement and lime) and the clay. The content of cement was determined from the study of Portland cement association based on the class of the soils on AASHTO.

Table 3.5.2.1.Estimated amounts of cement content for stabilization (PCA ,1992)

| AASHTO soil group | Usual range in cement requirement | |
|---|---|---|
| | Percent by volume | Percent by weight |
| A-1-a | 5-7 | 3-5 |
| A-1-b | 7-9 | 5-8 |
| A-2 | 7-10 | 5-9 |
| A-3 | 8-12 | 7-11 |
| A-4 | 8-12 | 8-13 |
| A-5 | 8-12 | 8-13 |
| A-6 | 10-14 | 9-15 |
| **A-7** | **10-14** | **10-16** |

As indicated in the index properties of the soil the soil is A-7 clay soil with stabilizing amount of cement 10%-14% by volume. For this research 10%,12% and 14% contents of stabilizer was taken based on table 3.5.2.1.

Since this study is a comparative study, to compare the effect of equal amount of stabilizer on the strength of the brick the content of the lime taken was the same as the estimated cement content which is 10%, 12% and 14%.

For the ratio 10% stabilization, 90 parts was clay soil and the 10 part was cement, i.e. 9:1 ratio of clay to cement. In the same way 7:1 and 6:1 ratio of clay to cement was taken for 12% and 14% contents of stabilizers respectively.

**2. Mixing of materials**

The material was measured by using a four liter plastic container as a gauge box based on the estimated ratio of clay soil to stabilizer. The mixing was done on an impermeable plastic cover. The measured clay soil sample was spread using a shovel to a reasonably large surface area. And the stabilizer was then spread evenly on the clay soil and the composite material thoroughly mixed by a shovel. The dry mixture was spread again to receive water which was added gradually while mixing, until the optimum mix water content of the mixture was attained. The optimum moisture content of the mixture according to American National Building Code, 2006 was determined by progressively wetting the soil and taking handful of the soil, compressing it firmly in the fist, then allowing it to drop on a hard, flat surface from a height of about 1.10m.When the soil breaks in to4 or 5 parts, the water is considered right (National building code, 2006).but since locale brick production in Jimma town is by hand molding using throwing by hands the moisture content was not enough to make the mix workable so some amount of water was added to during mixing. Mixing was done by hand and shovels thoroughly till a uniform mixture is obtained.

Table 3.5.2.2. Mixing water amount for different mix of stabilization

| Percent by volume | Mix ratio | Mixing water (lit) |
|---|---|---|
| | Clay :cement | |
| 10% | 9:1 | 8 |
| 12% | 7:1 | 6.5 |
| 14% | 6:1 | 5.5 |
| Percent by volume | Clay :lime | Mixing water(lit) |
| 10% | 9:1 | 8 |
| 12% | 7:1 | 6.5 |
| 14% | 6:1 | 5.5 |

**3. Molding of bricks**

Molding of stabilized bricks was done by using the wooden mold locally used by the local brick producers which is called “stampa” which is shown in figure 3.6.3.1 below. The inside dimension of this mold is 24cmx12cmx6cm.

Fig.3.5.3.1. “Stampa” a locale brick production mold in Jimma town

After thoroughly mixing the clay, the stabilizer and water, the mix was ready to mold. Molding was done as fast as possible after mixing is finished to prevent the drying of the mix. Since there was not any compactor the molding was done by increasing the number of molds (“stampas”) and man power to make the molding fast. During the molding process the mix thrown by force in to the mold 2 times and the surplus of the mix out of the mold removed by a tool which is locally called “fero”.”fero” is made up of a flexible bended stick and a thin wire. Then the molded mix removed from the mold. To detached the mix from the mold an ash is used which a remaining of local burning process,

Fig.3.5.3.2. Tools used during production of stabilized brick

**4. Curing of stabilized bricks**

After production the bricks were first allowed to air dry under a shade for 24hours.Thenafter, curing was continued by sprinkling of water morning and evening and covering the bricks with plastic cover for one week to prevent rapid drying out of the bricks which could lead to shrinkage cracking.

Fig 3.5.3.4.A.Produced bricks in shaded place and curing of bricks by sprinkles of water

## 3.6. Compressive strength test on bricks

Compressive strength test was carried out to determine the compressive strength of both fired and stabilized bricks following the test method of bricks on ASTM C 67. For the fired clay bricks the bricks taken to the laboratory and capped with1:2 ratio (by weight) of cement sand mortar and after 24hr the test was conducted. For the stabilized bricks, the bricks that have attained the ages of curing for strength test of 7, 14, and 28 days were taken from the curing area to the laboratory 3 days before the test was conducted, to conduct capping on the surface. The weight of each brick was taken before being capped by 1:2 ratios (by weight) of cement sand mortar. Before the compressive strength test conducted the capped bricks allowed for air drying for 24 hrs. The bricks were then crushed and the corresponding failure load recorded. The crushing force was divided by the sectional area of the bricks to arrive at the compressive strength. For each day of curing five bricks from each content of stabilizers were taken. That is 5x6(10% cement, 12% cement,14% cement,10%lime,12% lime and 14%lime) which are totally 30 bricks.

## 3.7. Other quality tests on bricks

### 3.7.1. Water absorption test

The water absorption test is one of the quality determining tests of bricks. The test was conducted as per ASTM C 67 on all types of bricks by taking 5 samples from each type of bricks at the age after 28 days of curing. For both locally fired and stabilized bricks the 24hr oven dried samples was weighted ($w_1$) carefully by a digital balance in laboratory. After that the samples cooled to room temperature and submerged in water for 24hrs.after 24 hrs. The samples taken out from the water and wiped by damp cloth and weighted ($w_2$) again then the absorption of the bricks determined by the following formula

$$\% \text{ absorption} = ((w2 - w_1)/ w_1)*100$$

The average absorption result of 5 bricks from each type of bricks then taken as the absorption of the brick type.

### 3.7.2. Dimension tolerance

The dimension tolerance test for this study conducted following the procedures of ASTM C 216. For this study all the bricks are considered as FBS (brick for general use in masonry). 10 bricks from each type were taken and the test was conducted by measuring the length width and height of each brick and the dimension was checked if it's within the ASTM C 216 standard limit.

### 3.7.3. Efflorescence

The efflorescence test of bricks was conducted as per ASTM C-67. The Ten bricks of the dimension tolerance test from each type of bricks was taken to determine the presence of salt on the bricks .The bricks was rated as ''effloresced'' and /or ''not effloresced'' as the standard on ASTM C 67 stated. The test samples were immersed in water for seven days and the rating was done by observing the surface of the bricks if they have white dots on the bricks.

## 3.8. Research approach

The research approach of this experimental study includes literature review, collecting laboratory test results, analyzing the data collected from different laboratory tests and finally finalizing the result and findings.

1. **Literature review**: reviewing literatures related to this study used to find out the methodologies, findings and way of analyzing results in related studies. And also different standards and specifications were determined to address the objectives of the study and to answer the research questions.
2. Laboratory test results : the other approach followed to conduct this experimental study were collecting laboratory test result of different tests. The laboratory tests includes
    2.1. index property tests of clay soil

2.2. compressive strength tests on bricks

2.3. other quality tests on bricks

**3.** Data analysis: all the findings of the laboratory results were analyzed and the results were discussed by using charts tables and by comparing with previous related studies.

**4.** Finalizing the study: this is the final stage of the research work which includes writing up of all finding including the conclusion and recommendation from the final finding of the study.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1. Laboratory test results for the index properties of soil

According to the explanation of (K.R.Arora, 2004) on his soil mechanics and foundation engineering book he said that simple tests which are required to determine the index properties of soil are known as classification tests; the soils are classified and identified based on the index properties. So that for this research these properties of clay soil were determined by conducting laboratory tests in JIT soil laboratory to classify the soil. The index properties of the soil determined were natural moisture content, particle size distribution, liquid limit, plastic limit, plasticity index, linear shrinkage, maximum dry density, optimum moisture content and specific gravity.

### 4.1.1. Sieve analysis

This test was conducted to determine the particle size distribution of the soil and the percentage of the soil sample that passes sieve no 200(0.075mm sieve) to decide whether the soil is coarse grained or fine grained since it's the first step to classify soil as per AASHTO soil classification method.the test was conducted in JIT soil laboratory as per the test method ASTM D 422 and the result is attached in appendix A.

From the sieve analysis test result on table 4.1.1.1.The percentage of the soil passing sieve no 200(0.075mm), for this study is **43.34%** which is greater than **35%** and makes the soil fine grained(**silt or clay (A4-A7)**) material according to AASHTO soil classification by method of elimination. A soil which contains Clay& silt content of 40%-65% is suitable for brick making (TARA, 2014)

Table 4.1.1.1. Particle size distribution of soil sample

| Sieve No | Sieve size in mm | Mass retained in (gm) | % mass retained | Cumulative % mass retained | % finer |
|---|---|---|---|---|---|
| | | (1) | (2)=((1)/$M_t$)*100 | (3) | (4)=100-(3) |
| No. 4 | 4.75 | 0 | 0 | 0 | 100 |
| No. 10 | 2 | 0 | 0 | 0 | 100 |
| No.20 | 0.85 | 12 | 4 | 4 | 96 |
| No.40 | 0.425 | 54 | 18 | 22 | 78 |
| No.100 | 0.15 | 59 | 19.67 | 41.67 | 58.33 |
| No. 200 | 0.075 | 42 | 14 | 55.67 | **44.34** |
| | Pan | 133 | 44.34 | 100 | 0 |

**Total sample of soil $M_t$=300gm**

### 4.1.2. Atterberg limit tests

The atterberg limits include liquid limit, plastic limit and plasticity index of a soil.

#### 4.1.2.1. Liquid limit

The liquid limit of the soil was determined at JIT soil laboratory as per ASTM D4318 by using Casagrande apparatus and the data was collected by the data sheet attached in appendix A. The value is found by determining the percentage of water content at 25 blows from the liquid limit flow curve which is attached in appendix A. The liquid limit of the soil for this study is **48%.**

The second point to consider classification of soils by AASHTO classification is the liquid limit. As shown in Table 4.2.1.1.The soil is already a silt clay soil based on the percentage pass by sieve number 200 (0.075mm). The liquid limit results are 40max, 41min, 40max, and 41min for the soil type A4, A5, A6 and A7 respectively.

#### 4.1.2.2. Plastic limit

The other atterberg limit is the plastic limit. it was also determined in the laboratory as per the test method ASTM D 4318. the result of the plastic limit for the soil sample for this study is **36%.**

Once the liquid limit and the plastic limit determined the plasticity index is simply the difference between the two.

**Plasticity index =liquid limit –plastic limit**

**48-36=12**

According to (TARA, 2014) a clay soils with plasticity index of 7%-16% are suitable for brick making [54].

The third and important aspect to classify the soil as per the AASHTO classification method is the plasticity index. According to the results of the percentage pass no 200 sieves and liquid limit the soil is either A4 or A7.the plasticity index of A4 is 10max and for A7 its 11min. the result of the plasticity index for this study is 12 so the soil is A7 which is clay soil.

Table 4.2.1.2.AASHTO soil classification

| General classification | Silt –clay materials (more than 35% passing no 200) | | | |
|---|---|---|---|---|
| Group classification | A4 | A5 | A6 | A7 |
| Liquid limit | 40max | **41min** | 40max | **41min** |
| Plasticity index | 10max | 10max | 11min | 11min |
| Soil type | Silt soils | | Clay soils | |

The Portland cement associations were estimate stabilization amounts for soils based on the type of the soil based on AASHTO classification. According to the above findings the type of the soil in this study is A-7 or A-7-5 clay soil with cement stabilizing amount of **10%-14%** by volume as expressed in Table 3.5.2.1.

### 4.1.3. Linear shrinkage

The linear shrinkage for this study was conducted for the soil sample according to test method CTM 228 -A4.The result of the linear shrinkage test is attached on appendix A. The test was conducted on a soil mix which is mixed with a water amount at about the liquid limit which was determined before.

The linear shrinkage result is **5.89%**. According to the study on characterization of brick making soil, they conclude that the Clay with linear shrinkage less than 5% are “non-critical”, 5% to 8% are “marginal” and values more than 8% are “critical”. Higher linear shrinkage is not desirable in brick making as this may create cracks on final products. Based on the above finding about the linear shrinkage, clay soil used in this study is suitable for brick making since the linear shrinkage value which is **5.89%** is between 5%and 8% (T.Mehedi et. al.,2012)

### 4.1.4. Other index properties

The other index properties of the clay soil for this study are summarized in the table below. The described properties in Table 4.1.4.1 are the index properties of the soil used for the production of locally fired clay brick and the stabilized clay bricks with cement and lime with 10%, 12% and 14% of stabilization separately. The results for the tests were collected by a data sheet attached on Appendix A of this research paper.

Table 4.1.4.1.Index properties of soil used in brick production

| Index property of soil sample | Test result value |
|---|---|
| Natural moisture content | 25.3% |
| Percent passing (0.075mm)or no 200 | 44.34% |
| Liquid limit | 48% |
| Plastic limit | 36% |
| Plasticity index | 12 |
| Linear Shrinkage | 5.89% |
| Maximum dry density(MDD) | 1529kg/$m^3$ |
| Optimum moisture content(OMC) | 18.8% |
| Specific gravity | 2.77 |
| AASHTO class | A-7 |

Both the MDD and OMC are determined by the standard proctor compaction test following the test method ASTM D 698.The values of moisture content and dry density for the samples taken was collected by a data collection sheet attached in appendix A. The compaction curve shown in figure 4.1.4.1.was drawn from the values of dry density and moisture content by using the moisture content as an abscissa and the dry density as coordinate. The pick point of the graph shows the maximum dry density and the moisture content corresponding to that dry density is the optimum moisture content. The MDD of the soil sample was **1529kg/m$^3$** and the OMC was **18.8%** as determined from the compaction curve in figure 4.1.4.1.

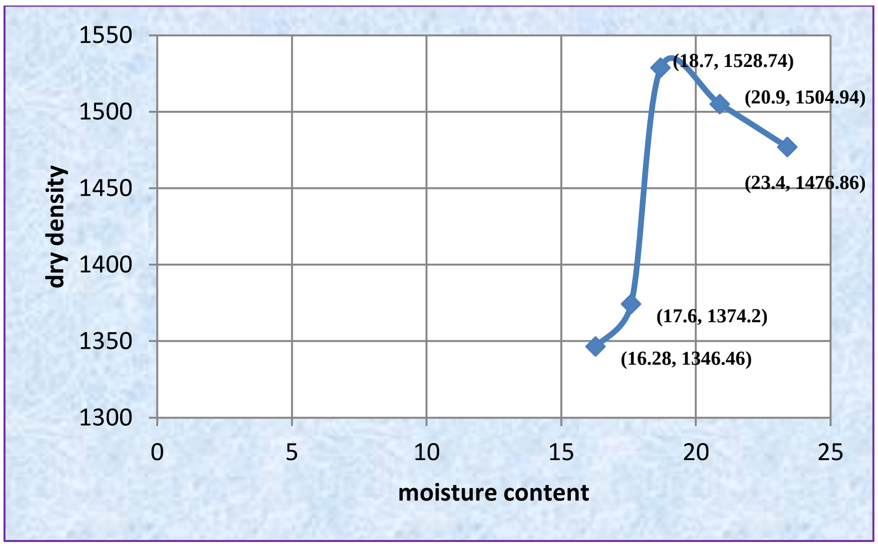


Fig 4.1.4.1 compaction curve of the soil sample

According to (K.R.Arora .2004) The standard proctor test provide a relationship between the water content and the dry density for the construction of earth dams, canal embankments, highways, runways and in many other engineering applications. Based on Indiana department of transportation office of materials management, soils with maximum dry density of 114 Ib/ft$^3$ or less are categorized to be clay soils with more than 35% passing sieve no 200 .The maximum dry density of the soil sample in this study is 1529kg/m$^3$ or 94.382 Ib/ft$^3$ which indicates the soil in this study is clay soil.

The OMC values for different soil types According to (K.R.Arora .2004), are presented in table 4.1.4.2. The range of the OMC value for clay soil type is from 14%-20% which in turn makes the soil sample of these study clay soil.

Table 4.1.4.2.optimum moisture content values of different types of soils

| Soil type | Sand | Silty sand | Silt | Clay |
|---|---|---|---|---|
| OMC | 6%-10% | 8%-12% | 12%-16% | 14%-20% |

The specific gravity of the soil was determined following the test procedure in ASTM D 854 and the data for determination collected by the data sheet attached in **appendix A**. the value of the specific gravity of the soil in this study is **2.77**.

Table 4.1.4.3.General range of Specific gravities for various soil types (Branjam D, 2002)

| Soil type | Range of specific gravity |
|---|---|
| Sand | 2.63-2.67 |
| Silt | 2.65-2.7 |
| Clay and silty clay | 2.67-2.9 |
| Organic soil | Less than 2 |

Table 4.1.4.3 shows the ranges of specific gravity values for different types of soils. The range of the specific gravity of clay soil is from 2.67-2.9 and the soil in this study has a specific gravity value of 2.77 this indicates the value is within the limits.

## 4.2. Comparison of compressive strength of bricks

### 4.2.1. Compressive strength of locally fired clay bricks

The compressive strength test of the locally fired clay bricks was conducted on locally fired clay bricks purchased from MURTESA micro and small scale local brick production enterprise. The results of the compressive strength of the locally fired clay bricks was collected from laboratory by a data collection sheet which is attached in appendix B.

Table .4.2.1. Compressive strength test results of locally fired clay bricks

| **Samples** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **Compressive strength value (Mpa)** | **3.47** | **3.76** | **1.53** | **2.67** | **2.2** |

Table 4.2.1.Shows the compressive strength results of the fired clay brick samples to determine the mean compressive strength of bricks. Five samples was taken randomly from the locally fired clay brick samples for this study. The compressive strength of the samples was determined following the test procedure in ASTM C 67.The difference in compressive strength of samples 2 and 3, which are the maximum and minimum values respectively, is 2.23mpa.this indicates the maximum strength of the locally fired clay brick samples is more than twice of the minimum value. Figure 4.2.1.1 below more illustrates the samples compressive strength as shown.

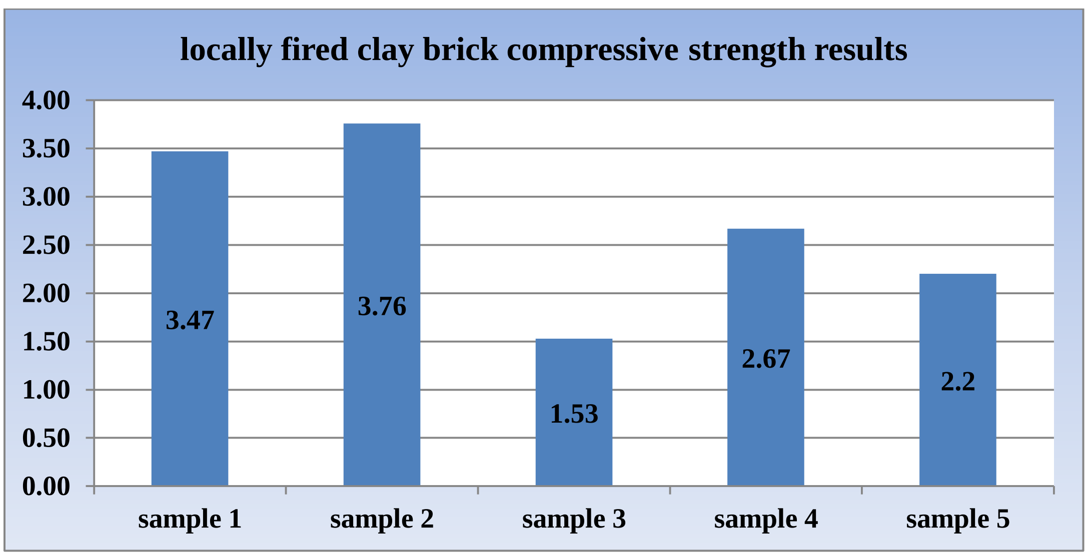


fig 4.2.1.1.Compressive strength of the samples of locally fired clay bricks

As shown in the figure 4.2.1.1the compressive strength of the samples of locally fired clay bricks vary significantly from one sample to another. As it's mentioned in the methodology the samples of the locally fired clay bricks were taken randomly from the top. Bottom and middle parts of the firing stock. Since the firing wood is inserted at the opening provided at the bottom of the prepared built up for firing, the bricks at the bottom will get high heat of burning and at the top will get lower heat of burning relatively. The average compressive strength of the locally fired clay brick samples from MURTESA small scale and micro enterprise found in jimma town is **2.73mpa**.This compressive strength has **1.2Mpa** difference of compressive strength from the minimum value of the samples.

According to the study of (Altayework .B,2013) on the effects of firing temperature on some physical properties of burnt clay bricks produced around addis ababa, he conclude that as the firing temperature of fired clay bricks increase the compressive strength of the produced clay bricks will also increase. From these the way of production or way of burning of the green bricks locally to produce locally fired clay bricks affects the compressive strength value of the bricks because the firing temperature of the locally fired clay bricks decreases from bottom to the top of the green bricks built up for firing. This clearly indicates that the quality of the locally fired clay bricks is not uniform due to the traditional firing technique.

#### 4.2.2. Compressive strength of stabilized clay bricks

In this study stabilized clay brick was produced by taking 10%, 12% and 14% by volume of stabilizer to mix with the clay soil.to make it easy for mixing in production site estimating the mix ratio of clay to stabilizer were necessary, based on that as its discussed in the methodology the mix ratios for the 10%, 12% and 14% amounts of stabilizers estimated to be 1:9, 1:7 and 1:6 ratio of stabilizer to clay.

The compressive strength test of stabilized bricks was conducted in JIT construction materials laboratory in $7^{th}$.$14^{th}$ and $28^{th}$ day of curing as per the test method on **ASTM C 67**. Five stabilized clay brick samples for each day of curing for the cement and lime 10%,12% and 14% separately stabilized bricks was taken and the compressive strength results of all the samples of the stabilized clay bricks was collected by the data sheet attached on **appendix B**.

##### 4.2.2.1. Compressive strength of cement stabilized clay bricks

**A. Compressive strength of cement stabilized clay bricks (CSCB) with 10% cement**

The 10 % cement stabilized bricks are stabilized clay bricks which are produced by a ratio of 1:9 of cement: clay by volume. The mean compressive strength results of the $7^{th}$ day, $14^{th}$ day and $28^{th}$ day cured stabilized clay bricks produced locally are presented in Fig 4.2.2.1.A. 2.01Mpa, 2.47Mpa and 2.91Mpa are the mean compressive strength results of 10% cement stabilized clay bricks for the day of curing by sprinkling of water for 7 days and cured for 14 and 28 days respectively. These mean results are the average results of five samples for each day of compressive strength test results which are attached in **appendix B.**

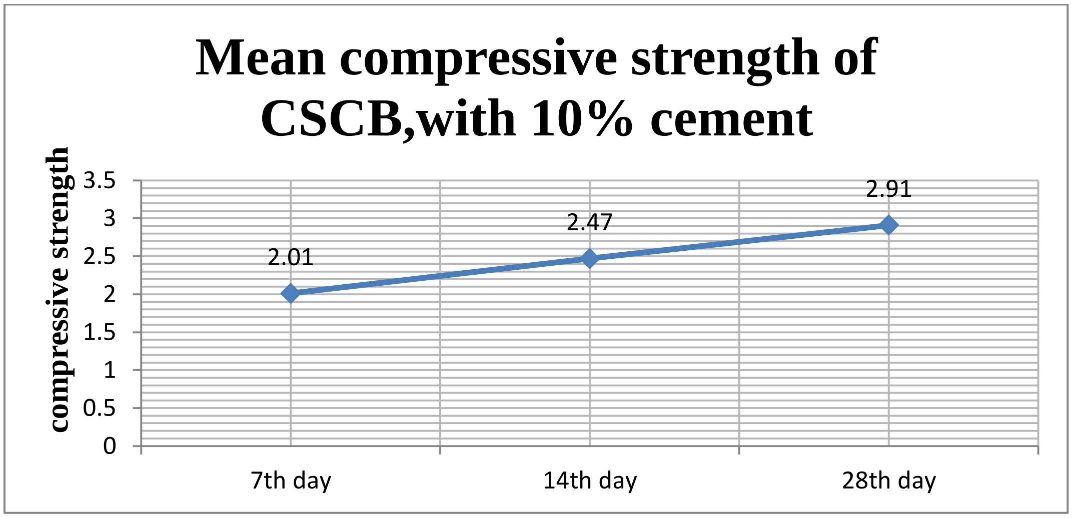


Fig 4.2.2.1.A. mean compressive strengths of cement stabilized clay bricks with 10% cement

As shown in the graph of Fig 4.2.2.1.A**.** The compressive strength of cement stabilized clay brick with 10% cement was increasing with the increase of the days of curing. This indicates that hydration of cement which gives the strength of the cement stabilized clay bricks by chemical action instead of firing the clay; attain its strength with the increase of curing days.

**B. Compressive strength of cement stabilized clay bricks (CSCB) with 12% cement**

The stabilization of clay soil for the production of cement stabilized clay bricks (CSCB) with 12% cement was conducted by taking cement clay ratio of 1:7 cement to clay ratio by volume. The compressive strength tests was carried out on $7^{th}$ ,$14^{th}$ and $28^{th}$ days of curing similar to the 10% stabilized clay bricks and the data was collected on a data sheet attached on **appendix B**.

Figure 4.2.2.1.B shows the compressive strength results of CSCB with 12% cement. The values of compressive strength of the CSCB with 12% cement are increased with the increment of the days of curing.

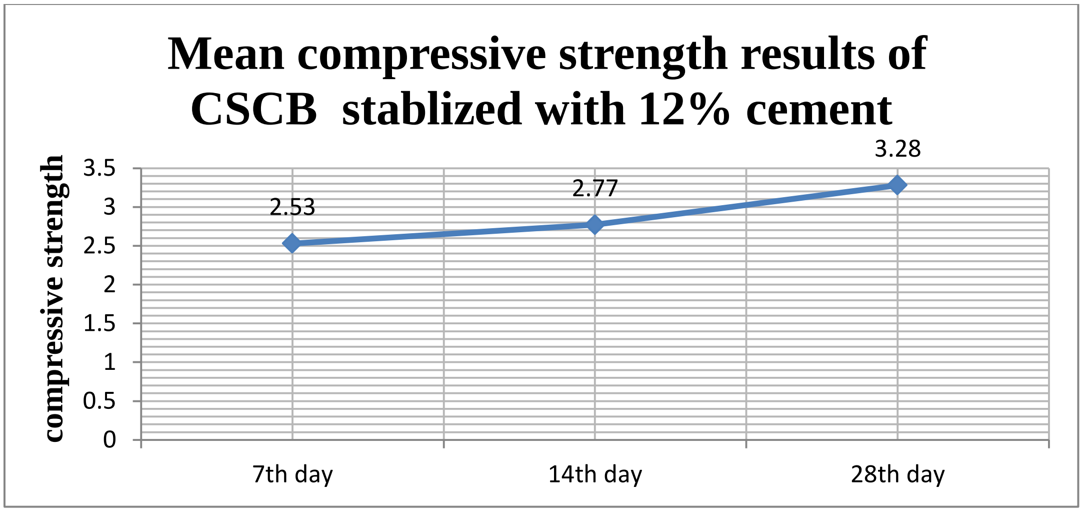


Figure 4.2.2.1.B mean compressive strength results of CSCB with 12% cement

The above figure illustrates that the trend of the increment of the compressive strength of the CSCB with 12% cement is the same with the 10% cement since the mean compressive strengths of the CSCB with 12% increases with the increment of days of curing. But the compressive strengths of the 12% stabilized bricks are greater than the values of 10% stabilized bricks corresponding to the 7$^{th}$, 14$^{th}$ and 28$^{th}$ days of curing.

**C. Compressive strength of cement stabilized clay bricks (CSCB) with 14% cement**

As it's mentioned in the methodology (chapter two) part of this thesis, the production of the 14% cement stabilized clay bricks were carried out by taking mix ratio of 1:6 by volume of cement to clay. The compressive strength test results of this CSCB with 14% cement was collected on a data collecting sheet attached on appendix B. 2.95Mpa, 3.28Mpa and 3.79Mpa are the mean compressive strength results of 14% cement stabilized clay bricks for the days of curing of 7$^{th}$ 14$^{th}$ and 28$^{th}$ respectively. These mean results are the average results of five samples for each day of compressive strength test results which are attached in appendix B.

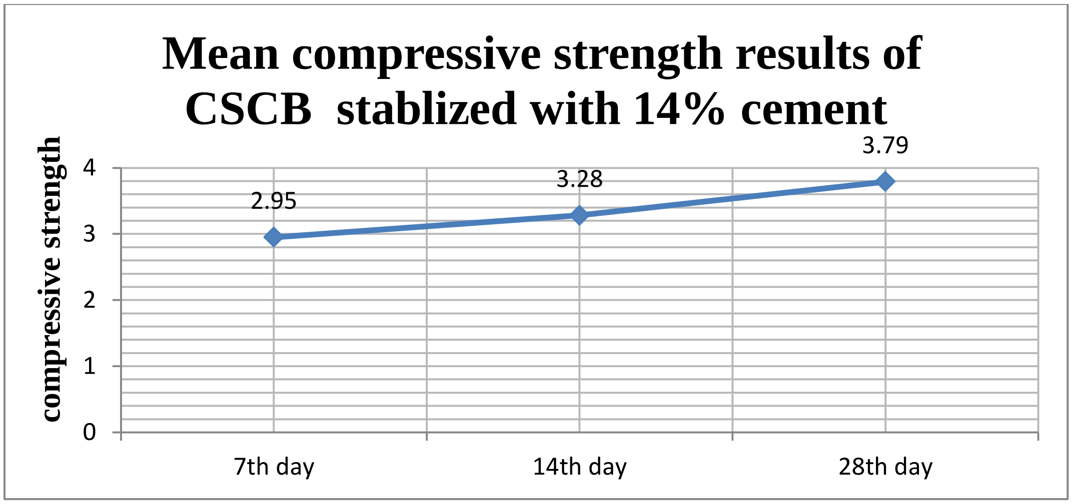


Fig 4.2.2.1.C.1 Mean compressive strength results of 14% cement stabilized clay bricks

As the two types of CSCBs stabilized with 10% and 12% cement contents, the mean compressive strength of cement stabilized clay bricks with 14% cement increases with the increment of age of curing as it is shown in figure 4.2.2.1.C.1. Additionally this type of CSCB has the highest mean compressive strength value which indicates that the 14% cement stabilize clay brick has the highest compressive strength values.

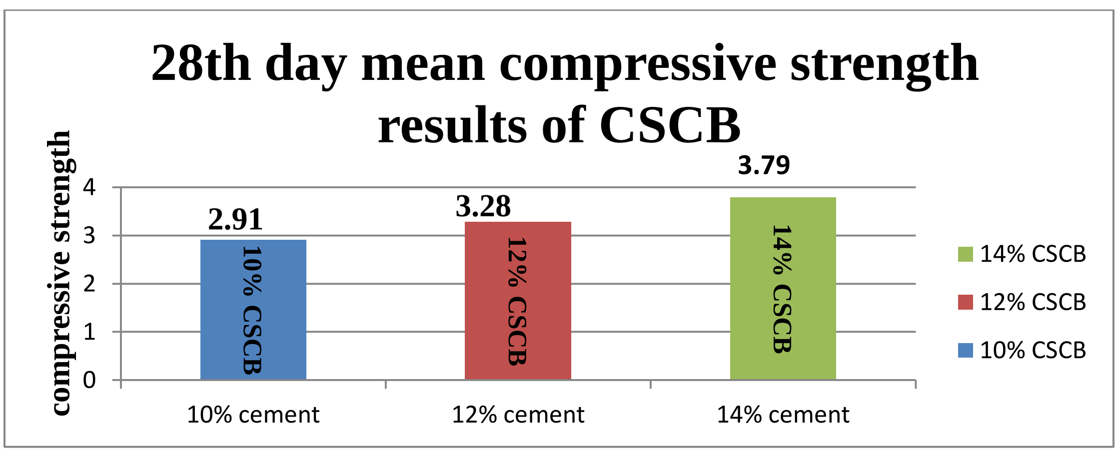


Fig 4.2.2.1.C.1.The 28th day Mean compressive strength results of cement stabilized clay bricks

Fig 4.2.2.1.C.1.shows the 28th day Mean compressive strength results of cement stabilized clay bricks. The 28th day compressive strength results of the 10%, 12% and 14% are 2.91Mp, 3.28Mpa and 3.79Mpa.The compressive strength results shows that the compressive strengths are increasing with the increment of the content of cement from 10% to 12% and to 14%.This indicates that as the content of cement in the mix increase the bonding of the minerals in clay soil increase the compressive strength then increased.

#### 4.2.2.2. Compressive strength of lime stabilized bricks

**A. Compressive strength of lime stabilized clay bricks (LSCB) with 10% lime**

The stabilizers used in this study are cement and hydrated lime ($Ca(OH)_2$) with the same amount of stabilization which are 10%,12% and 14%.the 10% LSCB was produce locally by using 1:9 lime to clay ratio by volume. The compressive strength of the 10% LSCB was conducted in a similar way with the CSCBs by taking five bricks of the sample for 7$^{th}$, 14$^{th}$ and 28$^{th}$ days of curing. The result of the compressive strength tests on the 10% LSCB is attached on **appendix B**.

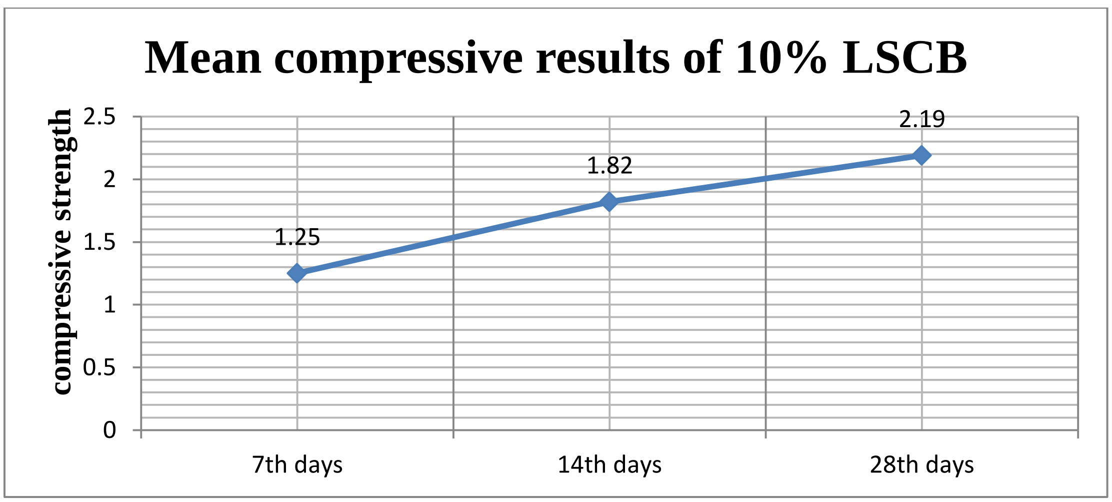


Fig 4.2.2.2 .A. Mean compressive strength results of 10% lime stabilized clay bricks

The above figure illustrates that the LSCB with 10% lime is increasing with the increment of the day of curing. Even though the compressive strength of the 10%LSCB are less than the 10% cement stabilized clay bricks, the trend shows the increment of compressive strength results with the age of curing.

**B. Compressive strength of lime stabilized clay bricks (LSCB) with 12% lime**

The 12% lime stabilized clay bricks are stabilized clay bricks which are produced by a ratio of 1:7 of lime: clay by volume. The results shows mean compressive result of five bricks taken for each 7$^{th}$, 14$^{th}$ and 28$^{th}$ days of curing and collected on a data sheet attached on appendix B. The mean compressive strength results of the 7$^{th}$ day, 14th day and 28$^{th}$ day cured lime stabilized clay bricks produced locally are presented in Fig 4.2.2.2.B.

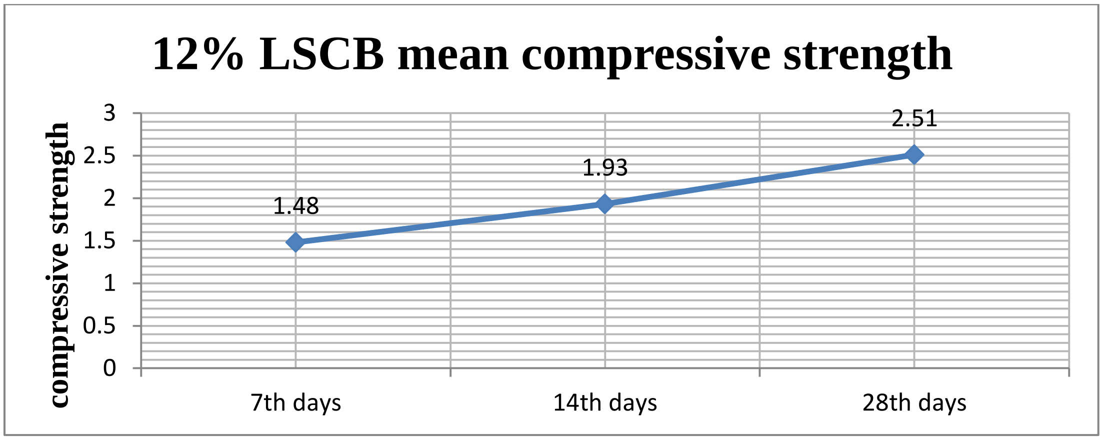


Fig 4.2.2.2.B.Mean compressive strength results of 12% lime stabilized clay bricks

As shown in the graph of Fig 4.2.2.2.B.The compressive strength of lime stabilized clay brick with 12% lime is increasing with the increase of the days of curing.

**C. Compressive strength of lime stabilized clay bricks (LSCB) with 14% lime**

The production of the 14% lime stabilized clay bricks were carried out by taking mix ratio of 1:6 by volume of lime to clay. The compressive strength test results of this LSCB with 14% lime was collected on a data collecting sheet attached on appendix B. the mean compressive strength values of LSCB with 14% is presented in Fig.4.2.2.2.C.1.

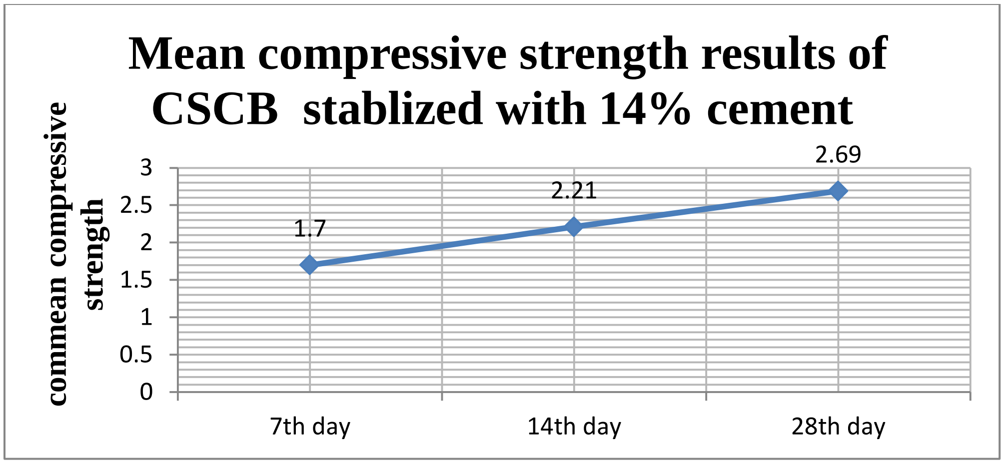


Fig.4.2.2.2.C.1. Mean compressive strength of 14% lime stabilized clay bricks

As shown in the graph of Figure 4.2.2.2.C.The compressive strength of lime stabilized clay brick with 14% lime is increasing with the increase of the days of curing.

For lime stabilized clay bricks the result shows that the compressive strength of the lime stabilized clay bricks increases with the increment of the stabilization amount of lime.

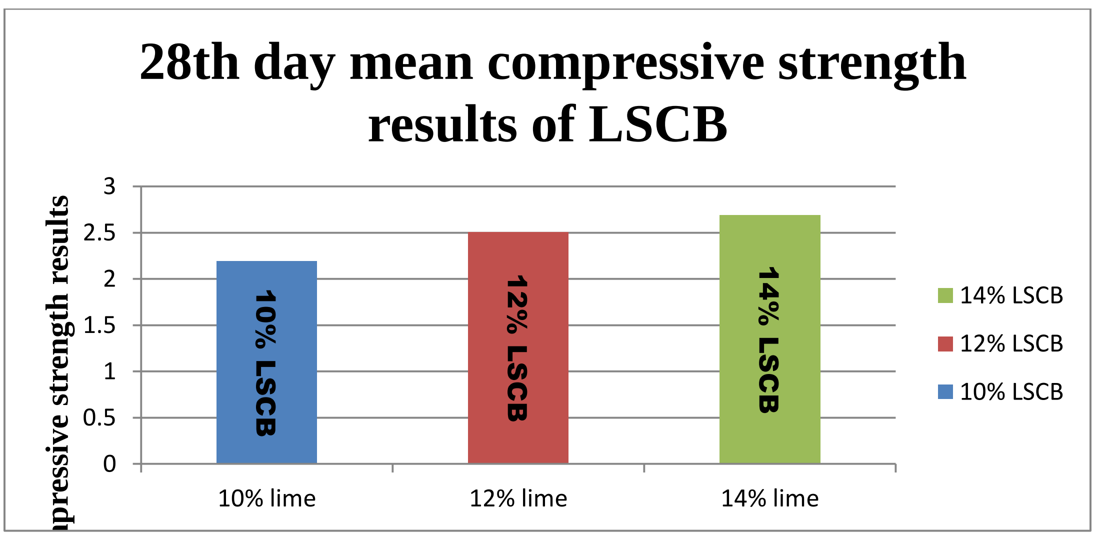


Fig. 4.2.2.2.C.2.The 28th days mean compressive strength of lime stabilized clay bricks

As it is shown in the chart presented in **Fig 4.2.2.2.C.2,** the compressive strength of the LSCBs increases with the increment of lime as stabilizer for the production of stabilized clay bricks.

This indicates that the lime's tendency of increasing the bondage between the soil minerals is increased with the increment of the lime content.

### 4.2.3. Comparing compressive strength of bricks

#### 4.2.3.1. Comparing compressive strength of locally FCB and CSCB

The mean compressive strength result of the fired clay brick is **2.73Mpa** and the compressive strength results of CSCB with 10% of cement are **2.01Mpa, 2.47Mpa** and **2.91Mpa** on the 7$^{th}$, 14$^{th}$ and 28$^{th}$ day of curing respectively. Here the compressive strength of the fired clay bricks is less than the compressive strength result of the 10% cement stabilized clay bricks at the age of 28$^{th}$ day of curing by **0.18Mpa**.Here it can be seen that by stabilizing the clay soil with 10% cement we can attain better strength than the locally fired clay brick compressive strength. Additionally the brick producers can produce much number of bricks within short period of time.

The compressive strength of the 12% CSCB has a mean compressive strength of **2.53Mpa, 2.77Mpa** and **3.28Mpa** for the 7$^{th}$, 14$^{th}$ and 28$^{th}$ day of curing respectively. Here both the 14$^{th}$ day and 28$^{th}$ day compressive strength results are higher than the locally fired clay bricks. The 12% CSCB 28$^{th}$ day mean compressive strength is greater than the locally fired clay bricks mean compressive strength by **0.55Mpa**.

The others are the 14% CSCBs, which has compressive strength results of **2.95Mpa, 3.28mpa** and **3.79 MPa**. As it's clearly shown they are much stronger than the locally fired clay brick which has a mean compressive strength of **2.73Mpa.** The 14% CSCB 28$^{th}$ day mean compressive strength is greater than the locally fired clay bricks mean compressive strength by **1.06Mpa**.

As it can be seen from the above results the difference in compressive strength of the locally fired clay bricks and the CSCB is increasing as the content of cement for stabilization increased. This indicates that as the content of cement stabilizer increased the strength of the stabilized clay bricks was increasing. This is due to that as the content stabilizer increase the strength of the bond between the soil particles will increase.

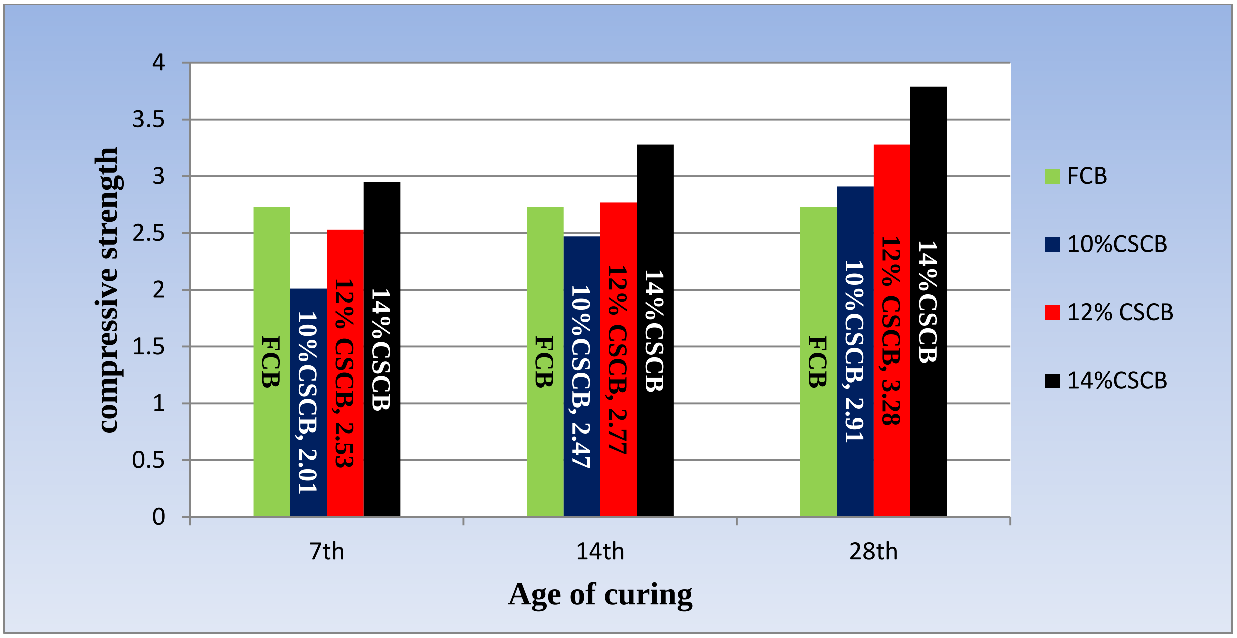


Fig.4.2.3.1. Comparison of mean Compressive strengths of locally FCB and CSCB

The tendency of the CSCB to increase their strength with the increment of the stabilizing amount can be seen on the chart in **Fig 4.2.3.1**., the 14% cement stabilized clay brick is the strongest one from the locally FCB, 10% and 12% cement stabilized clay bricks.

Generally all cement stabilized clay bricks at the age 28 days of curing has better strength than the locally fired clay bricks. This indicates that the bricks gained better strength by chemical action due to cement stabilization than the process of traditional firing.

#### 4.2.3.2. Comparing compressive strength of locally FCB and LSCB

The result of the mean compressive strength results of the 10% lime stabilized clay brick are **1.25Mpa, 1.82Mpa** and **2.19Mpa** in the 7$^{th}$ 14$^{th}$ and 28$^{th}$ days of testing respectively. All are less than **2.73mpa** which is the compressive strength of the locally fired clay brick. The locally fired clay brick mean compressive strength is greater than the 10%LSCB mean compressive strength by **0.54Mpa**.

The 12% lime stabilized clay bricks has the 7$^{th}$ 14$^{th}$ and 28$^{th}$ day mean compressive strength of **1.48Mpa**, **1.93Mpa** and **2.51mpa** for the 7$^{th}$, 14$^{th}$ and 28$^{th}$ days of curing. The locally fired clay brick mean compressive strength is greater than the 28$^{th}$ day mean compressive strength of 12%LSCB by **0.22Mpa**.

The 14% LSCB has a mean compressive strength value of **1.7Mpa**, **2.21Mpa** and **2.69Mpa** for the 7th, 14th and 28th days of curing. The locally fired clay brick mean compressive strength is greater than the 12%LSCB mean compressive strength by **0.04Mpa**.

As it can be seen from the above results even though the locally fired clay bricks compressive strength is greater than the LSCBs in all contents, the difference in compressive strength of the locally fired clay bricks and the LSCB is decreasing as the content of lime for stabilization increased. This indicates that as the content of lime stabilizer increased the strength of the stabilized clay bricks was increasing. This is due to that as the content stabilizer increase the strength of the bond between the soil particles will increase.

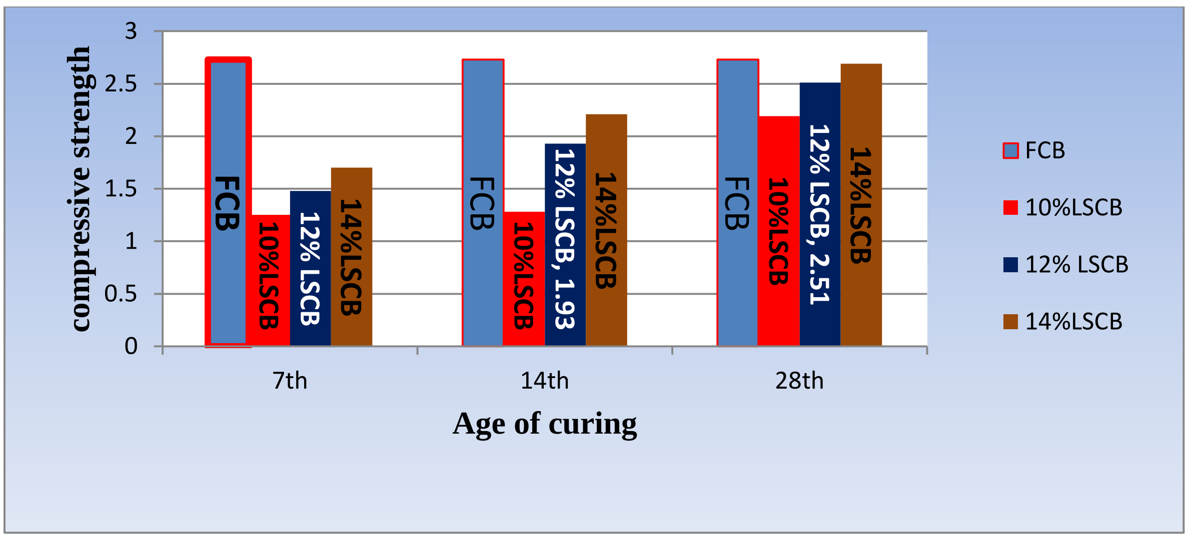


Fig.4.2.3.2. Comparison of mean Compressive strengths of locally FCB and LSCB

As shown in Figure 4.2.3.2.unlike to the cement stabilize clay bricks, all lime stabilize clay bricks are weaker than the locally fired clay bricks. This indicates that the bricks gained better strength by traditional firing process than by chemical action due to lime stabilization.

#### 4.2.3.3. Comparing compressive strength of CSCB and LSCB

Portland cement and lime (hydrated lime) are stabilizers used for the production of unfired stabilized clay bricks. The main objective of this study is comparing the compressive strengths of this stabilized bricks with the locally fired clay brick in Jimma town. As its discussed in section

4.2.3.3. All cement stabilized bricks were stronger than the locally fired clay bricks and all lime stabilized clay bricks were weaker than the locally fired clay bricks. The mean compressive strength results of the 10% cement and lime stabilized clay bricks are **2.01Mpa, 2.47Mpa, 2.91Mpa** and **1.25Mpa, 1.82Mpa, 2.19Mpa** respectively for the $7^{th}$ $14^{th}$ and $28^{th}$ days of curing.

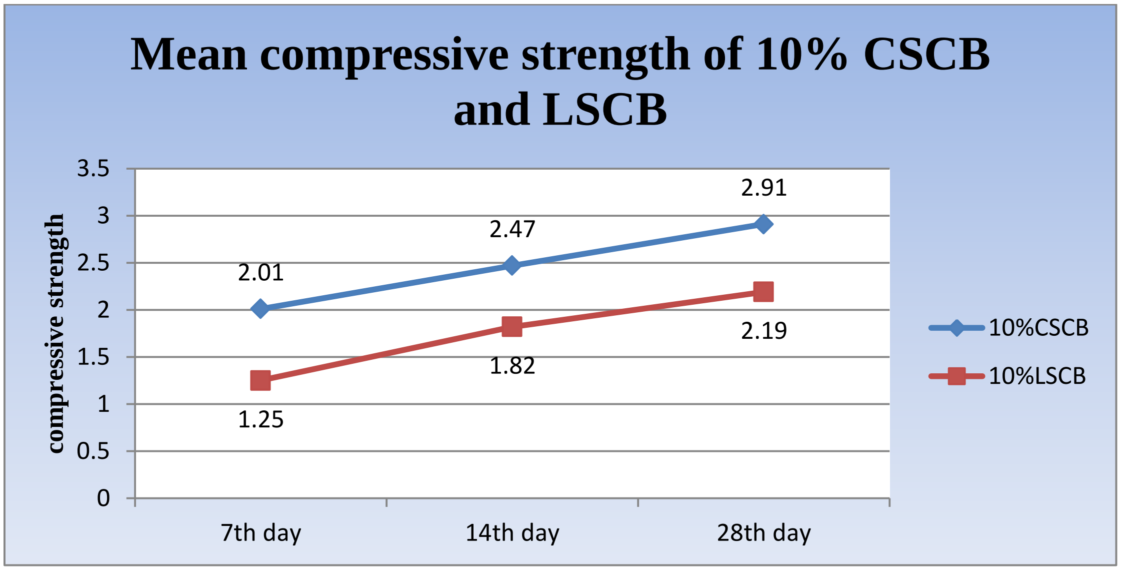


Fig 4.2.3.3.1 mean compressive strength values of 10% CSCB and LSCB

The graph in figure 4.2.3.3.1, shows the mean compressive strength values of 10% cement stabilized clay bricks and 10% lime stabilized clay bricks. The 10% CSCB compressive strength increase by 0.46Mpa from $7^{th}$ day to $14^{th}$ day period of curing. As the period of curing increase from 14 days to 28 days the compressive strength of 10% CSCB increase by 0.44Mpa.These shows that the compressive strength of the 10% cement stabilized clay bricks are increasing with the increment of days of curing. For the 10% LSCB the compressive strength result increases by 0.57Mpa from $7^{th}$ to $14^{th}$ day days of curing. Whereas from $14^{th}$ days to $28^{th}$ days of curing the compressive strength of 10% LSCB increases by 0.37Mpa.These shows that the compressive strength of both the 10% CSCB and 10% LSCB is increasing with the increment of days of curing.

At all ages of curing the 10% CSCB has better strength than the 10% LSCB. This shows that cement is stronger stabilizer than lime with 10% content of stabilization. This indicates that the effect of increasing the bondage of clay minerals is higher in cement stabilization than in lime stabilization applied by the same amount.

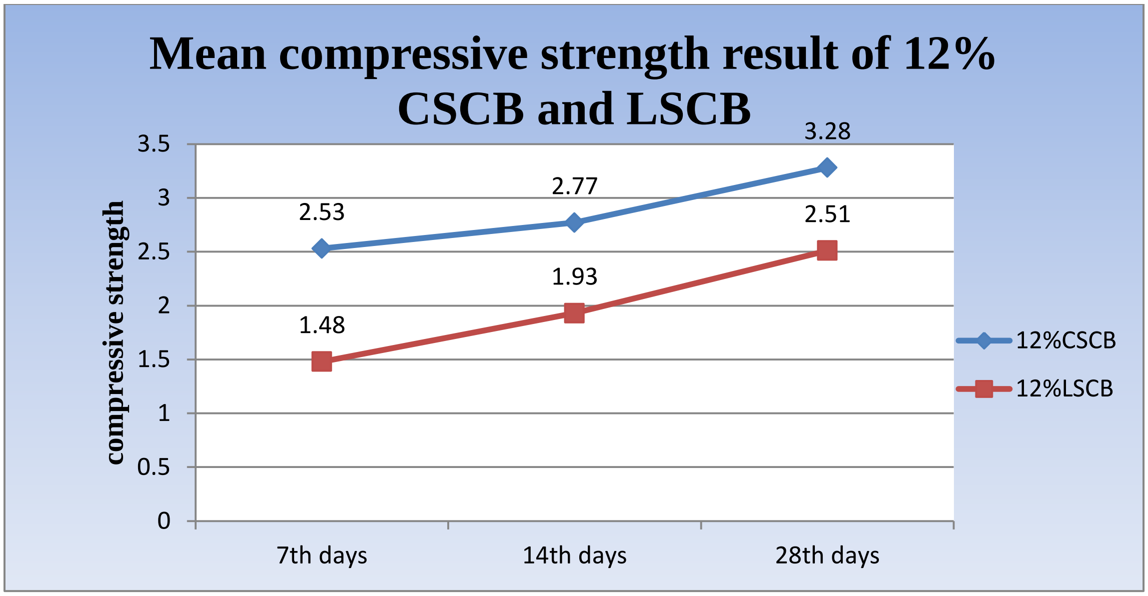


Fig 4.2.3.3.2.Mean compressive strength values of 12% CSCB and LSCB

The mean compressive strength of the 12% cement and lime stabilized clay bricks are as shown in the graph shown in Figure 4.2.3.3.2. By which the upper line indicates the 12% cement stabilized clay brick and the lower line indicates the mean compressive strength of the lime stabilized clay brick. The mean compressive strength of 12% CSCB increases by 0.24Mpa from $7^{th}$ days to $14^{th}$ days of curing. And also from $14^{th}$ days to $28^{th}$ days of curing the compressive strength of the 12% CSCB increased by 0.51Mpa.For the 12% LSCB also the compressive increased by 0.45Mpa from $7^{th}$ to $14^{th}$ days of curing. From 14 days to 28 days of curing the compressive strength of the 12% LSCB increased by 0.58Mpa.These shows that the compressive strength of both the 12% CSCB and 12% LSCB is increasing with the increment of days of curing. The 12 % CSCB attains better strength than the 12% LSCB in all days of curing. For the 12% stabilization also the CSCB is stronger than the LSCB. This indicates that the effect of increasing the bondage of clay minerals is higher in cement stabilization than in lime stabilization applied by the same amount.

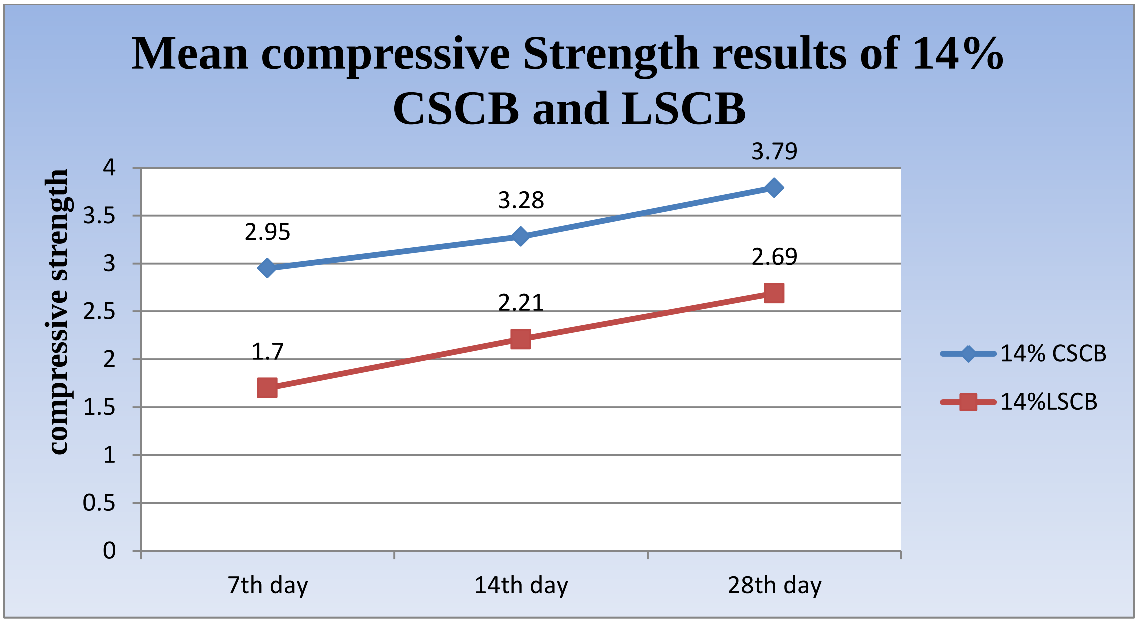


Fig 4.2.3.3.3.Mean compressive strength of 14% CSCB and LSCB

The mean compressive strength of the 14% cement and lime stabilized clay bricks are as shown in the graph shown in Figure 4.2.3.1.2.The 14%CSCB compressive strength increased by 0.33Mpa from 7 days to 14 days of curing. The strength also increased by 0.51Mpa from 14 days to 28 days of curing. For the 14% LSCB the strength increased by 0.51Mpa from 7 days to 14 days of curing. The strength also increased by 0.48 from 14 days to 28 days of curing. This shows that the compressive strength of both cement and lime stabilized clay bricks with 14% content of stabilization are increasing with the increment of days of curing.

The maximum compressive strength obtained in this study is the 28$^{th}$ day mean compressive strength of the 14% CSCB, which is **3.79Mpa**. but lime, was also applied with equal percentage of stabilization which is 14%.The mean compressive strength in each days of curing is lesser than the cement stabilized. Additionally the graph in the above figure also illustrates these phenomena. This indicates that the effect of increasing the bondage of clay minerals is higher in cement stabilization than in lime stabilization applied by the same amount.

## 4.3. Quality tests on FCB and SCB

In addition of compressive strength test, other quality tests were conducted on both the locally fired and stabilized clay bricks. Quality tests conducted on the bricks were water absorption, dimension tolerance and efflorescence according to **ASTM C216** and **C67** test methods.

### 4.3.1. Absorption of FCB and SCB

The absorption of the bricks for both the locally fired clay bricks and 10% CSCB,12% CSCB and ,14% CSCB was tested by using five bricks for each sample as per the test method of **ASTM C 67** and the test results was collected by a data sheet attached on **appendix B.**

For the stabilized bricks the test was conducted after the 28$^{th}$ day of curing. The absorption test could not work for all lime stabilized clay bricks since all the bricks were dissolved in water when they immerse in water for 24hrs.This indicates that the lime stabilized clay bricks gives the bricks lower water resistance. This is due to the manual compaction method which does not give the mixture enough bondage during molding. This weak bonding is easily penetrable by water and the product dissolved in water.

The mean absorption result of the locally fired clay brick is **15.90**% and the 10%, 12% and 14% cement stabilized clay bricks have mean absorption values of **14.74%, 14.59%** and **13.8%** respectively.

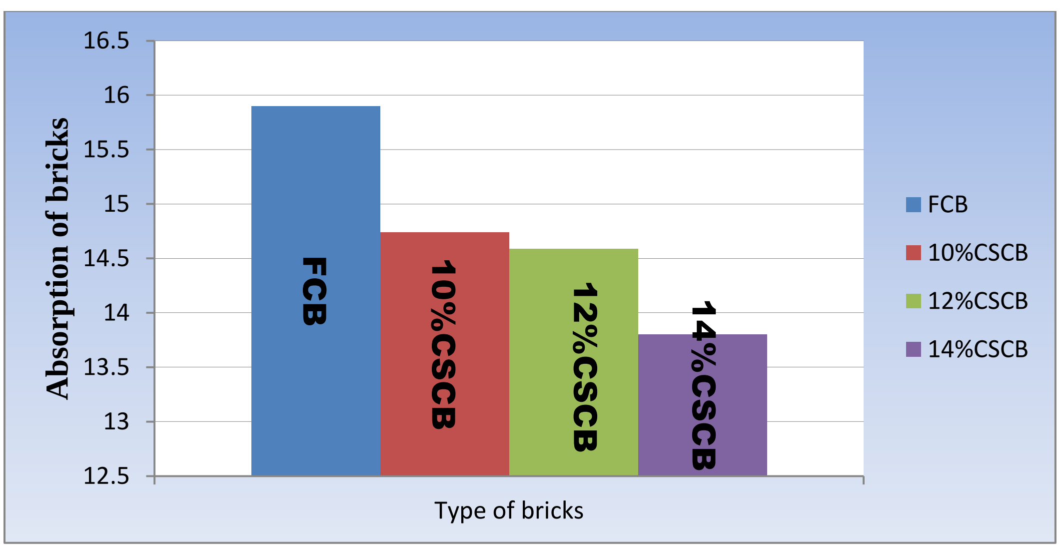


Fig 4.3.1.1 Mean absorption values of FC and CSCB

For the fired clay bricks the test was conducted on five bricks and the average was taken as a mean absorption value of the bricks. The mean absorption value of locally fired clay brick was 15.90%.For the 10% CSCB the absorption was 14.74%,for the 12% CSCB the mean value of absorption was 14.59% and finally for 14% CSCB the mean absorption value was 13.8%.

The existence of much pores on the surface of the bricks increased the absorption of the bricks. A brick with higher amount of absorption affects the final built up structure by absorbing much amount of water from the mortar and result in loss of bondage between the bricks. From the above results the CSCBs show lower amount of absorption than the locally fired clay bricks. Even if the burning process more likely gives the clay material ceramic property, with lower tendency of absorbing water from the surrounding, the cement stabilized bricks shows better quality of water absorption. This is because cement is stronger in creating bondage between the particles and minimizing the pores by which the water drains in to the brick. In another case the absorption values of CSCB decreased with the increment of cement stabilizer. This indicates that since cement has higher cementing or bonding property as the amount increased the absorption will decrease.

### 4.3.2. Dimension tolerance of FCB and SCB

The inside dimension of the mold used in this study was the mold used by the local fired clay producer enterprises in Jimma town which was 240mmx120mmx60mm.The dimension tolerance test is the simplest test from all the quality tests of brick. The test conducted on the locally fired clay bricks and all types of stabilized bricks by measuring the dimensions along the length, width and height separately The average variation(reduction) in (mm) of each type of bricks was compared with the ASTM standard. Dimension tolerance test for all brick types was conducted as per the test method of **ASTM C216** by taking ten bricks and measuring their dimensions. The data was collected on the data sheet attached on **appendix B.**

The dimension tolerance test on the locally fired clay bricks was conducted on the bricks which are ready to use after their firing stage. For the stabilized bricks the test was conducted at the ages around 30 days.

Table 4.3.2.1.Dimension tolerance test results along the length

| | Average Variation in(mm) of ten bricks | ASTM permissible maximum variation in(mm)for size (203mm-305mm) |
|---|---|---|
| FCB | 24mm | 7.9mm |
| 10%CSCB | 17.8mm | 7.9mm |
| 12%CSCB | 16mm | 7.9mm |
| 14%CSCB | 12mm | 7.9mm |
| 10%LSCB | 22mm | 7.9mm |
| 12%LSCB | 19mm | 7.9mm |
| 14%LSCB | 18mm | 7.9mm |

The dimension of the mold along the length is 240mm and ASTM permissible variation to this length is 7.9mm.as it's shown in **Table 4.3.2.1**.all the bricks didn't fulfill ASTM requirement. The bricks show more dimension changes than the ASTM permitted variation. For the locally fired clay bricks the variation in dimension was 24mm. Change in dimension in bricks caused by shrinkage during drying and burning. Higher Shrinkage occurs during drying and burning if the mix water and the water inside the bricks are very high and that higher amount of water is removed during drying and burning. As it is described in the methodology the molding of the bricks in this study was conducted by hand molding, to improve the workability of the mix local producers add water more than the optimum. This mixing water during drying and burning is removed resulting in high amount of shrinkage.

On the other hand the change in dimension of the stabilized bricks was better than the locally fired clay bricks. The cement stabilized clay bricks average reduction in dimension was 17.8mm, 16mm and 12mm for the 10%, 12 % and 14% contents of cement as stabilizer. It is clearly shown that as the content of the cement stabilizer increase the shrinkage due to drying decrease. According to the study of (Aime J.F.et al., 2014), this is because as the amount of stabilizers increases the bound between the particles within the paste increase. This increasing of the bound between the particles decreases the shrinkage.

For the lime stabilized bricks the variation in dimension along the length was 22mm, 19mm and 18mm for the 10%,12% and 14% content of lime stabilizer. The change in dimension of lime stabilized clay bricks is more than the cement stabilized clay bricks, this shows that cement has better bonding property than lime.

Table 4.3.2.2.Dimension tolerance test results along the width

| Types of bricks | Average Variation in(mm) of ten bricks | ASTM permissible maximum variation in(mm)for size (102mm-152mm) |
|---|---|---|
| FCB | 6.3mm | 4.8mm |
| 10%CSCB | 3.6mm | 4.8mm |
| 12%CSCB | 2.5mm | 4.8mm |
| 14%CSCB | 1.7mm | 4.8mm |
| 10%LSCB | 4.6mm | 4.8mm |
| 12%LSCB | 4mm | 4.8mm |
| 14%LSCB | 3.3mm | 4.8mm |

For the change in dimension along the width all the brick types fulfill the ASTM requirements. Size reduction of the bricks along the width is as presented in table 4.3.1.2.The dimension of the bricks which are fired locally shows highest reduction in measurement than the other and the cement stabilize brick with 14% cement has the lowest reduction in dimension. The reason of this phenomenon is the same as it is discussed in the dimension tolerance along the length.

Table 4.3.2.3.Dimension tolerance test results along the height

| Types of bricks | Average Variation in(mm) of ten bricks | ASTM permissible maximum variation in(mm)for size (76mm and under) |
|---|---|---|
| FCB | 5.1mm | 2.4mm |
| 10%CSCB | 2.4mm | 2.4mm |
| 12%CSCB | 2.1mm | 2.4mm |
| 14%CSCB | 1.6mm | 2.4mm |
| 10%LSCB | 4.9mm | 2.4mm |
| 12%LSCB | 3.6mm | 2.4mm |
| 14%LSCB | 2.9mm | 2.4mm |

The average dimension reduction of each type of bricks along the height is presented in **table 4.3.2.3.**the values of variation in size along the height of FCB and 10% LSCB passes the maximum permissible variation in size according to **ASTM C216**.

The reduction in dimension along the height is smallest for 14% cement stabilized clay bricks and higher for the locally fired clay bricks. The reason of this phenomenon is the same as it is discussed in the dimension tolerance along the length.

According to ASTM C 216 Because of the way brick are made, there will be some slight variations in size. Size variation is due to shrinkage during drying and firing. The amount of variation in shrinkage depends on many factors, such as variations in raw materials and manufacturing techniques. Brick manufacturers attempt to control these factors. Variations in brick size are compensated for by the mortar joint thickness to achieve fixed dimensions of the masonry.

Additionally the variation in dimension can be complemented by providing a mold size considering the expected change in dimension. For example for the 14% cement stabilized clay brick the average reduced dimensions along the length, width and height are 12mm,1.7mm and

1.6mm.To get a brick with a specified dimension of 240mmx120mmx60mm the brick manufacturer can prepare a mold with inside dimension of 138mmx119.3mmx59.4mm to get a brick with specified dimension after 28 days of curing. Since there is no change in dimension after 28 days the brick shall be ready for use. This indicates that the stabilization technique is faster than the locally fired clay brick production process.

#### 4.3.3. Efflorescence

Efflorescence test for all the bricks stabilized with cement and the FCB was conducted According to **ASTM C67**.The test was followed after the dimension tolerance test has accomplished. The result of the efflorescence test on all the FCB and SCB are attached in **appendix B**. And as the result shows all the bricks are **not effloresced**.

## 4.4. Comparing compressive strength of locally FCB and SCB with different standards

### 4.4.1. Comparing locally FCB compressive strength with standards

#### A. Comparing with Ethiopian standard minimum compressive strength

The minimum compressive strength of bricks corresponding to their classes according to **ES 86:2001** is presented in **table 4.4.1.A**

Table 4.4.1.A.minimum compressive strength of bricks (86:2001)

| Class | Minimum compressive strength | |
|---|---|---|
| | Average of 5 bricks | Individual brick |
| | $N/mm^2$ | $N/mm^2$ |
| A | 20 | 17.5 |
| B | 15 | 12.5 |
| C | 10 | 7.5 |
| D | 7.5 | 5.0 |

The mean compressive strength of locally fired clay brick of MURTESA small and micro enterprise is **2.73Mpa.**

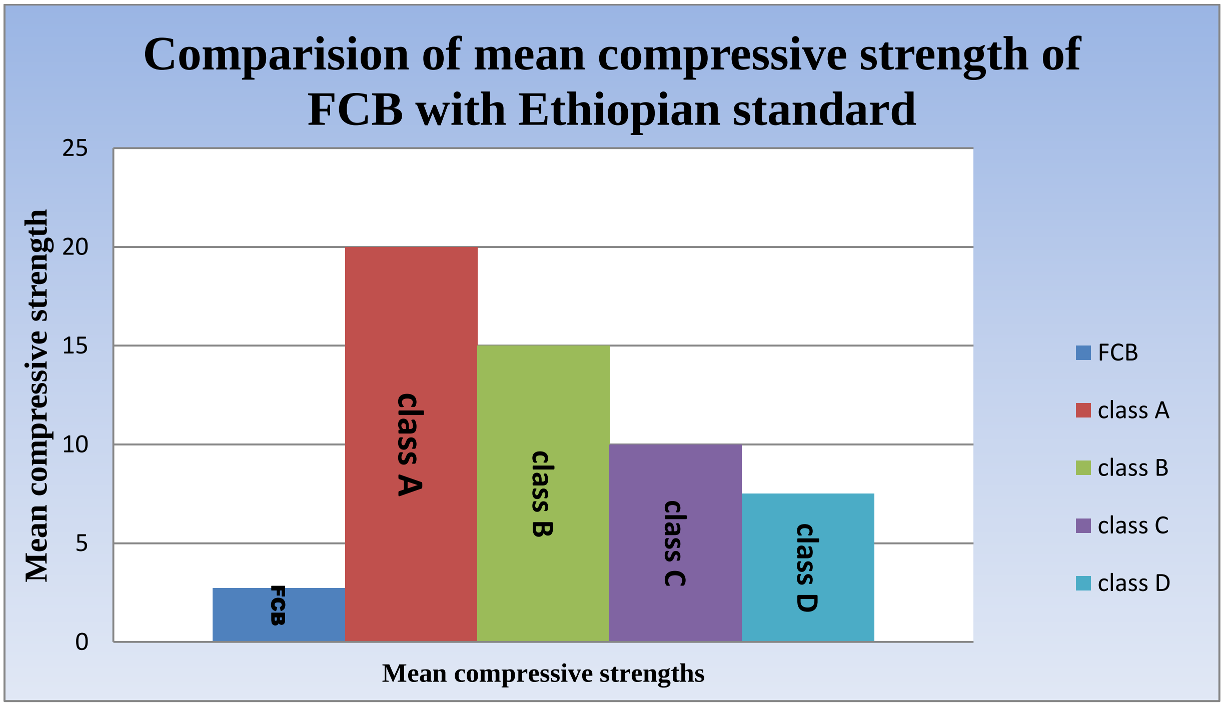


Fig.4.4.1.A. Comparison of mean compressive strength of locally FCB with ES brick classes

The figure above shows the compressive strength requirements of classes of bricks and the mean compressive strengths of the FCB of this study. As it is clearly shown the locally fired clay brick did not full fill the requirement of any class in ES.

**B. Comparing with ASTM Standard Specification for Building Bricks (ASTM C 216)**

Table 4.4.1.B.ASTM standard of bricks compressive strength **(ASTM C 216**)

| designation | Minimum compressive Strength ( Mpa ) | | Maximum water absorption by 5hr boiling (%) | | Maximum saturation coefficient | |
|---|---|---|---|---|---|---|
| | Average of 5 bricks | individual | Average of 5 bricks | individual | Average of 5 bricks | Individual |
| Grade SW | 20.7 | 17.2 | 17.0 | 20.0 | 0.78 | 0.80 |
| Grade MW | 17.2 | 15.2 | 22.0 | 25.0 | 0.88 | 0.90 |

The same as the Ethiopian standard the FCB in this study did not have a compressive strength not even close to the value of ASTM standard. The FCB in this study can be categorized as bricks with grade MW which means bricks subjected to moderate weathering. The value of the minimum compressive strength of five bricks for the moderate weathering type is in ASTM standard is **17.2Mpa.**

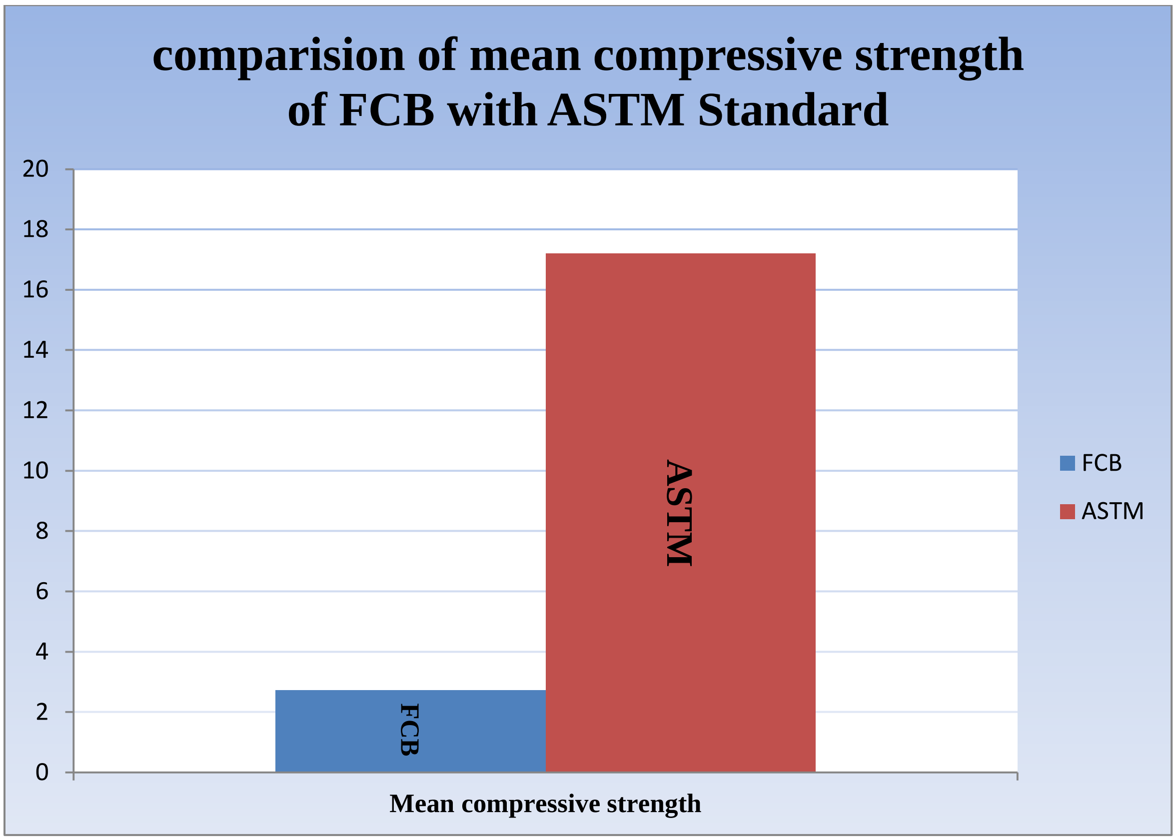


Fig.4.4.1.B. Comparison of mean compressive strength of locally FCB with ASTM minimum compressive strength requirement

As it is shown in the figure above the locally fired clay brick does not full fill the ASTM standard minimum compressive strength requirement.

**C. Comparing with Indian Standard Specification for Burnt clay Bricks (IS 1077-92)**

Table.4.4.1.C. Indian standard for the compressive strength of burnt clay bricks (IS 1077-92)

| Class designation | Minimum Average compressive strength |
|---|---|
| 35 | 35Mpa |
| 30 | 30Mpa |
| 25 | 25Mpa |
| 17.5 | 17.5Mpa |
| 12.5 | 12.5Mpa |
| 10 | 10Mpa |
| 7.5 | 7.5Mpa |
| 5 | 5Mpa |
| 3.5 | 3.5mpa |

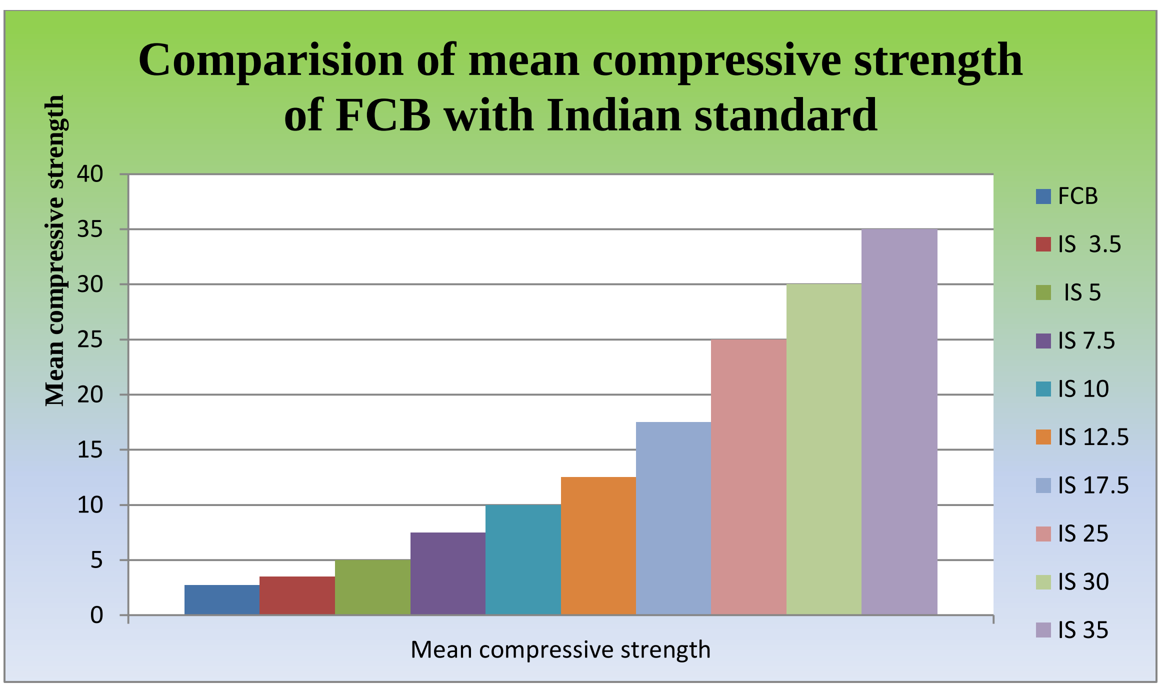


Fig.4.4.1.C. Comparison of mean compressive strength of locally FCB with Indian classes of bricks

Figure 4.4.1.C shows the comparison of mean compressive strength of locally fired clay bricks with Indian standard bricks.as it is illustrated in the figure the locally FCB mean compressive strength did not full fill the Indian classes mean compressive strength requirement.

**D. Comparing with British Standard Specification for Clay bricks (BS 3921:1985)**

Table 4.4.1.D British Standard Specification for Clay bricks (BS 3921:1985).

| No | Class of clay bricks | Compressive strength($N/mm^2$) | Water absorption (% by mass) |
|---|---|---|---|
| 1 | Engineering A | >70 | <4.5 |
| 2 | Engineering B | >50 | <7.0 |
| 3 | Damp-proof course 1 | >5 | <4.5 |
| 4 | Damp-proof course 2 | >5 | <7.0 |
| 5 | All others | >5 | No limit |

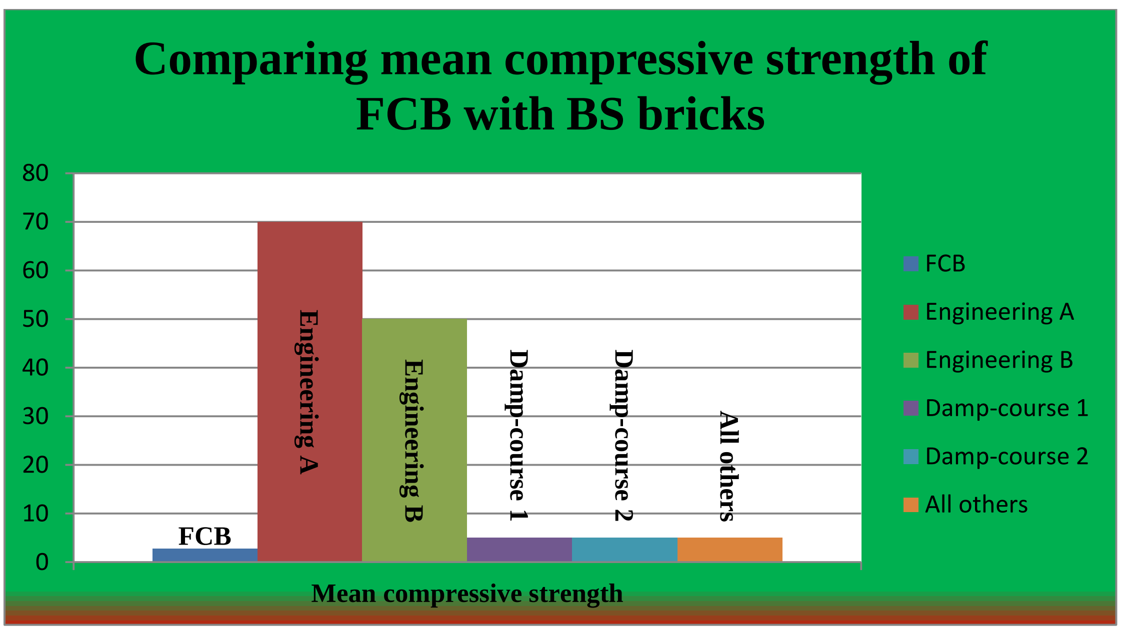


Fig.4.4.1.C. Comparison of mean compressive strength of locally FCB with British standard bricks

As it is clearly shown in figure 4.4.1.C the locally fired clay brick mean compressive strength value which is 2.73Mpa did not fulfill the BS class bricks mean compressive strength.

### 4.4.2. Comparing locally SCB compressive strength with standards

**A. Comparing with Indian Standard Specification for soil based blocks used in general building construction (IS 1725: 1982)**

Soil based blocks shall be manufactured from a mixture of suitable soil and ordinarily port land cement or lime mixture thoroughly mixed together, preferably in a mechanical mixer. The mixture is moulded and cast into blocks. (IS 1725: 1982)

Table 4.4.2.A.1.Indian Standard Specification for soil based blocks used in general building construction (IS 1725: 1982)

| Classes | Minimum compressive strength |
|---|---|
| Class 20 | 20kg f/cm$^2$ (1.96 Mpa) |
| Class 30 | 30 kg f/cm$^2$ (2.94 Mpa) |

Table 4.4.2.A.2.Mean compressive strength of stabilized clay bricks

| Types of bricks | Mean compressive strength of 5 bricks (Mpa) |
|---|---|
| 10% CSCB | 2.91 |
| 12%CSCB | 3.28 |
| 14%CSCB | 3.79 |
| 10%LSCB | 2.19 |
| 12%LSCB | 2.51 |
| 14%LSCB | 2.69 |

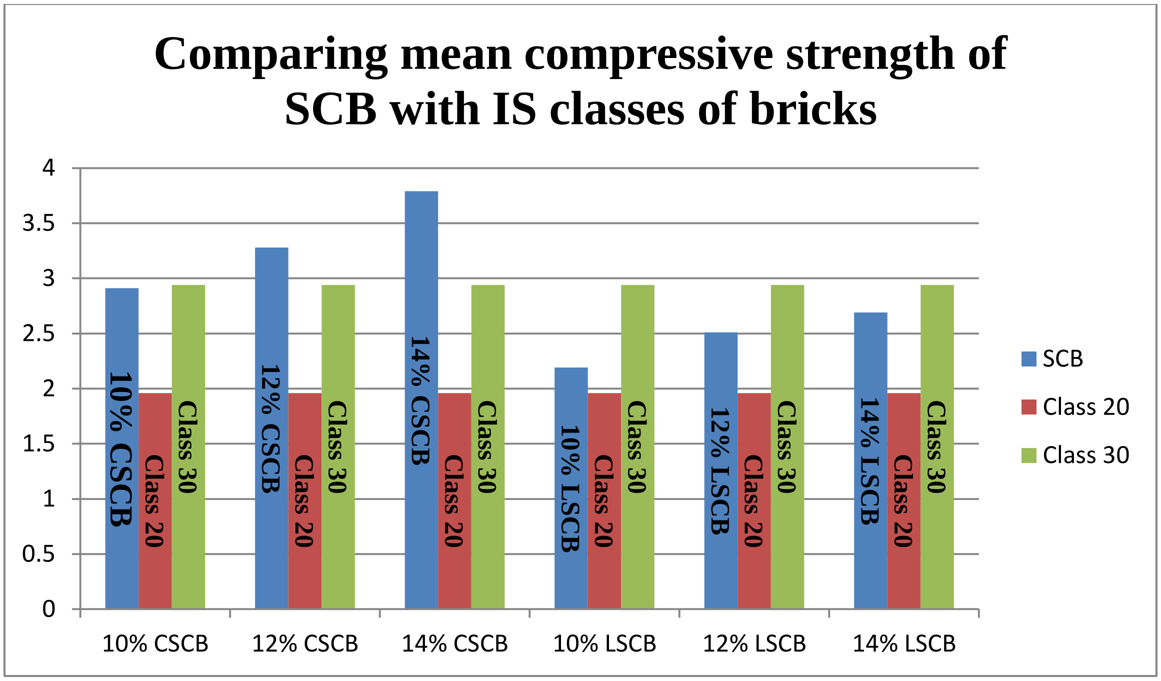


Fig.4.4.2.A.Comparing mean compressive strength of SCB with Indian classes of soil blocks

As it is shown in figure 4.4.2.A.all SCB of this study full fills the minimum compressive strength of class 20 bricks. Additionally 12%CSCB and 14% CSCB full fills the required minimum compressive strength of class 30 which is 2.94Mpa.

## 4.5. Comparing production cost of locally FCB and SCB

In this study the stabilized clay bricks were produced with ratios of 1:9, 1:7 and 1:6 for the 10%, 12% and 14% contents of stabilizers. The production cost was compared by considering the labor and material costs.

Table 4.5.1.Production cost of stabilized clay bricks

| **Type of SCB** | **Mix ratio** | **No of bricks produced from one mix(no)** | **Amount of stabilizer by four liter plastic container from one bag of stabilizer (no)** | **Production per one bag of stabilizer(no)** | **Cost of one bag of stabilizer (br)** | **Material cost per one brick (br)** | **Labor cost per one brick (br)** | **Total cost of production per brick(br)** |
|---|---|---|---|---|---|---|---|---|
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)=(3)x(4)** | **(6)** | **(7)=(6)/(5)** | **(8)** | **(9)** |
| 10%CSCB | 1:9 | 18 | 9 | 162 | 130 | 0.802 | 0.14 | **0.942** |
| 12%CSCB | 1:7 | 12 | 9 | 108 | 130 | 1.203 | 0.14 | **1.343** |
| 14%CSCB | 1:6 | 10 | 9 | 90 | 130 | 1.44 | 0.14 | **1.580** |
| 10%LSCB | 1:9 | 18 | 4 | 72 | 50 | 0.694 | 0.14 | **0.834** |
| 12%LSCB | 1:7 | 12 | 4 | 48 | 50 | 1.041 | 0.14 | **1.181** |
| 14%LSCB | 1:6 | 10 | 4 | 40 | 50 | 1.25 | 0.14 | **1.39** |

Table 4.5.1 above shows the production cost of stabilized clay bricks with cement and lime. Column (1) shows the list of stabilized clay bricks with their content of stabilization. Column (2) shows the mix ratios used for each contents of stabilization. Column (3) indicates the number of bricks produce for one mix with a given mix ratio. As it is discussed in chapter two for this study a four liter plastic container was used as a measuring gauge. Column (4) shows the number of four liter plastic container amount from one bag of stabilizer. Both cement and lime quantities are measured by quintal or bag. But for this study since the measuring gauge is four liter plastic container, it is necessary to know how much four liter plastic containers found from one bag of stabilizer. Accordingly from one 50kg bag of cement 9 plastic containers of cement was obtained during mixing and from one 25kg bag of lime 4 plastic containers of lime can be obtained. Column (5) says production per one bag of stabilizer. Since one mix contains one four liter

plastic gauge of stablizer, production per one bag of stabilizer can be obtained by multiplying the number of bricks from one mix with the number of four liter plastic gauge per one bag of stabilizer. Column (6) shows the cost of stabilizer per bag. Column (7) and (8) indicates cost of stabilizer and labor per one brick. The cost of labor determined from the current payment condition of MURTESA small scale local brick production enterprise. Accordingly one daily labor will paid 50 birr for tempering and molding of 500 bricks. This becomes 0.1 birr per brick, but considering additional 20birr labor cost for curing, the total cost becomes 0.14 birr per one brick. Finally column (9) shows the total production cost of stabilized bricks.

From the cost analysis, it is shown that as the stabilizer content increase the cost of production per one brick also increase.

For the locally fired clay bricks the costs to be analyzed are the firing cost and labor cost. The firing process conducts when 40,000-50,000 green bricks are ready. The small and micro enterprises purchase the wood for the firing of bricks from wood sealers. The labor cost for tempering and molding will be the same as the stabilized bricks which is 0.1birr/brick. For the firing process in addition of the cost of firing wood there is a need of labor cost for the construction of the firing stock and firing process. Constructing the firing stock conducted by plastering of the stockpiled dried bricks. Then firing of the bricks will started by inserting the prepared firing wood through the opening provided. This process will continue for 3-4 days. The small and micro enterprises have a total labor cost of around 3000birr for labors to conduct the firing process. These become 0.075birr/brick.

Table 4.5.2.Production cost of locally fired clay bricks

| | |
|---|---|
| **No. of green bricks prepared for firing (no)(1)** | **40000** |
| **Cost of firing wood for 40000 bricks(birr)(2)** | **20000** |
| **Labor cost /brick(birr)(3)** | **0.1** |
| **Cost of firing wood per brick(birr)(4)= (2)/ (1)** | **0.5** |
| **Labor cost for Firing /40000 brick(birr)** | **0.075** |
| **Total cost of production(birr)** | **0.675** |

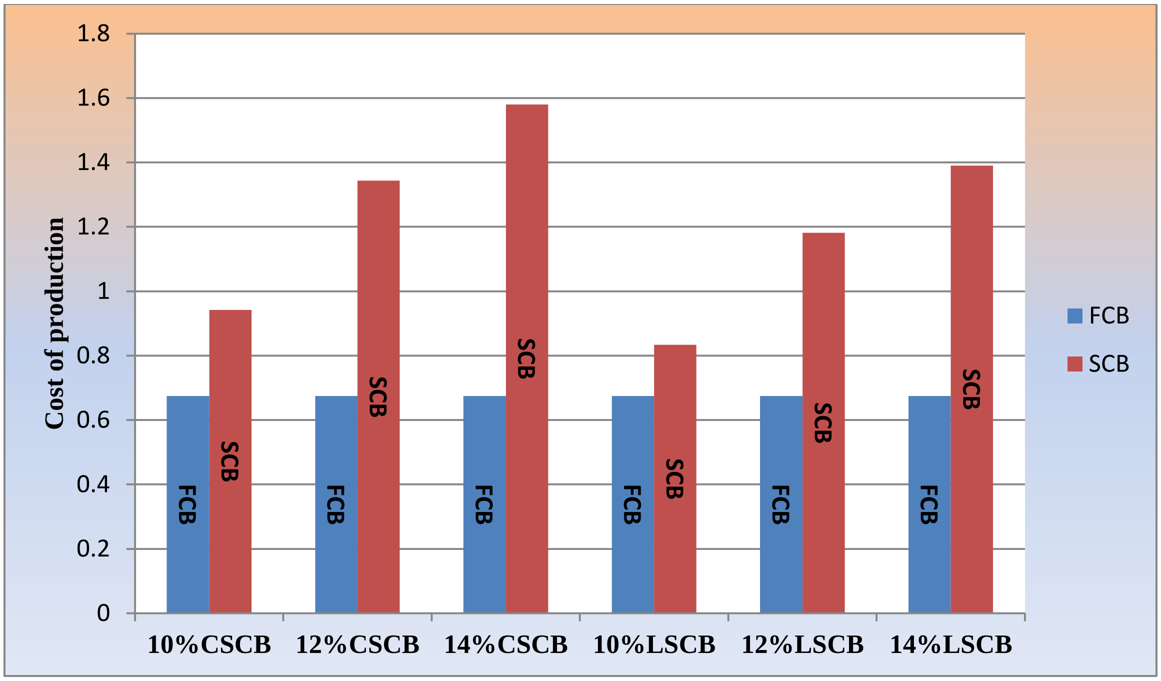


Fig 4.5.1.production costs of locally FCB and SCB

As shown in fig 4.5.1.The production cost of locally fired clay bricks were cheaper than the stabilized clay bricks. But the advantage of stabilized bricks is that the small and micro enterprises can produce much amount of bricks within a short period of time. For example for the production of 40000 bricks, there is a need of around two months if it is possibly molded per one day. But CSCB can be produced within 28-30 days with a best strength, uniform quality and without harming our environment by deforestation for firing process.

## 4.6. Summary

The main objective of this study was comparison of compressive strength of locally fired clay bricks and locally stabilized clay bricks using cement and lime as a stabilizer. The specific objectives was, determining index properties of soil used in brick production, determining the compressive strength of both fired and stabilized bricks and finally comparing the compressive strength with available standards. The results found in this study are summarized below.

### 4.6.1. Index properties

Table 4.6.1.1 index properties of soil

| Index property of soil sample | Test result value |
|---|---|
| Natural moisture content | 25.3% |
| Percent passing (0.075mm)or no 200 | 44.34% |
| Liquid limit | 48% |
| Plastic limit | 36% |
| Plasticity index | 12 |
| Linear Shrinkage | 5.89% |
| Maximum dry density(MDD) | 1529kg/$m^3$ |
| Optimum moisture content(OMC) | 18.8% |
| Specific gravity | 2.77 |
| AASHTO class | A-7 |

### 4.6.2. Compressive strength results

Table 4.6.2.1. Compressive strength results

| Types of bricks | Mean compressive strength of 5 bricks (Mpa) |
|---|---|
| FCB | 2.73 |
| 10% CSCB | 2.91 |
| 12%CSCB | 3.28 |
| 14%CSCB | 3.79 |
| 10%LSCB | 2.19 |
| 12%LSCB | 2.51 |
| 14%LSCB | 2.69 |

### 4.6.3. Other quality tests results

Table 4.6.3.1.Absorption and efflorescence results

| Type of bricks | Absorption (%) | Efflorescence |
|---|---|---|
| FCB | 15.90 | Not effloresced |
| 10% CSCB | 14.74 | Not effloresced |
| 12%CSCB | 14.59 | Not effloresced |
| 14%CSCB | 13.8 | Not effloresced |

**Note:** the lime stabilized bricks did not pass the absorption and efflorescence tests since all dissolve in water.

Table 4.6.3.2 Results of dimension tolerance tests

| Types of bricks | Average Variation in mm along the length | Average Variation in mm along the width | Average Variation in mm along the height |
|---|---|---|---|
| FCB | 24 | 6.3 | 5.1 |
| 10%CSCB | 17.8 | 3.6 | 2.4 |
| 12% CSCB | 16 | 2.5 | 2.1 |
| 14% CSCB | 12 | 1.7 | 1.6 |
| 10% LSCB | 22 | 4.6 | 4.9 |
| 12% LSCB | 19 | 4 | 3.6 |
| 14% LSCB | 18 | 3.3 | 2.9 |

### 4.6.4. Results of comparing compressive strengths of bricks with available standards

The mean compressive strength of the locally fired bricks in this study was compared with ES, ASTM and IS standard specification of compressive strength of clay bricks. The result shows that the locally FCB did not attain the compressive strength requirements of all the standards.

The mean compressive strength of SCB were also compared with IS standard of stabilized bricks and the result shows all the stabilized bricks of this study full fills the minimum requirement of the standards.

### 4.6.5. Result of cost analysis

Table 4.6.5.1.Result of production cost analysis

| **Types of bricks** | **Production cost (birr)** |
|---|---|
| FCB | 0.675 |
| 10%CSCB | 0.942 |
| 12%CSCB | 1.343 |
| 14%CSCB | 1.58 |
| 10%LSCB | 0.834 |
| 12%LSCB | 1.181 |
| 14%LSCB | 1.39 |

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATION

## 5.1. Conclusion

The main objective of this research was to compare the compressive strength of the locally fired clay bricks in jimma town and the locally stabilized clay bricks with cement and lime so that to reduce the deforestation in the area for the purpose of firing of the locally fired clay bricks. According to this study the stabilization was done by using ordinary Portland cement and lime (hydrated lime) with a content of 10%, 12% and 14% by volume.

The results of the index property tests of this study indicate that the soil is A-7 clay soil. The type of soil was determined by AASHTO soil classification system and the contents of the stabilizers were selected as per the class of soil on AASHTO. The plasticity index and shrinkage limit results of the soil indicates that the soil is suitable for brick making.

The determined compressive strength results shows that the cement stabilized clay bricks have better strength than both the lime stabilized and locally fired clay bricks. All LSCB shows lesser strength than the locally fired clay bricks. Cement is better stabilizing agent than lime resulting in less variation in dimension after drying and less absorption. All LSCB failed the absorption and efflorescence tests since they all dissolve in water after 24hr of immersion .Stabilizing the clay soil with cement gives better quality bricks.

Based on the comparison of the compressive strengths of the bricks with different standards the locally fired clay brick in this study does not fulfill minimum requirements of all the standards but the stabilized clay bricks has fulfill the minimum requirement of the Indian standard (IS).

Generally in addition to saving the environment stabilizing the bricks with cement is better in both quality and ease of production. These means the producers can get more production within short period of time by curing than the traditional drying and firing process.

## 5.2. Recommendation

The following recommendations are to be forwarded to the following concerned units:

A) Concerned Governmental units

According to this study it is recommended that the governmental construction body of Jimma town should give an attention for the safety of the environment by giving awareness to the small and micro local brick production enterprises to change their method of production.

B) Small and micro local brick producing enterprises

Since the cement stabilized bricks have a better quality and short time of production, Small and micro local brick producing enterprises shall adopt the technique of brick production by stabilization. Additionally the enterprises should design mold sizes for the specified size of bricks prior of production considering shrinkage due to drying or firing.it is also recommended that the enterprises shall apply molding machine for the bricks production to control the amount of mixing water.

C) Users of local brick

The users of local bricks in Jimma town are recommended to use the cement stabilized bricks which have better and uniform quality than the local fired clay bricks. About the cost, environment cannot be bought by any price and additionally the quality of the products should be considered.

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# Appendix A

**Laboratory Data Sheets for index properties**

**Jimma University**

**Civil engineering department**

**Soil testing laboratory**

## 1. Moisture content determination

Sample description ____**clay soil (grey in color)**____

Test method ____**ASTM D 2216**____

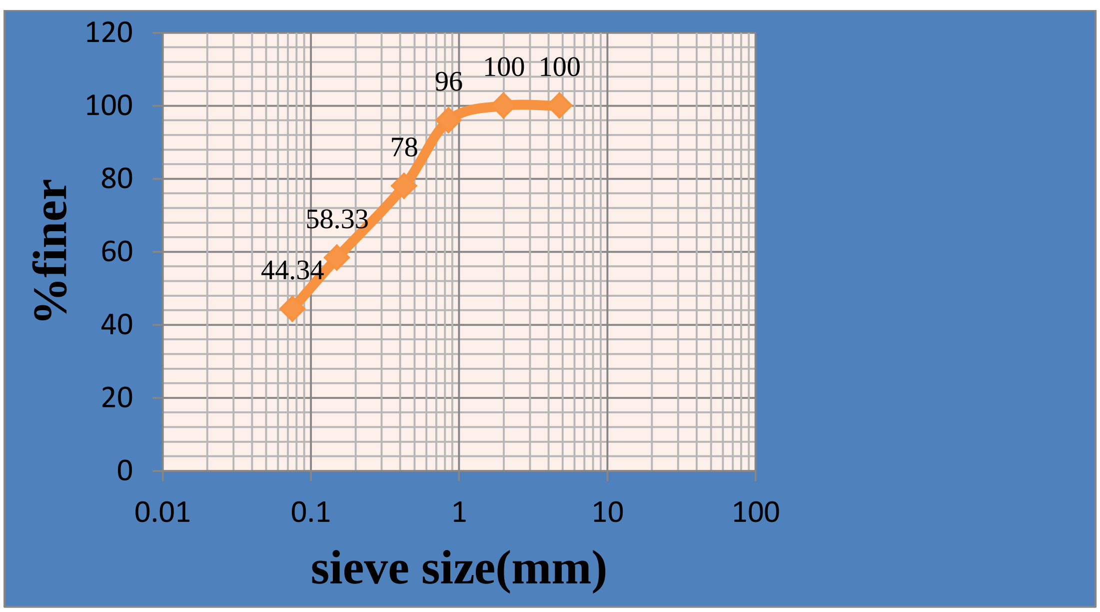
| Determination no. | 1 | 2 | 3 |
|---|---|---|---|
| Container (can) no | A2 | B34 | C5 |
| Mass of container ,$M_c$(gm) | 24 | 25 | 24 |
| Mass of container +wet specimen,$M_{cws}$(gm) | 128 | 125 | 122 |
| Mass of container +oven dried specimen ,$M_{cs}$(gm) | 107 | 105 | 102 |
| Mass of water ,$M_w$(gm) | 21 | 20 | 20 |
| Mass of solid particles $M_s$(gm) | 83 | 80 | 78 |
| Mass of wet soil $M_{so,}$(gm) | 104 | 100 | 98 |
| Moisture content ,% $w = \frac{M_{so} - M_s}{M_s} x100$ | 25.3 | 25 | 25.64 |
| Average moisture content w,% | **25.31%** | | |

## 2. Sieve analysis

Sample description clay soil (grey in color)

Test method ASTM D 422

| Sieve size in mm | Mass retained in (gm) | % mass retained | Cumulative % mass retained | % finer |
|---|---|---|---|---|
| | (1) | $(2)=((1)/M_t)*100$ | (3) | (4)=100-(3) |
| 4.75 | 0 | 0 | 0 | 100 |
| 2 | 0 | 0 | 0 | 100 |
| 0.85 | 12 | 4 | 4 | 96 |
| 0.425 | 54 | 18 | 22 | 78 |
| 0.15 | 59 | 19.67 | 41.67 | 58.33 |
| 0.075 | 42 | 14 | 55.67 | **44.34** |
| Pan | 133 | 44.34 | 100 | 0 |



**3. Specific gravity**

Sample description ______clay soil (grey in color)______

Test method ______ASTM D 854______

| Determination | 1 | 2 | 3 |
|---|---|---|---|
| Mass of pycnometer, Mp(gm) | 162 | 162 | 162 |
| Mass of pycnometer +water ,$M_{pw}$(gm) @ $T_i$=27 $^o$c | 660 | 660 | 660 |
| Mass of pycnometer+water+specimen, $M_{pws}$(gm) @ $T_x$ | 704 | 714 | 706 |
| Mass of pycnometer +specimen,$M_{ps}$(gm) | 230 | 245 | 235 |
| $T_x$=temperature of contents of pycnometer when $M_{pws}$ was taken, $^o$c. | 25 | 26 | 25.5 |
| K = conversion factor(@$T_x$ (from table) | 0.999 | 0.999 | 0.999 |
| Ti = observed temperature of water, $^o$c | 27 | 27 | 27 |
| density of water @ Tx | 0.997 | 0.997 | 0.997 |
| density of water @ Ti | 0.997 | 0.997 | 0.997 |
| $M_{pw}(atT_x)$ = [[density of water @ $T_x$/density of water @ $T_i$] [$M_{pw}$@$T_i$ – $M_p$]] + $M_p$ | 660 | 660 | 660 |
| $M_s$=$M_{ps}$-$M_p$ | 68 | 83 | 73 |
| $G_s = K[\frac{M_s}{M_s + M_{pw}(atT_x) - M_{pws}}$ | 2.80 | 2.85 | 2.68 |
| **Average Gs** | **2.77** | | |

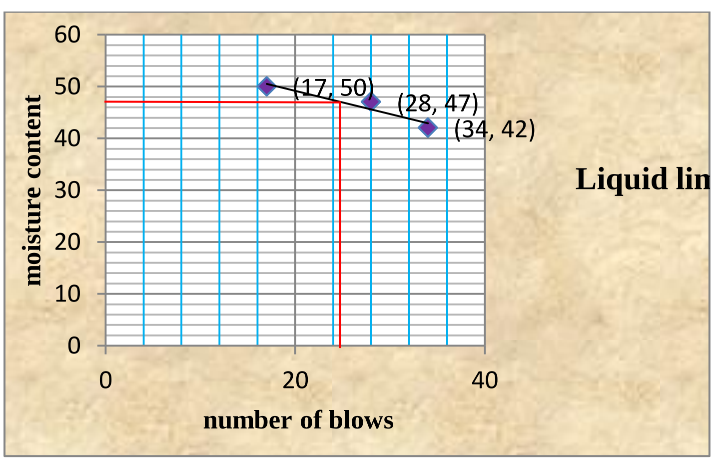
## 4. Atterberg limits

### A. Liquid limit

Sample description clay soil (grey in color)

Test method ASTM D 4318

| Determination no | 1 | 2 | 3 |
|---|---|---|---|
| No. of drops | 34 | 28 | 17 |
| Can no. | LL1 | LL2 | LL3 |
| Mass of can +moist soil, gm | 58 | 68 | 66 |
| Mass of can +dry soil,gm | 48 | 54 | 52 |
| Mass of can gm | 24 | 24 | 24 |
| Mass of watergm | 10 | 14 | 14 |
| Mass of dry soil,gm | 24 | 30 | 28 |
| Moisture content,w% | 42 | 47 | 50 |
| From the flow curve (no.of blows vs moisture content),moisture content at 25 blows, LL% | | | **48%** |



**B. Plastic limit**

Sample description ______ clay soil(grey in color) ______

Test method ______ ASTM D 4318 ______

| Determination | 1 | 2 |
|---|---|---|
| Can no. | PL1 | PL2 |
| Mass of can +moist soil,gm | 39 | 48 |
| Mass of can +dry soil,gm | 35 | 42 |
| Mass of can,gm | 24 | 25 |
| Mass of water,gm | 4 | 6 |
| Mass of dry soil,gm | 11 | 17 |
| Water content,% | 36.36 | 35.29 |
| Plastic limit,% | **36%** | |

**C. Plastic index**

**PI =LL-PL=48%-36%=12**

**D. linear shrinkage**

Sample description **clay soil(grey in color)**

Test method **CTM 228 -A4**

| **Determination** | **1** | **2** | **3** |
|---|---|---|---|
| Liquid limit (%) | 48% | 48% | 48% |
| Last no of blows | 17 | 17 | 17 |
| Original wet length of specimen in trough (mm) | 150 | 150 | 150 |
| Oven dried length of specimen in trough (mm) | 141.5 | 139.7 | 140.2 |
| Shrinkage (mm) | 8.5 | 10.3 | 9.8 |
| Factor(f) $f = \frac{100}{150} \times \frac{0.8}{1 - 0.008N}$ | 0.62 | 0.62 | 0.62 |
| Linear shrinkage (%)=(Shrinkage (mm)*f)x100 | **5.27%** | **6.38%** | **6.07%** |
| **Linear shrinkage** | | | **5.89%** |

## 5. Standard compaction test

Sample description clay soil(grey in color)

Test method ASTM D 698

| Trial No. | Mass of compacted soil + mold, g $M_{sm}$ | Mass of compacted soil, g ms | Wet unit weight (Kg/m³) $\gamma_{wet}=(M_{sm}-M_m)/V_m$ | Moisture content Determination | | | | | | | Dry unit weight (Kg/m³) $\gamma_{dry}=\gamma_{wet}/(1+w)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Can No. | Mass of wet soil + can, g | Mass of dry soil + can, g | Mass of water,g | Mass of can, g | Mass of dry soil,g | Moisture content, % w | |
| 1 | 6331 | 1524 | 1614.4 | 1 | 144 | 126 | 18 | 23 | 103 | 17.48 | 1374.2 |
| 2 | 3321 | 1476 | 1565.68 | 2 | 124 | 110 | 14 | 24 | 86 | 16.28 | 1376.47 |
| 3 | 3558 | 1713 | 1814.62 | 3 | 152 | 132 | 20 | 25 | 107 | 18.70 | 1528.74 |
| 4 | 3555 | 1718 | 1819.92 | 4 | 129 | 111 | 18 | 25 | 86 | 20.93 | 1504.94 |
| 5 | 3564 | 1719 | 1820.97 | 5 | 152 | 128 | 24 | 25 | 103 | 23.30 | 1476.86 |
| **From plot OMC =18.8% MDD = 1529Kg/m³** | | | | | | | | | | | |

# Appendix B

**Laboratory Data Sheets for compressive strength results of locally FCB and SCB**

**Jimma University**

**Civil engineering department**

**Construction materials testing laboratory**

1. **compressive strength test results of locally fired clay bricks**

**Brick type** **locally fired clay bricks**

**Date of testing** **May 18 2016 EC**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength(Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | Height | | | | |
| 1 | 24 | 12 | 6 | 2.27 | 0.0288 | 99.9 | 3.47 |
| 2 | 24 | 12 | 6 | 2.31 | 0.0288 | 108.4 | 3.76 |
| 3 | 24 | 12 | 6 | 2.3 | 0.0288 | 44 | 1.53 |
| 4 | 24 | 12 | 6 | 2.26 | 0.0288 | 77 | 2.67 |
| 5 | 24 | 12 | 6 | 2.31 | 0.0288 | 63.4 | 2.20 |
| | | | | | | Mean | **2.73** |

## 2. Compressive strength test results of 10% cement stabilized clay bricks

**Brick type** **10%CSCB** **Date of casting** **May 11 2016 E.C.**

**Date of testing** **May 18 2016 E.C** **Type of test** **7$^{th}$ days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | Width | height | | | | |
| 1 | 24 | 12 | 6 | 2.56 | 0.0288 | 54.7 | 1.90 |
| 2 | 24 | 12 | 6 | 2.60 | 0.0288 | 68.1 | 2.36 |
| 3 | 24 | 12 | 6 | 2.66 | 0.0288 | 56.3 | 1.95 |
| 4 | 24 | 12 | 6 | 2.67 | 0.0288 | 50.4 | 1.75 |
| 5 | 24 | 12 | 6 | 2.67 | 0.0288 | 59.5 | 2.07 |
| | | | | | | Mean | **2.01** |

**Brick type** **10%CSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **May 25 2016 E.C**

**Type of test** **14$^{th}$ days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | Width | height | | - | | |
| 1 | 24 | 12 | 6 | 2.36 | 0.0288 | 68.7 | 2.39 |
| 2 | 24 | 12 | 6 | 2.46 | 0.0288 | 71.5 | 2.48 |
| 3 | 24 | 12 | 6 | 2.39 | 0.0288 | 76.2 | 2.65 |
| 4 | 24 | 12 | 6 | 2.48 | 0.0288 | 65 | 2.26 |
| 5 | 24 | 12 | 6 | 2.46 | 0.0288 | 73.8 | 2.56 |
| | | | | | | Mean | **2.47** |

**Brick type** **10%CSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **Jun 8 2016 E.C**

**Type of test** **28th days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | Width | height | | | | |
| 1 | 22.1 | 11.2 | 6 | 2.16 | 0.0248 | 70 | 2.83 |
| 2 | 22.5 | 11.4 | 6 | 2.26 | 0.0257 | 68.8 | 2.68 |
| 3 | 22.6 | 11.5 | 6 | 2.24 | 0.0260 | 74.4 | 2.86 |
| 4 | 22.1 | 11.3 | 6 | 2.24 | 0.0250 | 76.1 | 3.05 |
| 5 | 22.7 | 11.2 | 6 | 2.15 | 0.0254 | 80 | 3.15 |
| | | | | | | Mean | **2.91** |

**3. Compressive strength test results of 12% cement stabilized clay bricks**

**Brick type** **12%CSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **May 18 2016 E.C**

**Type of test** **7th days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | height | | | | |
| 1 | 24 | 12 | 6 | 2.72 | 0.0288 | 76 | 2.64 |
| 2 | 24 | 12 | 6 | 2.50 | 0.0288 | 70.3 | 2.44 |
| 3 | 24 | 12 | 6 | 2.65 | 0.0288 | 77.1 | 2.68 |
| 4 | 24 | 12 | 6 | 2.70 | 0.0288 | 72.4 | 2.51 |
| 5 | 24 | 12 | 6 | 2.55 | 0.0288 | 69.2 | 2.40 |
| | | | | | | Mean | **2.53** |

**Brick type** 12%CSCB

**Date of casting** May 11 2016 E.C.

**Date of testing** May 25 2016 E.C

**Type of test** 14th days compressive strength

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN)(2) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | Height | | | | |
| 1 | 24 | 12 | 6 | 2.27 | 0.0288 | 80.7 | 2.80 |
| 2 | 24 | 12 | 6 | 2.42 | 0.0288 | 74.8 | 2.60 |
| 3 | 24 | 12 | 6 | 2.41 | 0.0288 | 81.2 | 2.82 |
| 4 | 24 | 12 | 6 | 2.43 | 0.0288 | 79.4 | 2.76 |
| 5 | 24 | 12 | 6 | 2.57 | 0.0288 | 82.1 | 2.85 |
| | | | | | | Mean | **2.77** |

**Brick type** 12%CSCB

**Date of casting** May 11 2016 E.C.

**Date of testing** Jun 8 2016 E.C

**Type of test** 28th days compressive strength

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN)(2) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | height | | | | |
| 1 | 22.7 | 11.5 | 6 | 2.12 | 0.0261 | 88 | 3.37 |
| 2 | 22.8 | 11.8 | 6 | 2.05 | 0.0269 | 85.3 | 3.17 |
| 3 | 22.5 | 12 | 6 | 2.25 | 0.0270 | 87.1 | 3.23 |
| 4 | 22.6 | 11.6 | 6 | 2.07 | 0.0262 | 86.4 | 3.30 |
| 5 | 22.4 | 12 | 6 | 2.15 | 0.0269 | 89.8 | 3.34 |
| | | | | | | Mean | **3.28** |

**4. Compressive strength test results of 14% cement stabilized clay bricks**

**Brick type** **14%CSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **May 18 2016 E.C**

**Type of test** **7th days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | height | | | | |
| 1 | 24 | 12 | 6 | 2.62 | 0.0288 | 87.6 | 3.04 |
| 2 | 24 | 12 | 6 | 2.76 | 0.0288 | 90.8 | 3.15 |
| 3 | 24 | 12 | 6 | 2.44 | 0.0288 | 80.6 | 2.79 |
| 4 | 24 | 12 | 6 | 2.55 | 0.0288 | 82.9 | 2.88 |
| 5 | 24 | 12 | 6 | 2.47 | 0.0288 | 83.1 | 2.89 |
| | | | | | | Mean | **2.95** |

**Brick type** **14%CSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **May 25 2016 E.C**

**Type of test** **14th days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | Height | | | | |
| 1 | 24 | 12 | 6 | 2.31 | 0.0288 | 96.2 | 3.34 |
| 2 | 24 | 12 | 6 | 2.12 | 0.0288 | 89.8 | 3.12 |
| 3 | 24 | 12 | 6 | 2.33 | 0.0288 | 93.6 | 3.25 |
| 4 | 24 | 12 | 6 | 2.12 | 0.0288 | 102 | 3.54 |
| 5 | 24 | 12 | 6 | 2.34 | 0.0288 | 91 | 3.16 |
| | | | | | | Mean | **3.28** |

**Brick type** **14%CSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **Jun 8 2016 E.C**

**Type of test** **28th days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | height | | | | |
| 1 | 22.9 | 11.7 | 6 | 2.22 | 0.0268 | 97.6 | 3.64 |
| 2 | 22.7 | 12 | 6 | 2.08 | 0.0272 | 103.8 | 3.81 |
| 3 | 22.8 | 12 | 6 | 2.15 | 0.0274 | 99.6 | 3.64 |
| 4 | 22.5 | 11.9 | 6 | 2.15 | 0.0268 | 104.9 | 3.92 |
| 5 | 22.9 | 12 | 6 | 2.25 | 0.0275 | 108.1 | 3.93 |
| | | | | | | Mean | **3.79** |

**5. Compressive strength test results of 10% lime stabilized clay bricks**

**Brick type** **10%LSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **May 182016 E.C**

**Type of test** **7th days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength(Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | height | | | | |
| 1 | 24 | 12 | 6 | 2.75 | 0.0288 | 40.4 | 1.40 |
| 2 | 24 | 12 | 6 | 2.67 | 0.0288 | 33 | 1.15 |
| 3 | 24 | 12 | 6 | 2.84 | 0.0288 | 35 | 1.22 |
| 4 | 24 | 12 | 6 | 2.91 | 0.0288 | 38 | 1.32 |
| 5 | 24 | 12 | 6 | 2.82 | 0.0288 | 33.5 | 1.16 |
| | | | | | | Mean | **1.25** |

**Brick type** **10%LSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **May 25 2016 E.C**

**Type of test** **$14^{th}$ days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength(Map) |
|---|---|---|---|---|---|---|---|
| | Length | width | Height | | | | |
| 1 | 24 | 12 | 6 | 2.43 | 0.0288 | 47.5 | 1.65 |
| 2 | 24 | 12 | 6 | 2.33 | 0.0288 | 49.8 | 1.73 |
| 3 | 24 | 12 | 6 | 2.31 | 0.0288 | 53.4 | 1.85 |
| 4 | 24 | 12 | 6 | 2.4 | 0.0288 | 54.2 | 1.88 |
| 5 | 24 | 12 | 6 | 2.38 | 0.0288 | 56.5 | 1.96 |
| | | | | | | Mean | **1.82** |

**Brick type** **10%LSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **Jun 8 2016 E.C**

**Type of test** **$28^{th}$ days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | height | | | | |
| 1 | 21.8 | 11.4 | 6 | 21.8 | 0.0249 | 53.6 | 2.16 |
| 2 | 21.9 | 11.3 | 6 | 2.33 | 0.0247 | 55.2 | 2.23 |
| 3 | 21.6 | 11.6 | 6 | 2.24 | 0.0251 | 54.8 | 2.19 |
| 4 | 22.2 | 11.5 | 6 | 2.15 | 0.0255 | 53.9 | 2.11 |
| 5 | 21.7 | 11.6 | 6 | 2.22 | 0.0252 | 56.5 | 2.24 |
| | | | | | | Mean | **2.19** |

**6. Compressive strength test results of 12% lime stabilized clay bricks**

**Brick type** **12%LSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **May 18 2016 E.C**

**Type of test** **7th days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength(Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | height | | | | |
| 1 | 24 | 12 | 6 | 2.89 | 0.0288 | 43.9 | 1.52 |
| 2 | 24 | 12 | 6 | 2.51 | 0.0288 | 38.7 | 1.34 |
| 3 | 24 | 12 | 6 | 2.69 | 0.0288 | 40.5 | 1.4 |
| 4 | 24 | 12 | 6 | 2.45 | 0.0288 | 50.1 | 1.73 |
| 5 | 24 | 12 | 6 | 2.75 | 0.0288 | 40.6 | 1.41 |
| | | | | | | Mean | **1.48** |

**Brick type** **12%LSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **May 25 2016 E.C**

**Type of test** **14th days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN)(2) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | Height | | | | |
| 1 | 24 | 12 | 6 | 2.35 | 0.0288 | 57 | 1.98 |
| 2 | 24 | 12 | 6 | 2.57 | 0.0288 | 55 | 1.91 |
| 3 | 24 | 12 | 6 | 2.43 | 0.0288 | 48.1 | 1.67 |
| 4 | 24 | 12 | 6 | 2.62 | 0.0288 | 59.8 | 2.08 |
| 5 | 24 | 12 | 6 | 2.51 | 0.0288 | 57.8 | 2.01 |
| | | | | | | Mean | **1.93** |

**Brick type** **12%LSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **Jun 8 2016 E.C**

**Type of test** **28th days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | height | | | | |
| 1 | 22.3 | 11.5 | 6 | 2.13 | 0.0256 | 63.9 | 2.49 |
| 2 | 21.9 | 11.5 | 6 | 2.32 | 0.0252 | 65.2 | 2.59 |
| 3 | 21.9 | 11.5 | 6 | 2.34 | 0.0252 | 59.5 | 2.36 |
| 4 | 22.4 | 11.2 | 6 | 2.25 | 0.0251 | 64.1 | 2.56 |
| 5 | 21.7 | 11.6 | 6 | 2.17 | 0.0252 | 63.7 | 2.53 |
| | | | | | | Mean | **2.51** |

**7. Compressive strength test results of 14% lime stabilized clay bricks**

**Brick type** **14%LSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **May 18 2016 E.C**

**Type of test** **7th days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | height | | | | |
| 1 | 24 | 12 | 6 | 2.78 | 0.0288 | 49.9 | 1.73 |
| 2 | 24 | 12 | 6 | 2.91 | 0.0288 | 50.5 | 1.75 |
| 3 | 24 | 12 | 6 | 2.68 | 0.0288 | 54 | 1.87 |
| 4 | 24 | 12 | 6 | 2.77 | 0.0288 | 52.5 | 1.82 |
| 5 | 24 | 12 | 6 | 2.65 | 0.0288 | 51.3 | 1.78 |
| | | | | | | Mean | **1.7** |

**Brick type** **14%LSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **May 25 2016 E.C**

**Type of test** **14th days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|
| | Length | width | Height | | | | |
| 1 | 24 | 12 | 6 | 2.55 | 0.0288 | 68.2 | 2.37 |
| 2 | 24 | 12 | 6 | 2.47 | 0.0288 | 65 | 2.26 |
| 3 | 24 | 12 | 6 | 2.61 | 0.0288 | 60 | 2.08 |
| 4 | 24 | 12 | 6 | 2.44 | 0.0288 | 54.9 | 1.91 |
| 5 | 24 | 12 | 6 | 2.62 | 0.0288 | 70.4 | 2.44 |
| | | | | | | Mean | **2.21** |

**Brick type** **14%LSCB**

**Date of casting** **May 11 2016 E.C.**

**Date of testing** **Jun 8 2016 E.C**

**Type of test** **28th days compressive strength**

| No | Dimension (cm) | | | Weight(Kg) | Area ($M^2$) | Failure load | Compressive strength(Mpa((2÷1)*1000) |
|---|---|---|---|---|---|---|---|
| | Length | width | height | | -1 | (KN)(2) | |
| 1 | 22.6 | 11.6 | 6 | 2.18 | 0.0262 | 67 | 2.56 |
| 2 | 21.6 | 11.6 | 6 | 2.29 | 0.0251 | 65.8 | 2.63 |
| 3 | 21.7 | 11.5 | 6 | 2.16 | 0.0250 | 73.1 | 2.93 |
| 4 | 21.9 | 11.5 | 6 | 2.22 | 0.0252 | 55 | 2.18 |
| 5 | 22.4 | 11.4 | 6 | 2.21 | 0.0255 | 80.3 | 3.14 |
| | | | | | | Mean | **2.69** |

**Absorption of FCB and CSCB**

1. Absorption of fired clay bricks

| Locally fired clay bricks | Oven dried weight($w_1$)(kg) | Water immersed weight ($w_2$)(kg) | Water absorption (%) |
|---|---|---|---|
| Sample 1 | 2.18 | 2.67 | 22.48 |
| Sample 2 | 2.26 | 2.51 | 11.06 |
| Sample 3 | 2.33 | 2.84 | 21.89 |
| Sample 4 | 2.29 | 2.58 | 12.66 |
| Sample 5 | 2.28 | 2.54 | 11.40 |
| | | **Mean** | **15.90** |

**2.** Absorption 10% CSCB

| 10% CSCB | Oven dried weight($w_1$)(kg) | Water immersed weight ($w_2$)(kg) | Water absorption (%) |
|---|---|---|---|
| Sample 1 | 2.09 | 2.38 | 13.87 |
| Sample 2 | 2.11 | 2.38 | 12.79 |
| Sample 3 | 1.99 | 2.29 | 15.07 |
| Sample 4 | 2 | 2.27 | 13.5 |
| Sample 5 | 1.84 | 2.18 | 18.47 |
| | | **Mean** | **14.74** |

**3.** Absorption 12% CSCB

| 12%CSCB | Oven dried weight($w_1$)(kg) | Water immersed weight ($w_2$)(kg) | Water absorption (%) |
|---|---|---|---|
| Sample 1 | 2.11 | 2.35 | 11.37 |
| Sample 2 | 2.13 | 2.46 | 15.49 |
| Sample 3 | 2.21 | 2.55 | 15.38 |
| Sample 4 | 2.12 | 2.42 | 14.15 |
| Sample 5 | 2.05 | 2.39 | 16.58 |
| | | **Mean** | **14.59** |

**4.** Absorption 14% CSCB

| 14% CSCB | Oven dried weight($w_1$)(kg) | Water immersed weight ($w_2$)(kg) | Water absorption (%) |
|---|---|---|---|
| Sample 1 | 2.05 | 2.35 | 14.63 |
| Sample 2 | 2.11 | 2.31 | 12.68 |
| Sample 3 | 2.19 | 2.48 | 13.24 |
| Sample 4 | 2.08 | 2.39 | 14.9 |
| Sample 5 | 2.06 | 2.34 | 13.59 |
| | | **Mean** | **13.8** |

5. **Dimension tolerance of FCB and CSCB**

**A. Dimension tolerance test along the length (240mm)**

| **Sample** | **Dimension (FBC)(mm)** | **Dimension (10% CSCB)(mm)** | **Dimension (12%CSCB) (mm)** | **Dimension( 14%CSCB) (mm)** | **Dimension (10%LSCB) (mm)** | **Dimension (12% LSCB)( mm)** | **Dimension (14% LSCB)(mm)** |
|---|---|---|---|---|---|---|---|
| sample 1 | 212 | 223 | 225 | 228 | 220 | 225 | 224 |
| sample 2 | 220 | 222 | 224 | 230 | 222 | 219 | 225 |
| sample 3 | 218 | 223 | 221 | 229 | 217 | 222 | 221 |
| sample 4 | 216 | 221 | 225 | 226 | 218 | 221 | 217 |
| sample 5 | 211 | 223 | 221 | 227 | 220 | 224 | 219 |
| sample 6 | 220 | 224 | 224 | 228 | 214 | 221 | 220 |
| sample 7 | 219 | 219 | 225 | 226 | 219 | 221 | 223 |
| sample 8 | 214 | 221 | 223 | 228 | 217 | 218 | 221 |
| sample 9 | 216 | 222 | 225 | 229 | 219 | 221 | 224 |
| sample 10 | 214 | 224 | 224 | 230 | 218 | 221 | 226 |
| Average result in (mm) | 216 | 222 | 224 | 228 | 218 | 221 | 222 |
| Average reduced dimension(mm) | **24** | **18** | **16** | **12** | **22** | **19** | **18** |
| ASTM dimension tolerance (mm) | **7.9** | **7.9** | **7.9** | **7.9** | **7.9** | | **7.9** |

**B. Dimension tolerance test along the width (120mm)**

| **Samples** | **Dimenion of samples(FBC)(mm)** | **Dimenion of samples (10% CSCB)(mm)** | **Dimenion of samples (12% CSCB)(mm)** | **Dimenion of samples(14% CSCB)(mm)** | **Dimenion of samples (10% LSCB)(mm)** | **Dimenion of samples (12% LSCB)(mm)** | **Dimenion of samples (14% LSCB)(mm)** |
|---|---|---|---|---|---|---|---|
| sample 1 | 115.0 | 116.0 | 119.0 | 118.0 | 114.0 | 117.0 | 117.0 |
| sample 2 | 114.0 | 116.0 | 117.0 | 117.0 | 114.0 | 116.0 | 115.0 |
| sample 3 | 115.0 | 115.0 | 117.0 | 116.0 | 114.0 | 118.0 | 118.0 |
| sample 4 | 112.0 | 117.0 | 119.0 | 119.0 | 118.0 | 114.0 | 116.0 |
| sample 5 | 113.0 | 118.0 | 120.0 | 120.0 | 116.0 | 115.0 | 115.0 |
| sample 6 | 114.0 | 115.0 | 117.0 | 116.0 | 117.0 | 115.0 | 118.0 |
| sample 7 | 115.0 | 117.0 | 116.0 | 120.0 | 117.0 | 114.0 | 116.0 |
| sample 8 | 113.0 | 118.0 | 118.0 | 120.0 | 114.0 | 116.0 | 117.0 |
| sample 9 | 112.0 | 117.0 | 116.0 | 119.0 | 117.0 | 119.0 | 119.0 |
| sample 10 | 114.0 | 115.0 | 116.0 | 118.0 | 113.0 | 116.0 | 116.0 |
| Average result in (mm) | 113.7 | 116.4 | 117.5 | 118.3 | 115.4 | 116.0 | 116.7 |
| Average variation dimension(mm) | **6.3** | **3.6** | **2.5** | **1.7** | **4.6** | **4.0** | **3.3** |
| ASTM dimension tolerance (mm) | **4.8** | **4.8** | **4.8** | **4.8** | **4.8** | **4.8** | **4.8** |

**C. Dimension tolerance test along the width (120mm**)

| **Samples** | **Dimenion of samples(FBC)(mm)** | **Dimenion of samples(10% CSCB)(mm)** | **Dimenion of samples (12% CSCB)(mm)** | **Dimenion of samples(14% CSCB)(mm)** | **Dimenion of samples (10% LSCB)(mm)** | **Dimenion of samples (12% LSCB)(mm)** | **Dimenion of samples (14% LSCB)(mm)** |
|---|---|---|---|---|---|---|---|
| sample 1 | 55.0 | 58.0 | 58.0 | 58.0 | 55.0 | 55.0 | 58.0 |
| sample 2 | 54.0 | 58.0 | 60.0 | 60.0 | 55.0 | 57.0 | 57.0 |
| sample 3 | 54.0 | 57.0 | 58.0 | 58.0 | 54.0 | 58.0 | 60.0 |
| sample 4 | 56.0 | 57.0 | 57.0 | 58.0 | 54.0 | 54.0 | 54.0 |
| sample 5 | 55.0 | 57.0 | 58.0 | 59.0 | 56.0 | 57.0 | 60.0 |
| sample 6 | 55.0 | 56.0 | 56.0 | 58.0 | 54.0 | 58.0 | 55.0 |
| sample 7 | 54.0 | 56.0 | 58.0 | 59.0 | 56.0 | 57.0 | 54.0 |
| sample 8 | 56.0 | 59.0 | 57.0 | 56.0 | 58.0 | 57.0 | 59.0 |
| sample 9 | 55.0 | 60.0 | 58.0 | 58.0 | 55.0 | 54.0 | 60.0 |
| sample 10 | 55.0 | 58.0 | 59.0 | 60.0 | 54.0 | 57.0 | 54.0 |
| Average result in (mm) | 54.9 | 57.6 | 57.9 | 58.4 | 55.1 | 56.4 | 57.1 |
| Average variation dimension(mm) | **5.1** | **2.4** | **2.1** | **1.6** | **4.9** | **3.6** | **2.9** |
| ASTM dimension tolerance (mm) | **2.4** | **2.4** | **2.4** | **2.4** | **2.4** | **2.4** | **2.4** |

## 6. Efflorescence of FCB and CSCB

| Samples | Dimension (FBC)(mm) | Dimension (10% CSCB)(mm) | Dimension (12%CSCB) (mm) | Dimension(14%CSCB) (mm) |
|---|---|---|---|---|
| sample 1 | Not effloresced | Not effloresced | Not effloresced | Not effloresced |
| sample 2 | Not effloresced | Not effloresced | Not effloresced | Not effloresced |
| sample 3 | Not effloresced | Not effloresced | Not effloresced | Not effloresced |
| sample 4 | Not effloresced | Not effloresced | Not effloresced | Not effloresced |
| sample 5 | Not effloresced | Not effloresced | Not effloresced | Not effloresced |
| sample 6 | Not effloresced | Not effloresced | Not effloresced | Not effloresced |
| sample 7 | Not effloresced | Not effloresced | Not effloresced | Not effloresced |
| sample 8 | Not effloresced | Not effloresced | Not effloresced | Not effloresced |
| sample 9 | Not effloresced | Not effloresced | Not effloresced | Not effloresced |
| sample 10 | Not effloresced | Not effloresced | Not effloresced | Not effloresced |