JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING

(CONSTRUCTION ENGINEERING AND MANAGEMENT STREAM)

ASSESSMENT ON EFFECT OF VARYING FIRING TIME AND TEMPERATURE ON SOME PHYSICAL PROPERTIES OF BURNT CLAY BRICKS PRODUCED AROUND JIMMA TOWN

By**:** Eshetu Tsega

Advisors:-Dr.**-**Ing Fikadu Fufa (PhD)

Eng.Alemu Mosisa (MSc.)

June, 2016

Jimma, Ethiopia

JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIROMENTAL ENGINEERING
(CONSTRUCTION ENGINEERING AND MANAGEMENT STREAM)

ASSESSMENT OF EFFECT OF VARYING FIRING TIME AND TEMPERATURE ON SOME PHYSICAL PROPERTIES OF BURNT CLAY BRICKS PRODUCED AROUND JIMMA TOWN

A Thesis submitted to the School of Graduate Studies of, Jimma Institute of Technology, Jimma University, in partial Fulfillment of the Degree of Master of Science in Civil Engineering (Construction Engineering and Management)

By**:** Eshetu Tsega

Advisors:-Dr.-Ing Fikadu Fufa (PhD)

Eng.Alemu Mosisa (MSc.)

June, 2016

Jimma, Ethiopia

Jimma University

Jimma Institute of Technology

School of Civil and Environmental Engineering

Construction Engineering and Management Stream

Assessment of Effects Varying firing time and temperature on some Physical Properties of Clay bricks Produced around Jimma Town

By: **Eshetu Tsega Ayanu**

Approved by Board of Examiners:

________________________	__________________	____/____/______
Chairperson	Signature	Date
________________________	__________________	____/____/______
Main Advisor	Signature	Date
________________________	__________________	____/____/______
Co-advisor	Signature	Date
________________________	__________________	____/____/______
Internal Examiner	Signature	Date
________________________	__________________	____/____/______
External Examiner	Signature	Date

DECLARATION

I, the undersigned, declare that this thesis entitled “Assessment of effects varying firing time and temperature on some physical properties of clay bricks production around 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.

Name: *Eshetu Tsega Ayanu* *Signature:* ___________ *Date* _____/____/____

ACKNOWLEDGMENT

I really would like to open my acknowledgment thanking the Almighty God, for all things that he did for me in my life.

It might be honest to state that a research work cannot be carried out by oneself without the help of the others. My deepest gratitude goes to my advisor, Dr. - Ing. Fekadu Fufa; for his continuous support and interest on my research work.

My heartfelt thanks also go to my Co-advisor Eng. Alemu Mosisa (MSc.); Civil and Environmental Engineering department head in providing related reference books and papers that would essentially help in shaping the research in such a beautiful manner through all my works of this research.

I would like also to thank the staff of traditional brick making micro enterprise located around Jimma, and for all those who have given the responses for the survey data collection activity for the research. This work might have not been possible if it was not with their help.

After everything else, my friends, family and special compliment goes to my youngest brother and Embutiye for their continuous hold up and motivation during my study.

ABSTRACT

Brick is one of the most widely used conventional construction materials throughout the World. The production cost of clay brick is significantly affected by the cost of energy required for firing; Different mechanisms have been used to reduce the energy required for clay brick production. For better energy utilization during brick production, controlling of firing temperature is a usual practice in the recent brick manufacturing technology. However, over and under firing clay bricks production and poor firing kiln management are major problem in traditional brick production. Generally controlling the firing temperature during clay bricks production plays a decisive role in both quality and production cost.

The aim of this research is to study the effects of different firing temperature and time on the compressive strength, water absorption and saturation coefficients of fired clay bricks and evaluate effect of firing process in brick manufacturing on the properties, color and appearance of the brick..

The raw materials for this study were sampled from two quarries and clay bricks are produced from two soil samples. The physical property requirements of these clay bricks which dried clay bricks are fired at various temperatures of 700, 970 and 1200°C and fired for duration of 2h, 4h, 6h and 8h firing are tested and analyzed.

*Laboratory test and Interview questionnaires are designed to study the firing temperature management practices of some traditional brick production in and around Jimma. In addition to the interview, observational based study is conducted by visiting their production processes. During the production process effect of different heating rates on physical properties of firing standard bricks will be analyzed. In this investigation, different heating rates were used: slow heating rate and fast heating rate***.** *Change will be checked with increment of firing temperature and all bricks were tested for their physical and mechanical properties.*

The results of this study show that with increment of firing temperature within the allowable firing temperature range; increase the compressive strengths and lower both the water absorptions and saturation coefficients of clay bricks. Increment of duration of firing slightly increases the compressive strength and lowers both the water absorption and saturation coefficient. The firing temperature control of the traditional brick factories surveyed during this study show that they have no temperature controlling device for their kiln but it is done with the observation of their kiln operator's. Over and under firing of clay-bricks is their usual loss. Moreover, according to the response of the interviewee's, the significance of firing temperature is less understood when compared to other stages in clay-bricks production.

It was concluded that the allowable mechanical property for brick samples within the temperature range considered is obtained at 970 to 1200 ^{o}C and firing duration of 6hr to 8hr according to Ethiopian standard specification ES- 86:2001.

KEYWORDS: *Burnt Clay brick, Compressive strength, Temperature, Water absorption, saturation coefficient,* firing *temperature management.*

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	The American Society for Testing and Materials
BF	Brick factory
BP	Brick production
BS	British standard
CSA	Central Statistical Authority
ESA	Ethiopian Standards Agency
ES	Ethiopian Standards
ERA	Ethiopia road authority
GWT	Ground water table
JIT	Jimma institute technology
LL	Liquid limit
PL	Plastic limit
PI	Plasticity index
SC	Saturation coefficient
VSCK	Vertical shaft continuous kiln
WA	Water absorption

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Clay brick is one of the oldest prefabricated building elements in human history. It is produced from the readily available clay soil and water on earth. At high firing temperature, the mixed and shaped clay material is irreversibly converted into a solid, hard and durable material which makes it a timeless and classic prefabricated building element (Companies, 2004).

Clay brick is the first man made artificial building material and one of the oldest building materials known. Its widespread 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 physical properties of the clays used to manufacture the unit, the manufacturing process and the firing temperature (Hendry, 1991).

The construction industry is a backbone to any nation. In India it is witnessing a strong growth due to huge infrastructure development. As the construction progresses rapidly, the demand of good quality construction and building materials also increases. Brick is a popular building material all over the world because of its highly economical cost, superior finish as well as high compressive strength and durability (Rounak Attri2, Utilization of WTP sludge &Tea waste, 2015).

Clay brick has been found in ruins of ancient civilizations including parts of the Great Wall of China. Properties of bricks are affected as a result of physical and chemical changes. Compressive strength and water absorption are two major physical properties of brick that are good predicators of bricks ability to resist cracking of face (Mbumbia I, performance characteristics of lateritic soil bricks fired at low tempratures, (2000)).

Clay bodies undergo several changes during drying and firing stages as a result of Physical and chemical modifications. During firing of fired clay brick, a series of transformation occurs which determine the final properties of the brick product. The main factors involved in manufacturing bricks are the type of raw materials, fabrication method, drying procedure, firing temperature and firing profile. These factors will affect the quality of the final product (G. Cultrone E. Sebastian M. J. De la Torre, (2005)39).

Since the production cost of clay brick is significantly affected by the cost of energy required for firing, different mechanisms have been used to reduce the energy required for it. For better energy utilization during production, controlling of firing temperature by using a temperature sensor usually called thermocouple becomes a usual practice in the recent brick manufacturing technology. This device is used to know the amount of firing temperature in brick kiln. (Brick making enterprises in Hai Duong, 2004.).

Varying firing temperature and firing time has important effects on quality bricks. Decreasing firing temperature and shortening firing time do not only reduce the cost of production but, also increase the productivity of the factory (sedat karaman, 2006).

Brick is one of the most widely used conventional construction materials throughout the World, since ancient times by using local clayey matter ((Franke L and Schoppe I, 1989). However, nowadays conservation of natural resources and utilization of industrial by-products are very important issues.

Informal brick making is not a new phenomenon in Jimma. Informal brick making supported construction industries in Jimma earlier years of development. Rapid urbanization has created a high demand for construction materials and has created conducive environment for the proliferation of un-gazette brick making that has a serious impact on the environment such as the one found around Jimma. The area around Jimma is underlain with the granite and the dominant soil types are clays soils which are conducive for vegetation.

In Jimma brick market, one can find both under burnt and over burnt clay bricks. The under burnt clay bricks have poor quality and the over burnt bricks have poor aesthetical values due to their partly darker color. The degree of firing of clay bricks does not only affect the quality but also increase the cost of production. So, it becomes interesting to know the effects of firing temperature on some physical properties requirement of burnt clay bricks (The federal Democratic republic of Ethiopia, 2004).

The limitations and the methods to achieve the research objectives are also presented. The final section of the chapter outlines the structure of the thesis and informs the reader certain conventions used throughout the thesis.

1.2 Statement of the problem

Most of the traditional clay brick production system in and around Jimma are old and produce limited type and amount of clay bricks compared with other countries .Furthermore, over and under fired clay bricks production is the regular practice of these traditional factories.

One of the major contributing factors for this problem is poor kiln firing temperature controlling mechanism. So, in addition to the study of the kiln firing temperature controlling mechanism of these traditional production systems, determination of the effect of firing temperature on the values of compressive strength, water absorption and saturation coefficient of clay bricks will be an input for all stake holders in the Ethiopia brick industry. These are the facts which drawn the attention to conduct this study.

1.3 Research Question

- What is effect of varying firing temperature on physical property of burnt clay brick?
- What is effect of varying firing time on some physical properties of burnt clay bricks?
- What are some of the physical properties of clay soil sample?
- What is the optimal firing temperature and firing time used for making better quality bricks?

1.4 General objective

To assess the effects of firing temperatures and time on physical properties of clay bricks production.

1.4.1 Specific objectives of the research are:

- To investigate the effects of firing temperature on compressive strength, water absorption and saturation coefficient of burnt clay brick.
- To determine the liquid limit, plastic limit, plastic index and specific gravity of clay soil sample.
- To identify the effects of firing time on compressive strength, water absorption and saturation coefficient of burnt clay bricks.
- To determine optimum firing temperature and time for the production of good quality bricks.

1.5 Significance of the Study

Firing temperature control during production of clay bricks is an important quality and cost management. With better controlling of firing temperature it can be possible to produce better and consistent quality of clay bricks with optimum production cost. Furthermore, study of the allowable firing temperature for a known raw material in clay bricks production, is not only improving the physical requirements of the clay bricks but also plays a great role to save energy and optimize the production cost. In this context allowable firing temperature means a firing temperature at which the necessary physical and chemical reaction takes place to attain the physical requirements of fired clay bricks. So, testing the allowable firing temperature for a known raw material in clay brick production is an important duty to be done.

1.6 Scope and limitation of the study

During the investigation, the study is limited to get soil sample from two sites, because of time and budget constraints. Therefore this research investigation is relied on the soil from Jimma at Bedabuna and Askola areas. These two soils were transported to JiT and tested for physical composition like: - Aterberg limit test, Plasticity Index tests, moisture content test and physical property of clay bricks where tested. This soil was transported to the JiT Construction material testing laboratory.

1.7 Report Structure

This thesis is divided into five major chapters. The first chapter is the introduction part which includes back ground of the study, objective of the study, Scope of the study and significance of the research. Chapter two describes the findings from the review of different literatures including: books, historical records, thesis reports and websites which are relevant to the study topic. Moreover, Ethiopian standards for solid clay bricks (ES 86:2001), ASTM and BS standards have been reviewed. Chapter three describes methodologies used in this study including methods of data collections, data analysis, research tools, site selection for raw materials, types of tests done for the sampled raw materials, laboratory tests done for the fired clay bricks. In chapter four the laboratory test results are summarized and discussed. Chapter five includes conclusions, recommendations and recommendations for further studies.

CHAPTER TWO

LITERATURE REVIEW

2.1 Definition of Clay Brick

Clay brick is defined as a solid masonry unit, usually made of clay, molded into a rectangular shape while plastic and it is one of the most accommodating masonry units due to its properties. The firing process could affect the physical and mechanical properties, colours and appearance of the manufactured brick. Many studies have been carried out by manipulating the firing process at different temperature, utilizing fast firing and traditional firing but most of the research are more focusing on the physical and mechanical properties of fired clay bricks only. It is also a ceramic structural material, in modern times, is made by pressing clay into blocks and firing them to the necessary hardness in a kiln.

2.2 `History of Clay Bricks Production

Bricks are without doubt, one of the oldest known building materials. They date back to 7000BC where they were first found in southern Turkey and around the city of Jericho. The first bricks were sun dried and made from mud. Fired bricks were found to be more resistant to the harsher weather conditions, which made them a far more reliable brick to be used in the construction of permanent buildings, where mud bricks would not have been sufficient. Fired bricks were also very useful for absorbing any heat generated throughout the day, and releasing it at night. (Retrieved, 2012.)

The Ancient Egyptians also used sun dried mud bricks as building materials, evidence of this can still be seen today at ruins such as Harappa Buhen and Mohenjo-daro. Paintings on the tomb walls of Thebes portray Egyptian slaves mixing, tempering and carrying clay for the sun dried bricks. These bricks also consisted of a 4:2:1 ratio which enabled them to be laid more easily. (Retrieved, 2012.)

The Romans further distinguished those which had been dried by the sun and air and those bricks which were fired in a kiln. Preferring to make their bricks in the spring, the Romans held on to their bricks for two years before they were used or sold. The Romans also only used clay that was white or red to manufacture their bricks.

Using mobile kilns, the Romans were successful in introducing kiln fired bricks to the entire Roman Empire. The bricks were then stamped with the mark of the legion who supervised the brick production. These bricks were different from other ancient bricks in size and shape. Roman bricks were more commonly round, square, oblong, triangular or rectangular. The kiln fired bricks measured 1 or 2 Roman feet by 1 Roman foot, but with some larger bricks at up to 3 Roman feet. The Romans preferred this type of brick making during the first century of their civilization and used the bricks for public and private buildings over the entire Roman Empire. The ancient fired brick was manufactured by forming the mixed clay in molds and then bricks were fired by stacking them in a loose array called clamp covering the clamp with earth or clay, building a wood fire under the clamp and maintaining the fire for several days (Jeorge J. Venta, 1998.)

Bricks tend to be more commonly used in the construction of buildings than any other material, with the exception of wood. Brick and terracotta architecture is dominant within its field and a great industry has developed and invested in the manufacture of many different types of bricks of all shapes and colours. With the advancement of modern machinery, earth moving equipment, powerful electric motors and modern tunnel kilns, making bricks has become far more productive and efficient than ever before. Bricks can be made from a variety of materials the most common being clay but also calcium silicate and concrete. With clay bricks being the most popular, they are now manufactured using three processes. These brick manufacturing processes are soft mud, dry press and extruded. Also during 2007 the new 'fly ash' brick was created using the by-products from coal power plants. (Retrieved, 2012.)

Good quality bricks have a major advantage over stone as they are reliable, weather resistant and can tolerate acids, pollution and fire. Bricks can be made to any specification in colour, size and shape which makes bricks much easier to build with than stone. Brickwork is also much cheaper than cut stone work. However there are some bricks which are more porous and therefore more susceptible to dampness when they are exposed to water. For best results in any construction work, the correct brick should be selected in accordance with the job specifications.

Brick making improvements have continued into the twentieth century. Improvements include rendering brick shape absolutely uniform, lessening weight, and speeding up the firing process. Generally there is no recorded production history of clay bricks in Ethiopia but, according to the oral response of the interviews for this study it is long time ago for traditional clay brick production in Jimma.

2.2.1 Clay brick production in some countries

The world annual fired clay bricks production is estimated to be 450 billion pieces (by 2008 year). Bricks are one of the most important building materials used in China especially in the rural areas. Almost all buildings use bricks as a major building material. In recent years, with expanding urbanization and increasing demand for construction materials, brick kilns have grown both in numbers and capacity in china. China dominates global brick production (about 54%) which is about 243 billion pieces per year (by 2008 year). The fired clay brick making is one of the traditional handicraft industries and has a history of more than 2000 years in China (wang, 2010).

The clay brick sector in India is the second largest producer of bricks in the world after China, estimated to produce 140 Billion bricks annually and consuming 24 million tones of biomass. Brick production in India takes place in small units, using manual labour and traditional firing technologies (Rimpel, 2011.).

Brick making industry is considered as one of the important industrial sectors of Vietnam. At present there are nearly 1,300 brick enterprises that are owned by both private and public sectors. The yearly production is nearly 9.2 billion pieces with 7.194 billion bricks from traditional kilns and 1.973 billion from tunnel kilns. Tunnel kilns are used by all state owned enterprises while traditional kilns are employed largely by small & medium enterprises (SMEs) in the private sector (Hung Yen, 2004.).

In UK Approximately 2.5 billion fired-clay bricks are produced annually. The current market value of clay bricks is about £550 million per annum with some 1200 varieties of clay brick available. Facing bricks, which account for over 90% of UK sales, are used primarily in the domestic housing market. Engineering bricks, with their higher strengths and lower porosity, are used for load-bearing masonry structures and in more aggressive environments generally. The UK brick industry consumes 8 million tones of clay each year and is energy intensive, its total annual energy consumption being around 6.3 terawatt hours of primary energy. This is, however, less than 1.5% of the total energy consumed by the UK manufacturing industry (A.Bown, 2013)

In South Africa 4 billion pieces of clay bricks are produced annually. The annual production of fired clay bricks in the Sudan is estimated to be about 2.8 billion. This is mainly produced by traditional methods where biomass fuels (fuel wood and dung cake) are used for brick firing.

Bricks tend to be more commonly used in the construction of buildings than any other material, with the exception of wood. Brick and terracotta architecture is dominant within its field and a great industry has developed and invested in the manufacture of many different types of bricks of all shapes and colours. With the advancement of modern machinery, earth moving equipment, powerful electric motors and modern tunnel kilns, making bricks has become far more productive and efficient than ever before. Bricks can be made from a variety of materials the most common being clay but also calcium silicate and concrete. With clay bricks being the most popular, they are now manufactured using three processes. These brick manufacturing processes are soft mud, dry press and extruded. Also during 2007 the new 'fly ash' brick was created using the by-products from coal power plants. (Syed Ashraful Alam, 2006.).

Good quality bricks have a major advantage over stone as they are reliable, weather resistant and can tolerate acids, pollution and fire. Bricks can be made to any specification in colour, size and shape which makes bricks much easier to build with than stone. Brickwork is also much cheaper than cut stone work. However there are some bricks which are more porous and therefore more susceptible to dampness when they are exposed to water. For best results in any construction work, the correct brick should be selected in accordance with the job specifications.

Modern brick production where fuel oil is used covers less than 2% of the total annual brick production (Syed Ashraful Alam, 2006.). The annual clay bricks produced in productions found in Ethiopia is not more than 30 million pieces. This quantity is very small when compared to the amount produced in other countries. Clay bricks are transported hundreds of kilometers from these productions to regional cities. Traditional clay bricks are produced in Oromia Regional state, around Jimma and recently near Holeta towns. According to the Ethiopian Central Statistical Authority (CSA), 2004 analytical report, concerning Construction material of wall, distribution of households by construction material of wall is described. Even if this analytical report is presented before 9 years, significant changes are not done until now. Based on this analytic report, about three-fourths (76.0 percent) of the country's total households reside in dwelling units with walls constructed from wood and mud. These types of houses are more common among urban households (82.4 percent) than rural (74.8 percent). Slightly more than 9 percent of rural and one percent of urban households are also indicated to dwell in wood and thatch houses. Households living in housing units with walls constructed of stone and mud constitute 9.1percent in rural and 6.3 percent in urban areas. Dwelling units with wall constructed by other types of materials are uncommon (less than 10 percent) in both the urban and the rural areas. According to this analytical report, in Ethiopia, only 0.1% used bricks as a walling material. This indicates that the use of clay bricks in the Ethiopian construction industry as a walling material is lowest. Some of the main reasons are their higher costs when compared with hollow concrete blocks, limited amount and shapes of production, etc. So, input of the concerned bodies for the development of the clay brick industry is vital (The federal Democratic republic of Ethiopia, 2004)

2.3 Raw Materials for Burnt Clay Bricks Manufacturing

2.3.1 Raw materials

The quality of brick which can be made at a particular site is largely predetermined by the type of soil available. There are some simple soil tests which don't need very special equipment. In the sedimentation jar test, a sample of soil is dissolved in a jar of water. When the soil settles you can get an idea of the fractions of clay, fine and coarse sand that are present. Another test is the linear shrinkage test. A sample column of wetted and mixed soil is pressed into a mould and allowed to dry. The shrinkage indicates how much clay there is in the soil and whether problems can be expected when drying bricks. Soil test are useful indicators, but you really only find out whether good bricks can be made by firing samples. Before investing in a full size kiln, however, it is possible to fire cubes or eggs of soil either in a laboratory kiln or a simple field oven.

Natural clay minerals, including kaolin and shale, make up the main body of brick. A wide variety of coating materials and methods are used to produce brick of a certain color or surface texture. To create a typical coating, sand (the main component) is mechanically mixed with some type of colorant. The quality variation in burnt clay bricks production is mainly due to fluctuation in raw material mineralogical composition, the degree of firing and the difference in manufacturing method. Clay is one of the most abundant natural mineral on earth. It is the basic materials in the production of bricks. The unique plastic characteristics of clay soils are a result of the enormous amount of surface area inherent in this particle size and shape. Clay is well suited to the manufacture of bricks. It is plastic when mixed with water, and easily molded or formed into the desired shapes; it has sufficient tensile strength to maintain those shapes after moulds are removed; and its particles are highly fused at high temperatures. It is this plasticity which facilitates the molding and shaping of moist clay into usable shapes. So, it is important to know the types and mineralogical composition of clay which determines the quality of the end product i.e. bricks (Companies, 2004).

2.3.2 Clay Types

The properties and quality of bricks depend on the type of clay being used. The most common form of clay used for everyday bricks, has a sandy consistency of silicate or alumina, which usually contains small quantities of lime or iron oxide. Silica, when added to pure clay in the form of sand, tends to prevent cracking, shrinking and warping of the brick. Clay is the most widely used raw material in brick production. It is defined as a mixture of natural deposits of fine grained earthen material which contains clay minerals and is formed by the weathering of certain rocks. It is usually plastic and cohesive, shrinking when dry and expanding when wet. It gains strength with retention of shape on firing and with particle size range of 2μm and below.

Clay used for brick manufacturing should have the following properties:

- ❖ Plastic when mixed with water
- ❖ Have enough tensile strength to keep its shape
- ❖ Clay particles must fuse together

Clay soils are compounds of silica and alumina. Calcareous clays have calcium carbonate and will burn to a yellow or cream color. Non-calcareous typically contain feldspar and iron oxides, and will burn to a brown, pink or red, depending on the amount of iron oxide. The silica in the clay, when fired at 900-1200 degrees C, will turn to a glassy phase. This process, called vitrification, will turn the clay to a crystalline structure. Therefore, for the process of vitrification temperature is important. If under-fired, the bonding between the clay particles will be poor and the brick will be weak. If the temperature is too high, the bricks will melt or slump. Vitrification does not have to be complete, and does not actually occur in many of the small traditional brick making plants around the world. However, the vitrification does occur enough to give sufficient strength to the brick. It takes approximately 3 cubic meters of clay soil to make 1000 bricks.

According to different literatures, clay soils are classified into surface clays, shale and fire clays. (Companies, 2004).

- **Surface clay**

  Surface clays may be the up thrusts of older deposits or of more recent sedimentary formations. As the name implies, they are found near the surface of the earth

  This type of clay soils are usually preferred by brick productions due to their least price but require blending with other clay soils which have less oxide content. It is found close to the earth's surface and most accessible and simply mined. So, it is the least expensive clay soil.

- **Shale**

  Shale's are clays that have been subjected to high pressures until they have nearly hardened into slate. It is a metamorphic form of clay hardened and layered under natural geologic conditions. This is very dense and harder to remove from the ground than other clays, and as a result, is more costly. Like surface clay, shale contains a relatively high percentage of oxide fluxes.

- **Fire clay**

Fire clays are usually available at greater depth than either surface clay or shale, it is expensive for exploration. Surface and fire clays have a different physical structure from shale's but are similar in chemical composition.

The lower percentage of oxide fluxes gives fire clay a much higher softening point than surface clay and shale, and the ability to withstand very high temperatures. And this reproduction quality makes fire clay best suited to produce brick for furnaces, fireplaces, flue liners, ovens, and chimney stacks.

Plasticity of clay soils is one of the physical characteristic which determines its workability. In clay soils the three principal identified clay minerals can be characterized in terms of activity and plasticity:

i.Montmorillonite (or Smectite) — Since it has more absorption and inter particle attraction compared with the others, this material is ideal for use as a drilling mud in soil exploration and in drilling oil wells. It is also commonly injected into the ground around basement walls as a water barrier (swells to close off water flow paths) to stop basement leaks. It is also blended with local site material to produce water barriers to protect the ground water table (GWT) from sanitary landfill drainage. The plasticity index (PI) of an uncontaminated montmorillonite is 15O+.

ii. Illite— A clay mineral that is intermediate in terms of activity. The plasticity index (PI) of a pure illite ranges from about 30 to 50.

iii. Kaolinite —the clay mineral with the least activity. This material is commonly used in the ceramic industry and for brick manufacture. The plasticity index (PI) of a pure kaolinite ranges from about 15 to 20 (Joseph E.Bowles)

2.4 Processes of Fired Clay Bricks Production

Essentially, brick are produced by mixing ground clay with water, forming the clay in to the desired shape, and drying and firing. In ancient times, all molding was performed by hand. Even if the recent technologies for clay bricks production are innovative and mechanized; the basic processes of production are almost similar in its history. The development of clay bricks production is mainly associated with the use of the recent machines which replace intensive human labour. And firing temperature optimization by using energy saving kilns and proper firing temperature management in the kiln improves the product quality and optimizes production cost. The common manufacturing process has six general phases: 1) mining and storage of raw materials, 2) preparing raw materials, 3) forming the bricks, 4) drying, 5) firing and cooling and 6) De-hacking (The brick industry association, 2006.)

2.4.1 Mining and Storage

Surface clays, shale's and some fire clays are mined in open pits with power equipment. Then the clay or shale mixtures are transported to plant storage areas. Continuous brick production regardless of weather conditions is ensured by storing sufficient quantities of raw materials required for many days of plant operation. Normally, several storage areas (one for each source) are used to facilitate blending of the clays. Blending produces more uniform raw materials, helps control color and allows raw material control for manufacturing a certain brick body.

2.4.2 Preparation

To break up large clay lumps and stones, the material is processed through size-reduction machines before mixing the raw material. Usually the material is processed through inclined vibrating screens to control particle size.

2.4.3 Forming

Tempering, the first step in the forming process, produces a homogeneous, plastic clay mass. Usually, this is achieved by adding water to the clay in a pug mill a mixing chamber with one or more revolving shafts with blade extensions. After purging, the plastic clay mass is ready for forming. There are three principal processes for forming brick: stiff-mud, soft-mud and dry-press.

a. Stiff-Mud Process: - In the stiff-mud or extrusion process, water in the range of 10 to 15 percent is mixed into the clay to produce plasticity. After purging, the tempered clay goes through a Dearing chamber that maintains a vacuum of 15 to 29 in. (375 to 725 mm) of mercury. De-airing removes air holes and bubbles, giving the clay increased workability and plasticity, resulting in greater strength. Next, the clay is extruded through a die to produce a column of clay. As the clay column leaves the die, textures or surface coatings may be applied. An automatic cutter then slices through the clay column to create the individual brick. Cutter spacing and die sizes must be carefully calculated to compensate for normal shrinkage that occurs during drying and firing. About 90 percent of brick in the United States are produced by the extrusion process.

b. Soft-Mud Process:-The soft-mud or molded process is particularly suitable for clays containing too much water to be extruded by the stiff-mud process. Clays are mixed to contain 20 to 30 percent water and then formed into brick in molds. To prevent clay from sticking, the molds are lubricated with either sand or water to produce “sand-struck” or “water-struck” brick. Brick may be produced in this manner by machine or by hand.

c. Dry-Press Process:-This process is particularly suited to clays of very low plasticity. Clay is mixed with a minimal amount of water (up to 10 percent), then pressed into steel molds under pressures. But in addition to these forming processes, it requires to use the amount of water for mixing based on the plasticity index of the raw materials.

2.4.4 Drying

Before the brick is fired, it must be dried to remove excess moisture. If this moisture is not removed, the water will burn off too quickly during firing, causing cracking. Wet brick from molding or cutting machines contain 7 to 30 percent moisture, depending upon the forming method. Before the firing process begins, most of this water is evaporated in dryer chambers. Although heat may be generated specifically for dryer chambers, it usually is supplied from the exhaust heat of kilns to maximize thermal efficiency. In all cases, heat and humidity must be carefully regulated to avoid cracking in the brick.

2.4.5 Firing and cooling

a) Definition of firing`

Firing, -is a process of heating material to elevated temperatures. The temperatures are usually in excess of 930^{0}C. The extent of firing is a function of both time and temperature. The firing develops the inter-particulate bond, the strengths, the pore structure, and the colour of the product. The extent of firing should be sufficient to produce the level of these properties required by the specifications for the particular product.

According to this terminology, in clay-bricks production:-

The temperatures are usually in excess of 930^0C:-Which irreversibly transform the clay particles into solid bodies and accompanied with shrinkage and colour change.

The firing develops the inter-particulate bond, the pore structure and the colour of the product. According to ASTM C 43-98a, fired bond in brick production is a bond developed between particulate constituents of brick solely as the result of the firing process. The bond may result from fusion or melting of one or more constituents of the composition or the surface of the particles. Other thermal mechanisms such as sintering and inter particle reaction may be responsible for the bond.

The higher the heat treatment was the greater the extent of bonding and consequently the greater the developed strength, the lower the resulting porosity. The bond development should be sufficient to provide the specified strength, porosity and durability for any particular product. The extent of firing is a function of both time and temperature. The degree of firing depends on the duration of firing and the amount of temperature used for firing.

The extent of firing should be sufficient to produce the level of these properties required by the specifications for the particular product. So, the physical requirements of brick are dependent on the degree of firing which is a function of time and amount of firing temperature.

After forming and coating, the bricks are dried using either tunnel dryers or automatic chamber dryers. Next, bricks are loaded onto cars automatically and moved into large furnaces called tunnel kilns. Firing hardens and strengthens the brick. After cooling, the bricks are set and packaged.

High temperatures in furnaces called kilns. In general, the cars that moved the bricks through the drying process are also used to convey them through the tunnel kiln. These cars are pushed through the kiln's continuously maintained temperature zones at a specific rate that depends on the material. The majority of kilns in the United States use gas as a fuel source, though a third of the brick currently produced is fired using solid fuels such as sawdust and coal. Tunnel kilns have changed in design from high-load, narrow-width kilns to shorter, lower-set wider kilns that can fire more brick. This type of design has also led to high-velocity, long-flame, and low-temperature flame burners, which have improved temperature uniformity and lowered fuel consumption. If fired bricks were on hand, they were used to construct the outer walls of the kiln and the surface was daubed with mud to contain the heat. If no fired bricks were available, the kiln was constructed entirely of green or raw bricks which were stacked in such a way as to act as their own kiln. These kilns were called clamps or scove kilns. Wood and coal were used for fuel. (National research council of Canada, 1984)

2.4.6 De-hacking

It is the process of unloading bricks from a kiln after the bricks have been cooled. Bricks are sorted, graded and packaged. Then they are placed in storage which becomes ready for delivery. The clay bricks production processes in the surveyed brick factories is similar with the above processes. But the productions use old machine and methods of production.

2.5 Kiln Brick Burning

Following the initial drying process, all the bricks are placed in a kiln for burning or firing, which finishes off the brick to achieve the optimum strength and colour.

There are some different types of kilns which are currently used to fire bricks.

- **The Scotch Kiln:** This type of kiln is the most commonly used in the United Kingdom. This is a rectangular building which is open at the top and has side doors with fire holes built from fire bricks. The kilns will contain approximately 80,000 bricks at full capacity. Raw bricks are arranged in the kiln leaving gaps in between each brick to ensure they receive an even burn. It takes approximately three days to burn off the moisture from the bricks, at which point the firing is increased for the final burn. It takes between 48 and 60 hours to completely burn a brick to achieve its maximum strength. The bricks from the centre of the kiln will be of the highest quality whilst the ones from the edges are sometimes clinkered and unsuitable for exterior work.
- **Up Draft Kiln:** These kilns are more often used for handmade bricks and in small brick yards; this old fashioned type of kiln is only up to about 15 feet high.

- **Down Draft Kilns:** These kilns are generally of a beehive type shape with fire produced outside of the kiln and carried in through flues. It is believed that all types of clay whether it be pottery or brick work, burn more evenly in a down draft kiln. For Terracotta brickwork this type of kiln is usually used.
- **Continuous Kilns:** These are the most expensive type of kiln to construct. This type of kiln is a continuously fired tunnel in which the bricks pass through very slowly on a rail to achieve a consistently durable brick. This is continuous conveyor belt with bricks being dried and added at one end while at the other end they are being burnt. This is a very efficient way of burning bricks. They also achieve a greater number of grade 1 bricks using this method of firing.

The colour of the brick is influenced by the chemical and mineral content of the mixture it is made from but also how high the temperature was during the firing process. Bricks are generally red, but an increase in temperature can change them to dark red, purple, brown or grey. Bricks containing silicate depend on the colourant used. The colour and place of manufacture is reflected in the brick names.

2.6 Tests Done During Production

2.6.1 Granular Composition of soils

The granular composition of soil should preferably fall within the limits of the shaded area of on the diagram of texture as which mostly gives satisfactory results. Its approximate limits that recommended were in the shaded area.

If the types of the soil granular composition falls outside the shaded area it may still give acceptable results, but it is recommended that it was subjected to other a series of tests that enables its suitability.

2.6.2 Atterberg Limits

Atterberg limits are the limits of water content used to define soil behavior. The consistency of soils according to atterberge limits gives the following diagram.

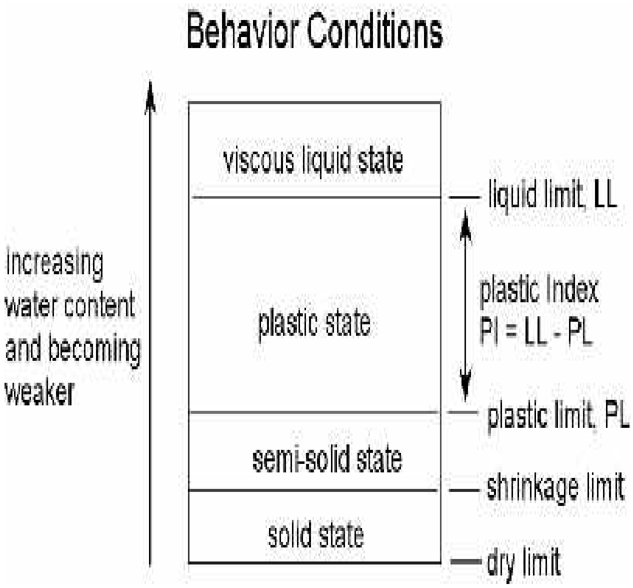


Figure 0-1: Diagram the Atterber limit

2.6.2.1 Plasticity

The plasticity of clay soils should preferably fall within the limits of the shaded area of the following diagram of plasticity. Approximately the clay soil plasticity which recommended should fall in the shaded area gives the satisfactory results. It does not mean that the clay soils which fall outside the shaded area was not suitable so were recommended to assess its suitability through a series of tests that shows its suitability.

Figure 2 — Diagram of plasticity

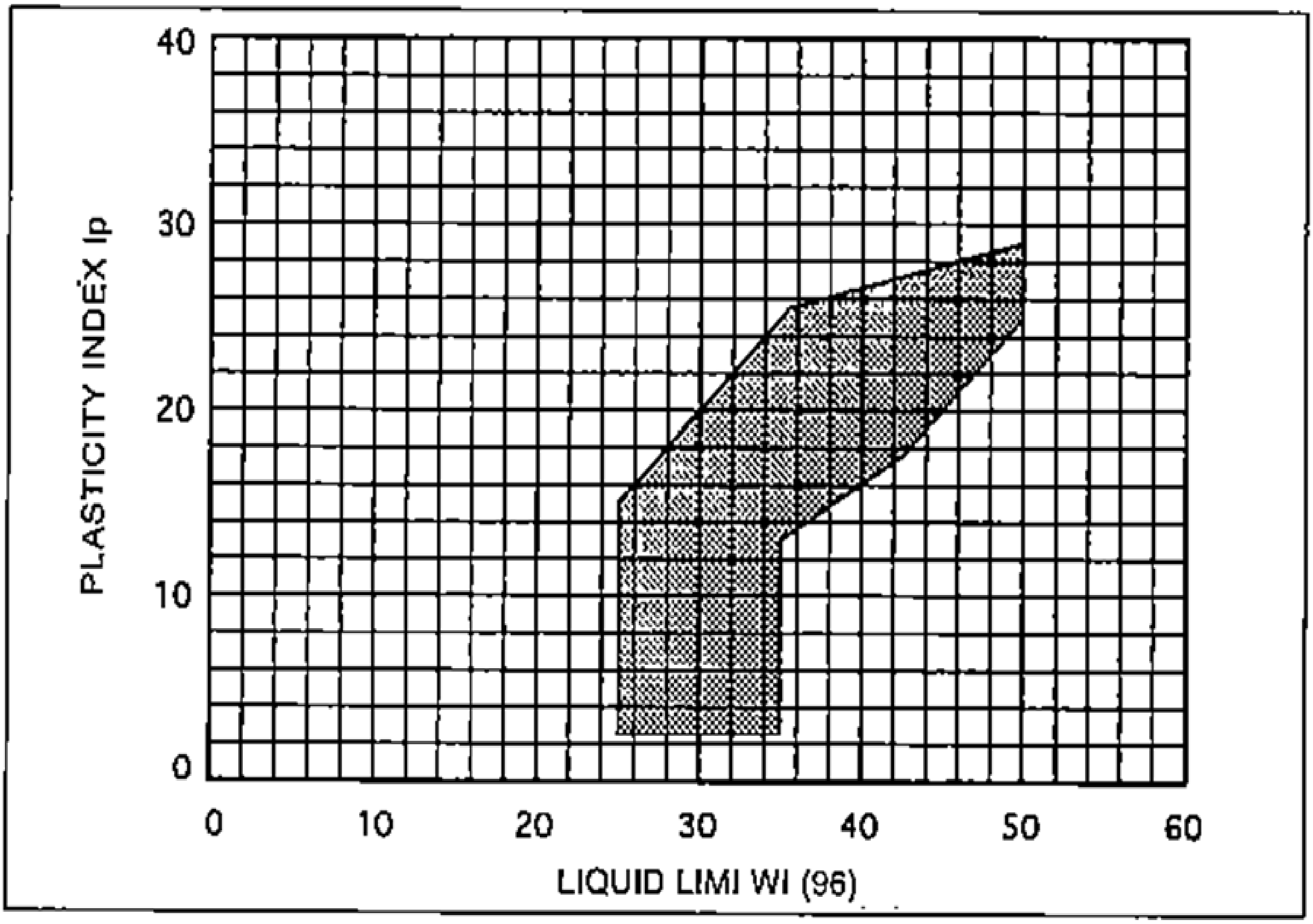


Figure 0-2: Diagram of plasticity for clay soils suitable for clay bricks

2.6.2.2 Liquid limit

2.6.3 Tests for index properties of soils

The raw materials or clay used for the production of clay bricks should be workable i.e. it has to be easily molded. Workability of a soil is a function of gradation of its particles and its moisture content. A well graded soil is more workable. In addition to this, the physical properties of most fine-grained soils, and particularly clayey soils, are greatly affected by moisture content. The consistency of clay may be very soft, that is a viscous liquid; or it may be very hard, having the properties of a solid depending on its moisture content. In between these extremes, clay may be molded and formed without cracking or rupturing the soil mass. In this condition, it is referred to as being plastic. Among the different soil index properties or engineering properties, test for its plasticity is important (U.S. Department of the interior bureau of reclamation, 1998) .Also among the engineering properties of soil; volume change due to shrinkage is an important property of brick raw materials. This is due to the fact that clay in the production process of brick has moisture at its plastic state and it shrinks during drying and firing when it loses its moisture content. So, it is important to consider this shrinkage values while molding the clay at it plastic state.

2.6.4 Tests for moisture content of the raw materials

Moisture content, is defined as the ratio (expressed as a percentage) of mass of water to mass of solids soil. Moisture (water) is the most influential factor affecting soil properties (United States government printing Office, 1998). In clay brick production the moisture content of the soil should be below the liquid limit and greater than or equal to the plastic limit this range is called the plasticity index. With this value of moisture content the soil becomes workable which makes it to be molded easily.

2.6.5 Test for specific gravity

Specific gravity is defined as the ratio between the density of a substance and the density of water at 4^0C in investigating a soil, the most easily visualized condition involves the volume occupied by solid soil, the volume occupied by water, and the volume occupied by air, in the soil mass. However, most measurements are more readily obtained by mass. To correlate mass and volume, the specific gravity factor is required (United States government printing Office, 1998). Values of specific gravity are as high as 3.0 and as low as 2.3 to 2.4 are not uncommon.

2.6.6 Tests for fired clay-bricks

2.6.6.1 Tests for compressive strength

Compressive strength is a mechanical properties used in bricks specification, which has assumed great importance for two reasons. Firstly, with higher compressive strength, other properties like flexure, resistance to abrasion, etc, also improve. Secondly, while other properties are relatively difficult to evaluate, the compressive strength is easy to determine (Adeola, 1977). From quality control point of view, the compressive strength of bricks is the accepted measure of the quality of most brick work. Generally, compressive strength decreases with increasing porosity but strength is also influenced by clay composition and firing.

2.6.6.2 Tests for water absorption

Bricks are taken and the bricks are weighed dry and the average dry weight of 5 bricks is calculated. Bricks are then immersed in water for a period of 24 h. After 24 h of immersion, bricks are weighed again and average of 5 bricks is calculated. The difference of the final average weight and initial average weight indicates the amount of water absorbed by the bricks. It should not in any case exceed 20percent of average weight of dry bricks. Generally the water absorption of a brick is defined as the weight of water taken up by the brick under given laboratory test conditions or specification, and is expressed as a percentage of the dry weight of the unit. (Abebe Dinku, 2002)

2.6.6.3 Test for saturation coefficient

Saturation coefficient or C /B ratio is a measure of the relationship of two aspects of water absorption: the amount freely or easily absorbed water and the amount absorbed under pressure. The former (C) is determined by the 24-hour cold water absorption test, and the latter (B) by the 5-hour boiling water absorption test. It is the ratio of the twenty-four hours cold water absorption value over the five hours boiling absorption value, is an approximate indication of the space available in the brick to accommodate the expansive pressure of freezing of water; i.e., the lower the saturation coefficient the more space there is for the freezing pressure to be relieved, thus it is less likely for the brick to be damaged (National research council of Canada, 1984)

For a given clay and method of manufacture, higher compressive strength values and lower absorption values are associated with higher firing temperatures. Although absorption and compressive strength can be controlled by manufacturing and firing methods, these properties depend largely upon the properties of the raw materials (Reston Virginia, 2007).

2.7 Standard Specifications for Clay Bricks

Specifications are essential part of quality assurance and control in the construction industry. To attain quality workmanship and suitable performance, the concerned parties must carefully outline the products and standards of the construction. Reference standards should be used to manage the quality of specified products. Considering all these facts, different countries have standard specifications of burnt clay bricks which specify definition, classification (classification based on: - dimensions, size, durability, efflorescence, compressive strength and water absorption), sampling for tests, dimension deviation, markings and method for testing durability parameters. Thus based on these physical property requirements, the clay bricks are classified. (brick Specifications for and classification of, 2007.) In different specifications, the main parameter for classifying clay bricks is their physical requirements. For example, according to ASTM C 62- 97a, clay bricks are classified based on their compressive strength and water absorption. BS also classifies clay bricks based on their compressive strength and water absorption.

2.7.1 Ethiopian standard specification

The former Ethiopian standard specification for solid clay bricks (ES 86:1990) was formally replaced by another designation ES- 86:2001 (Ethiopian Standards Agency (ESA), 2011).

2.7.1.1 Tests for compressive strength

Based on the laboratory test result of mean compressive strength, according to Ethiopian standard (ES 86:2001); bricks are classified as shown in Table 2-1

Table 0-1: Minimum Compressive Strength of Solid Clay-Bricks (Es 86:2001)

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

2.7.1.2 Tests for water absorption

According to Ethiopian standard, based on their water absorption, bricks are classified as shown in Table 2-2

Table 0-2: Maximum Water Absorption of Solid Clay Bricks (Es 86:2001)

Class	After 24h immersion		After 5h 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

2.7.1.3 Test for saturation coefficient

According to Ethiopian standard, based on their Saturation coefficients, bricks are classified as shown in Table 2-3

Table 0-3: Maximum Saturation Coefficients of Solid Clay Bricks (Es 86:2001)

Class	Saturation coefficient	
	Average of 5 bricks	Individual bricks
A,B	0.96	0.99
C,D	No limit	No limit

2.7.2 British Standard Specification for Clay bricks (BS 3921:1985)

According to BS 3921, bricks are classified based on their compressive strength and water absorption.

Table 0-4: Classification of Clay Bricks by Compressive Strength and Water Absorption (Bs 3921: 1985) **(British Standard Institution, 1985.)**

No	Classes 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

Note1: There is no direct relationship between compressive strength and water absorption as given in this table and durability.

Note2: Damp proof course 1 bricks are recommended for use in buildings whilst damp proof course 2 bricks are recommended for use in external works.

2.7.3 The American Society for Testing and Materials; Standard Specification for Building Bricks (ASTM C 62-97a)

According to ASTM, standard specification for building bricks (C 62- 97a), clay bricks are classified based on their compressive strength, water absorption and saturation coefficient as discussed (The ASTM Committee on standards, 1999.)

Table 0-5: Classification of Clay Bricks Based On Their Physical Requirements

Designation	Minimum compressive strength, gross area (MPa)		Maximum water absorption By 5h boiling, (%)		Maximum saturation coefficient	
	Average of 5 bricks	Individual bricks	Average of 5 bricks	Individual bricks	Average of 5 bricks	Individual brick
Grade SW	20.7	17.2	17	22	0.78	0.8

Grade MW	17.2	15.2	22	25	0.88	0.9
Grade NW	10.3	8.6	No limit	No limit	No limit	No limit

On this specification:

Grades classify bricks according to their resistance to damage by freezing when wet, as defined in note 1.Three grades are covered and the grade requirements are listed in Table 2.5.

i. Grade SW (Sever weathering)- bricks intended for use where high and uniform resistance to damage caused by cyclic freezing desired and where the brick may be frozen when saturated with water.

ii. Grade MW (Moderate weathering) - bricks intended for use where moderate resistance to cyclic freezing damage is permissible or where the brick may be damp but not saturated with water when freezing occurs.

iii. Grade NW (Negligible weathering) - bricks with little resistance to cyclic freezing but which are acceptable for applications protected from water absorption and freezing.

Note 1: The word "saturated" with respect to this standard, refers to the condition of a brick that absorbed water to an amount equals to that resulting from submersion in room temperature water for 24h.

2.8 Field Tests for Fired Clay-Bricks

In Ethiopian most construction industry sites which are found in rural areas have no site laboratories. Moreover, these sites are not able to get laboratory services in the nearby areas. In such occasions it is better to know visual tests of clay bricks on the field. The following visual tests and field tests can be carried out to determine good quality burnt clay-bricks for use in works (S.K. Duggal, 2000.).

- A good quality brick should be regular in shape and size, with smooth sides and no cracks or defects.
- They posses sharp and square edges.
- Well burnt clay-bricks are copper colored and are free from cracks.
- When struck with each other, they produce clear metallic ringing sound.
- They absorb minimum water when immersed in water.
- Good bricks are hard on their surface and leave no impression when scratched with nails.
- Good bricks when soaked in water and dried; do not show white patches or white deposits on their surface.

CHAPTER THREE

RESEARCH METHODOLOGIES

3.1. Methodology

The research work begins with literature review followed by assessment of the case in Ethiopia and followed the Jimma town. For the development of concepts for the study, the concepts and problems are stated and reviewed. The method to solve the problems requires data that decide on the type and method of data collections and their analysis.

Data collection methods such as experiments, observations, and archival records are examined and used where suitable. Both primary data (collected personally) from the source itself and secondary data from different countries is collected and used for the analysis.

Primary data is collected at controlled environments by testing in laboratories by using electro mechanical equipment's.

3.1.1. Sampling procedure

The collected data is analyzed in qualitative and quantitative methods.

1. The soils from both sites means Bedabuna and Askola are selected and visualized on the site itself.

2. After on site selection criteria's, both soil samples are taken to the laboratory to investigate its physical properties.

3. The same soil type will be used for the compressive strength tests by producing a clay brick blocks using wood mold.

4. Therefore, to produce the fired clay brick blocks both soil samples will be brought from the site to the production center.

5. The amount of water also calculated and evaluated to be added on the stabilization requirement.

6. Finally by sprinkling the required amount of water on soil samples and mix each other to form plastic ready for molding brick block.

7. Every produced clay brick blocks will be marked on it by the paints or markers which specify their temperature difference, time difference, and the types of site.

8. The produced clay bricks blocks should be arranged in one layer and air dried for a period of ten to fifteen days to release its moisture.

9. After ten days drying the bricks will be taken to mechanical engineering laboratory for firing using furnace buy varying time and temperature and again fired clay brick is brought to Civil engineering laboratory for physical property test.

10. Finally discussion will be made based in the test results from physical property test, the compressive strength, water absorption and saturation coefficient test results for all produced clay bricks under varying time and temperature.

In this chapter, the methods of data collection, data analysis, the production processes of bricks and laboratory tests conducted at different stages of the clay bricks production utilized for this study are discussed.

3.1.2. Data collection

Data for this study are collected from non-participative observation method and relevant literatures are reviewed. During non-participative observation survey, the brick production process and firing management of some traditional brick factories around Jimma were studied. Particularly the firing temperature control experience of factories is studied by taking photos supporting observational data. In addition to these, laboratory test results are also used.

3.1.3. Research tools

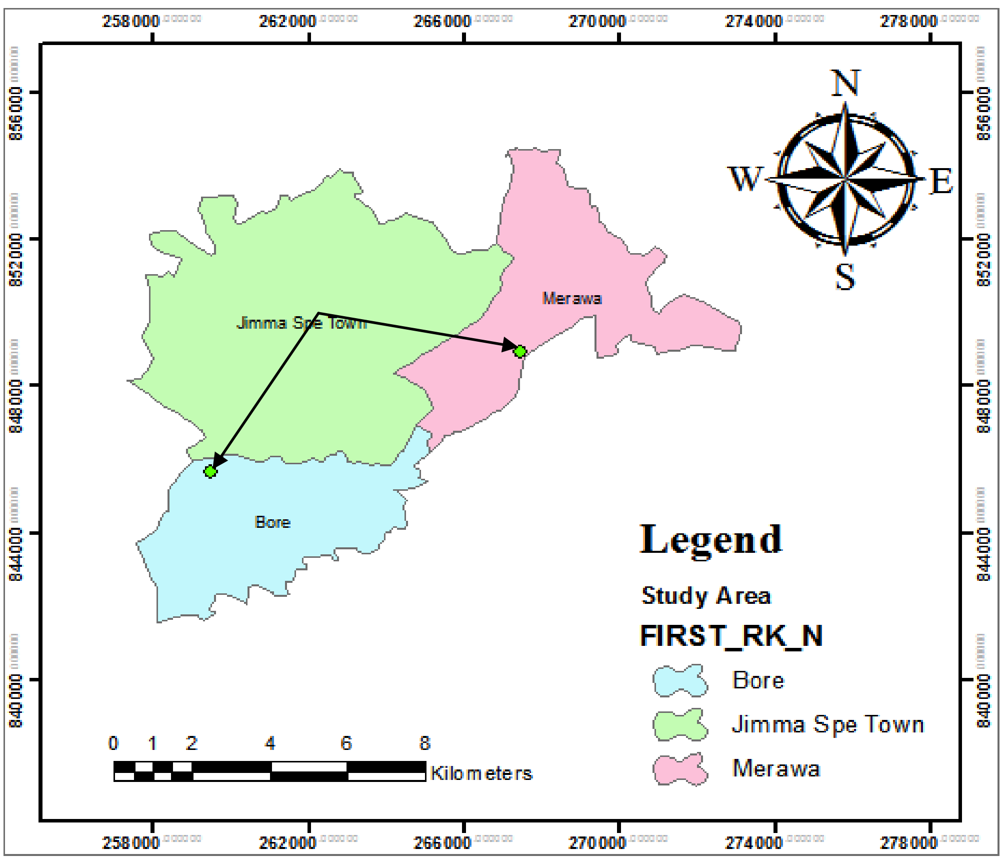
The data retrieval methods for the research studies are observation and publications and internet. The research tools utilized for studies are visit of the traditional brick productions for observational method, and books, journals and websites for publications and internet.

3.2. Selection of Sites for the Raw Materials

Raw material for this study are planned to be explored from two sites. The first site is Bedabuna, which is found 7.5km along the road from Jimma - Addis Ababa where traditional brick making is a dominant practice in this area by micro enterprise. The other site is Askola, which is found 5km along the road from Jimma - Bonga town.

The clay soils from raw material source one are red clay soil from Bedabuna area and white soil from Askola site. Both materials are explored without any cost except exploration and transportation cost. The soils from the two sites are sampled and tested in the laboratory. But for this study, the red soil from raw material source one i.e. from Bedabuna area and the white soil from Askola site are used for brick production.

The location of the quarry sites of the two soil samples and the studied brick productions is shown on Fig. 3-1.



Source (Ministry of water, irrigation and energy, GIS department)

Figure 0-1: The location of the quarry sites of the two soil samples and the studied brick production

The physical tests of soils including the Atterberg's limit (liquid limit and plastic limit) and the specific gravity are tested in JiT Construction material Laboratory and the test results are discussed in the next chapter.

3.6. Atterber limit Laboratory Tests Procedures

3.6.1. Determination of Liquid Limit (LL)

Liquid limit was determined using the Casagrande method. The Casagrande tool was adjusted by means of a gauge. When the adjustment was completed, the adjustment plate was secured by tightening its screws. 125gm of soil was passed through a 425 micron sieve, and mixed with distilled water in the evaporation dish so that a paste was formed. The soil was left so that water permeated. The mature time was 24 hours. A portion of the paste was taken and placed in the Centre of the cup so that it was almost half filled. The top was leveled so that it was paralleled to the rubber base and the maximum depth of the soil depth (1cm). With the help of a grooving tool "a" the paste was divided along the cup Diameter. Thus, a V-shaped gap, 2mm wide at the bottom and 11mm at the top and 8mm deep, was formed. The handle of the apparatus was turned at the rate of 2 revolutions per second, until the two parts of the soil came in contact with the bottom of the groove along a distance of 10mm. The number of revolutions required to cause the groove to close for the approximate length of 10mm were recorded. The remaining soil was removed from the cup and mixed with the soil left earlier on the marble plate. The consistency of the mix was changed by adding more water or leaving the soil to dry, depending on the soil moisture condition. The number of revolutions to close the groove was recorded, the liquid limit was determined according to ASTM procedure D 4318.

3.6.2. Determination of Plastic Limit (PL)

The plastic limit was calculated, using the Casagrande method, air-dried soil passing through a 425 micron sieve was used. The sample was mixed with distilled water to make it plastic enough to be shaped into a ball. The plastic material was left for at least 24 h to mature to allow water to permeate. About 8gm of the plastic soil were taken and molded into a ball, then rolled on marble or glass. With the hand and just sufficient pressure, the ball was rolled into a thread of uniform diameter throughout its length. When the diameter of the thread decreased to 3mm, the specimen was kneaded together and rolled out again. The process was continued until the thread just crumbled at 3mm diameter. The readings were obtained for determination of the plasticity of the soil.

3.6.3. Determination of Plasticity Index (PI)

Plasticity index was calculated from plastic limit and liquid limit as follows:

PI = LL – PL

3.3. Brick Production Processes

The processes utilized in this study for the production of clay bricks includes preparation of the raw materials, mixing, shaping, drying and firing of bricks. The schematic diagram which shows the production processes of clay bricks for this study is shown on Fig. 3-2.

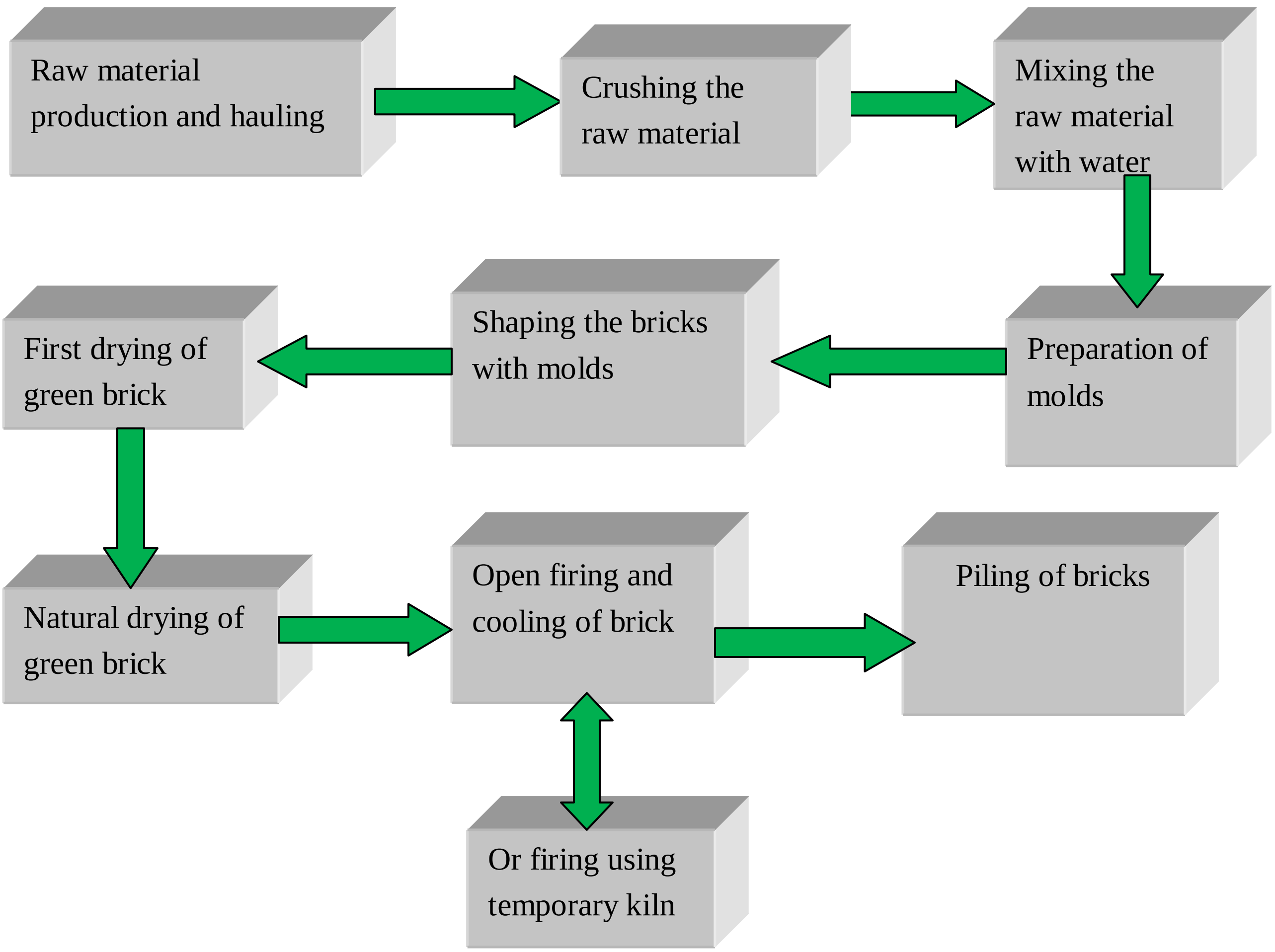


Figure 0-2: Schematic diagram representing the production processes of bricks

3.3.1. Preparation of the raw materials

The red clay soil and the white clay soil from Bedabuna and Askola quarry sites respectively are transported to the production site. The production site for this study is in Jimma town. After the selected soils are transported from the quarry they are left to be dried with air, they were sieved with a wire mesh. The over sized soil particles are manually crushed and sieved again and again.

3.3.2. Forming

For the production of clay bricks from the two soil samples, these samples are mixed with water and the amount of water used for mixing each soil samples is based on their plastic and liquid limits test results. The amount of water used for mixing these soil samples is listed in the next chapter. Mixing of the raw materials is done manually. Shaping of the mixed soils at their plastic state for this study is done using a wood mould of size 25cmx12cmX6cm from Bedabuna and size 25cmx12cmX6cm from Askola traditional brick making site. Since the available space of the furnace used for firing of the bricks is very small, this small sized bricks mould is selected. Moreover, wood ash is used to lubricate the formwork so that it prevents the plastic raw material mix from sticking on the formwork. All the shaping activities are done manually. During shaping the plastic clay is compacted manually to reduce the void in the mix.

3.3.3. Drying

The green bricks are left in a room for four days and then they are left in a shed to be dried with air for six days. The time of drying is dependent on the moisture content of the green bricks and the humidity of the production area.

3.3.4. Firing

The physical properties tests of the fired clay bricks are done in JiT construction materials testing laboratory. The tests include; compressive strength, water absorption and the saturation coefficients. Firing for this study is done in JiT Mechanical Engineering Testing laboratory using a furnace. The firing temperatures used for this study are 700, 970 and 1200^{0}C. Brick made from the two sites are fired separately for 6 h with these three different temperatures.

Moreover, the bricks produced from the two sites are fired for 2h, 4h, 6h and 8h separately at a constant temperature of 970^{0}C to test the effects of duration of firing temperature on the physical properties of these bricks.

3.4. Laboratory Tests during the Production Processes

The moisture content of the red bricks of the two site soils is determined in the laboratory. In addition to this the physical properties of fired bricks are also tested. The results are discussed in the next chapter.

3.5. Laboratory Tests of the Fired Clay Bricks

The fired clay bricks compressive strength, Water absorption and saturation coefficient which are produced from the two sites are tested in JiT, Construction Materials Testing Laboratory using Ethiopian standard specification for solid clay bricks. The test results are analyzed based on the Ethiopian standard specification of solid clay bricks (ES 86: 2001) and ASTM and are classified accordingly. The results are described in chapter four.

3.6. Methods of Data Analysis

The data analysis for this study is based on the laboratory test results. The experimental results are numerical data which are shown on appendix one and they are shown in chapter four as summarized as possible with graphs and tables to interpret the findings of the study shortly.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This chapter includes the presentation and interpretation of results obtained from interview response, observations during the interview, visit of the traditional brick productions and experimental results.

4.1. Interview Response

During this study, one interviewee from each of the two studied traditional brick productions was interviewed and all of them were volunteers to answer the interview questionnaires. The relevant interviewee's which have long experience in the traditional brick making and technical eligibility about the clay brick production were selected by micro enterprise managers of each traditional brick factory after discussions were made about this study and the interview questioners. Their response for the interview questionnaires are discussed below and summarized in Tables 4-1 and 4-2.

4.1.1. Raw materials and processes of clay brick production

1) Both the studied traditional brick productions are located near their raw materials quarries and have no owned laboratory to test the raw materials used for the production of clay bricks. White and red clay soils of Askola and Bedabuna respectively are used for the production of clay bricks. The traditional factories pay to the government a royalty fee which is equivalent to 2 birr per m3 of the raw material used. Which is calculated based on the volume of the produced fired clay bricks.

2) Processes of clay bricks Production

The clay brick production in both traditional productions is similar. The stages of clay bricks production includes: exploration and transportation of the raw materials, crushing, mixing of the raw materials with water, shaping of the green bricks, drying of the green bricks, firing and cooling. The critical stage of production according to the responses of the interviewee's is summarized in Table 4-2.

4.1.2. Firing of clay bricks

1) Both these traditional brick production kiln have no a temperature sensor device or thermocouple. But the degree of firing is controlled by the observation of their kiln operator's. So, energy utilization in these production kilns is poor which results in over and under fired clay bricks. The duration of firing of clay bricks by these productions is 48h. Their firing temperature controlling experience is summarized in Table 4-2.

2) Since these traditional production kilns have no owned laboratory, they do not test the fired clay bricks. In addition,

- Over and under fired clay bricks are common products in both these kilns.
- The over fired clay bricks are sold with less cost.
- The under burnt clay bricks are either broken or they have more absorption. These broken bricks are cart away to disposal area and do not reused as raw material for clay brick production due to absence of crushing mill.

Due to absence of competition and availabilities of limited production capacity, their products have no market problem which indicates that the demand is much greater than the supply. According to the response of the interviewee's, the quality of clay bricks produced in both traditional production kilns varies and the reason for this is due to their old mechanisms that these kilns use for the production.

Table 0-1: Company profile of traditional brick production surveyed during this study

No	Name of the company	Name of interviewee's	Responsibilities in the productions	Present annual brick production capacity(pcs)	No. of employees	
					Male	Female
1	Bedabuna traditional BP	Ato Belachew Gemeda	Brick expert	1,200,000	15	2
2	Askola traditional BP	Ato Girma Roba	Brick expert	800,000	14	5

N.B. –Bedabuna BP has lower employees compared with its largest production. This shows that in this factory, there is a better labour management compared with the other factories.

BP- means brick production.

Table 0-2: Brick production firing temperature control, raw materials and fired clay-bricks testing.

No.	Name of brick production	Testing methods		Critical stage of brick production based on interviewee's response's	Source of energy for firing	Kiln temperature sensor device	Kiln temperature control mechanism
		of raw materials	of fired clay bricks				
1	Bedabuna traditional BP	By experience	No tests.	Shaping	Wood	Not available	By observation
2	Askola traditional BP	By experience	No tests.	Raw material selection	Wood	Not available	By observation

4.2. Observational Findings

Broken bricks resulting from under firing and partly black and partly brown red colored bricks which have poor aesthetical values resulted from over firing of the bricks are the usual loss of these traditional brick production. In addition to the availability of specifications only for solid clay bricks in the Ethiopian Standard specification (ES 86:2001), the only types of bricks produced in these traditional productions are faced bricks (FB) and all these products have sizes of 25cm x 12cm x 6cm. According to the observation made in these traditional brick production kilns and based on the responses of the interviewee, the significance of firing temperature is little understood by all when compared with other stages of brick production. This shows that in these traditional kilns there is poor way of energy utilization causing higher production cost.

4.3. Laboratory Results

The laboratory test results include; the physical properties of the two soil samples, the moisture content of the bricks during production and the physical properties of the fired clay bricks.

4.3.1 Physical properties of soil sample

The physical properties tests results of the two soils are described in Table 4-3. Liquid limit, plastic limit, plastic index and specific gravity of the soil samples are tested to know the amount of water used for mixing these raw materials by keeping the plasticity of the mix as a constant variable so that the amount of water used for mixing vary within the index of plasticity of each soil.

As shown on Table 4-3, the amount of water used for mixing each soil sample is less than its liquid limit. This indicates that the mixed soil sample is in its plastic sate.

Table 0-3: Physical properties of sampled soils

soil sample	LL	PL	PI	Specific gravity	Water used for mixing (% by weight)
Bedabuna	38	28	10	2.5	30
Askola	62	40	22	2.48	47

4.3.2 Effects of firing temperature

Compressive strength of bricks is remarkably improved by firing at higher temperatures. With increase in firing temperature, compressive strength increased as follows: 700-800^{0}C and 700-1100^{0}C.Sharp increase in strength at 1000^{0}C and above may be attributed to the enhanced vitrification in the clay materials (Karaman, 2006).

The results are shown in tables in appendix one. And the result summary of mean compressive strength values is shown on Fig. 4-1.

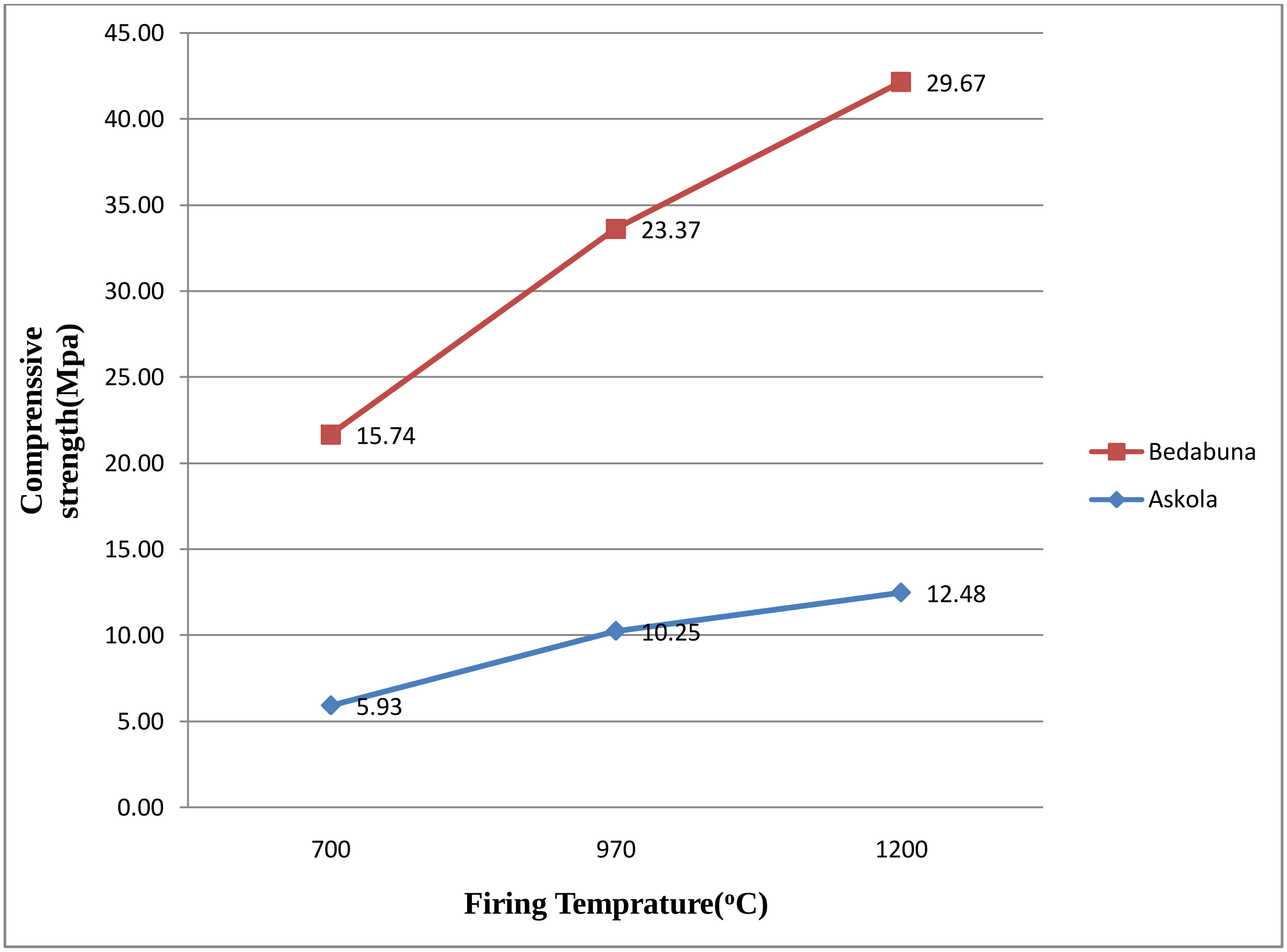


Figure 0-1: Effect of different firing temperature on the mean compressive strength of clay-bricks.

The average compressive strength of bricks produced from soil samples Bedabuna, and Askola increases as the firing temperature rises from 700 to 970 and 1200^{O}C. particularly the rapid increment occurs above 700^{O}C where vitrification takes place as shown on Fig. 4-1.

Moreover, in this study it is observed that the clay bricks produced from soil samples containing larger proportion of white clay soils of Askola start melting at lower temperature than the one which has larger amount of red clay soils of Bedabuna. This implies that the melting point of the white soil sample is lower than the red soil sample. Therefore, it is observed that the degree of firing is also dependent on the soil type from which the bricks are produced. According to the compressive strength results, the optimum firing temperature of bricks produced from Bedabuna site soil samples is from 970 to 1200^0C but, the compressive strength of clay brick produced from Askola site has lower compressive strength as compared to Bedabuna site which is due to different physical properties of clay soil even though it is slightly increase from 700 to 1200^0C.

The average compressive strength of bricks produced from soil samples Bedabuna site, increases rapidly as the firing temperature rises from 700 to 970^OC and average compressive strength slightly increase above this temperature as sown on Fig. 4-1.

Table 0-4: Average compressive strength of bricks and their classification.

Raw materials	firing temperature (^{O}C)	Mean compressive strengths of 5 bricks (MPa)	Classification (ES 86:2001)	Classification ASTM
Bedabuna	700	15.74	B	NW
	970	23.37	A	SW
	1200	29.67	A	SW
Askola	700	5.93	-	-
	970	10.25	C	-

	1200	12.48	C	SW

At 700 and 970 ^{0}C, bricks produced from Askola site soil sample, have minimum compressive strength compared with the compressive strengths of bricks produced from Bedabuna. The possible reason for this is due to variation of physical properties of clay soil. At 1200^{0}C, maximum compressive strength is achieved by bricks produced from Bedabuna site soil sample. The possible reason for this is due to Varity of physical properties of clay soil.

4.3.3 Effects of firing Duration

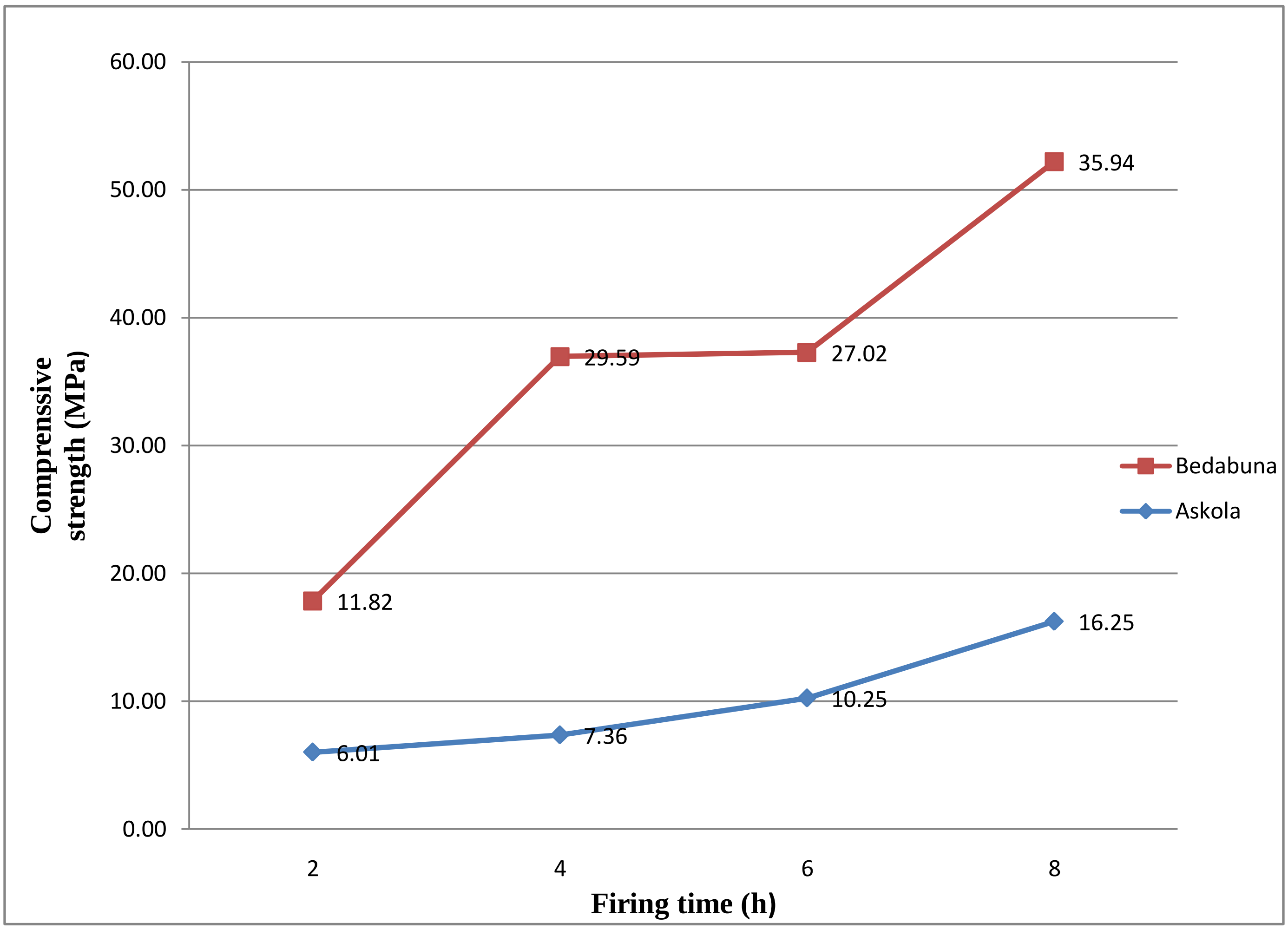


Figure 0-2: Compressive strength of bricks produced a with different firing duration

Firing time (120-480min) is the time that the material was subjected to the firing process at the corresponding firing temperature (700-1100^{0}C).Firing time had no significant effect on the compressive strength. (Karaman, 2006).

However, the average compressive strength of the bricks produced from Bedabuna site soil sample which are fired at a constant temperature of 970^{0}C, rapidly increases as the duration of firing increases but, the average compressive strength of the bricks produced from Askola site soil sample which are fired at a constant temperature of 970^{0}C, slightly increases as the duration of firing increases shown on Fig 4-2. Due to different physical properties of clay soil of the study area.

Table 0-5: Average WA and SC of bricks and their classification.

Raw materials	Firing temperature (^{0}C)	Mean Water absorption of 5 bricks and their classification			Mean saturation coefficients of 5 bricks and their classification		
		WA (%)	ES86:2001)	ASTM	SC	ES 86:2001)	ASTM
Bedabuna	700	8.80	A	SW	0.88	A,B	SW
	970	6.38	A	SW	0.76	A,B	SW
	1200	6.52	A	SW	0.68	A,B	MW
Askola	700	19.64	A	MW	0.84	A,B	MW
	970	17.35	A	SW	0.86	A,B	SW

	1200	10.80	A	MW	0.66	A,B	MW

The average water absorption determined by submersion in water for 24h must be less than 18% (Karaman, 2006). Likewise, in this study, water absorption of both bricks produced at each firing temperature and firing time met the criteria specified by Ethiopia standards according to Table 4-5 and the physical property requirements of fired clay bricks are different in different standard specifications. This is due to the fact that based on the existing weathering conditions; different countries have different physical property requirements of fired clay bricks in their specifications. For instance, lower values of water absorption are required in BS standard specification for classifying clay bricks when compared with ES86:2001 and ASTM standard specifications as discussed in chapter two. In addition to this as shown on Table 4-5; based on mean Water absorption, clay brick which is classified as class A according to ES86:2001 is classified as MW based on ASTM standard specification. These shows that classification of fired bricks based on different standard specifications are different. The clay bricks produced from the same raw materials Bedabuna site fired at 700 ^{o}C as shown on Table 4-4 and 4-5 are classified as class B, A and A, B based on their mean compressive strengths, mean Water absorption and mean saturation coefficient respectively. This is according to the requirement of ES86:2001.

Table 0-6: WA and SC of bricks fired at 970^{0}C but different duration of firing.

Soil sample	Firing temperature (^{0}C)	Firing time(hours)	Mean Water absorption of 5 bricks and their classification			Mean saturation coefficients of 5 bricks and their classification		
			WA (%)	(ES86:2001)	ASTM	SC	(ES 86:2001)	ASTM
Bedabuna	970	2	10.01	A	SW	0.84	A,B	MW
		4	7.92	A	SW	0.69	A,B	SW
		6	6.57	A	SW	0.69	A,B	SW
		8	5.58	A	SW	0.69	A,B	SW
Askola	970	2	37.51	C,D	NW	0.96	A,B	NW
		4	26.31	C,D	NW	0.82	A,B	MW

		6	12.23	A	SW	0.75	A,B	SW
		8	11.89	A	SW	0.72	A,B	SW

As shown in Table 4-5, both the mean water absorption and saturation coefficients are reduced for all the bricks produced from both soils as the firing temperature increases. Moreover, the results of mean water absorption and saturation coefficients of bricks produced from Bedabuna site which are fired at constant temperature of 970^{0}C for different duration are as shown in Table 4-6, shows that as the duration of firing increases, the two physical properties are slightly improved. So, according to this study, the water absorption and saturation coefficients of bricks are improved when both the firing temperature and duration of firing increases within the allowable firing temperature range.

During the production processes of the fired clay bricks from the two site soil samples the sizes of the green bricks, the air dried bricks and the fired bricks are measured. Accordingly, for all the produced bricks as the bricks lose their moisture due to drying and firing, their mean sizes decreases and their mean size of bricks at different stages of productions are listed in Table 4-7.

Table 0-7: Mean Sizes of green bricks, air dried bricks and fired bricks**.**

Brick raw materials	Size of green Bricks (cm)	Mean Size of air dried Bricks (cm)	Firing temperature (^{0}C)	Mean Size of fired Bricks (cm)
Bedabuna	25x12x6	23.2x11.2x5.9	700	22.65x10.58x5.60
			970	22.630x10.54x5.34
			1200	22.60x10.26x5.32
Askola	25x12x6	23.1x11.4x5.7	700	22.64x10.61x5.48
			970	22.62x10.60x5.46
			1200	22.62x10.50x5.44

4.4. Cost of Clay Bricks

Both the surveyed traditional brick productions for this study are only solid face clay bricks of size 25cm x 12cm x 6cm. The productions sales price of face clay bricks is almost the same as shown on Table 4-7. Based on the sales price of the brick productions, the cost of clay bricks produced for this study is shown in Table 4-7. This cost estimate is done by considering the volume of the bricks and, also the quality of clay bricks has been considered.

4.4.1. Brick sales price

According to Brick Products Production micro enterprise, the sales price of clay bricks produced from Bedabuna and Askola brick production kilns is fixed on the basis of the production costs and the profit (Brick Products Production Share Company, 2013.).

A- Production costs: - include the fixed costs, variable costs and administrative costs.

i.Fixed costs: are costs for salary, wages, pension, depreciation, uniforms, insurances, land tax, building tax, etc. It is 25% of the total production cost.

ii. Variable costs: -are costs for fuel and lubricants, repair and maintenance, electricity, material and supply expenses, clinic and sanitation, medical, royalty fee etc. It is 60% of the total production cost.

iii. Administrative costs: - are costs for head office rental fee, salary, insurance, stationary, pension, depreciation, medical and other costs at the head office. It is 15% of the production costs.

B. Profit: - According to the micro enterprise, the profit vary from 18% to 30% of the production cost. The profit varies mainly due to variation of the production costs. The existing micro enterprise price of a piece of Face clay brick produced from Bedabuna and Askola traditional brick productions. is fixed based on the above listed different costs and profit as summarized in Table 4-8**.**

Table 0-8: Sales price of a piece of clay brick by Brick Production micro enterprise.

No.	Description	Birr/one face brick	Remark
	Fixed costs	0.401	It is 25% of the production costs
	Variable costs	0.962	It is 60% of the production costs

Production	Administrative costs	0.24	It is 15% of the production costs
Profit		0.352	It is 18-30% of the production costs
Total production cost		1.955	
	Vat (15%)	0.345	
	Sales price	2.3	

Table 0-9: Cost of clay bricks produced in traditional brick productions.

Types of bricks and sizes	Tradional Factory price(Birr/ one brick)		Remark
	Bedabuna	Askola	
Face brick (25cmx12cmx6cm)	2	2	Only face bricks are produced in both Bedabuna and Askola

Note: The material and labour cost of the produced clay bricks for this study is estimated to be 10 cents per pieces. The minimum cost is due to the fact that the raw materials are not transported from other places. This cost can be minimized because the production takes place near the raw material sources and mass production takes place.

CHAPTER FIVE

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

According to the results of this study,

1) The studied traditional brick productions:

a. Have no temperature sensor device or thermocouple to know their kiln firing temperature. But the degree of firing of clay bricks in these productions. is decided by their kiln operator's. Which results is in over and under fired clay bricks.

b. Have no owned laboratory so that they do not test and know the allowable firing temperature for their raw materials. Also they do not test the physical properties of the fired clay bricks.

So, firing temperature control in these traditional brick productions is poor so that over and under firing of clay bricks are their usual lose.

2) The allowable firing temperature of clay bricks produced from soil sample Bedabuna site is from 970 to 1200^{O}C and with Askola is from 900 to 970^{0}C. As the firing temperature rise within the allowable firing temperature range of these soil samples;

i. The compressive strength of the fired clay bricks produced from these samples increased and;

ii.The water absorption and saturation coefficient of the clay-bricks produced from these sample are reduced.

So, as the firing temperature rises within the allowable firing temperature range of these two soils; the compressive strength, the water absorption and the saturation coefficient of clay bricks produced from them increased, decreased and reduced respectively. Which verify that firing temperature significantly affect these physical requirements of fired clay bricks.

3) For a constant amount of firing temperature, as the duration of firing increased from 2 to 8 h, clay bricks produced from soil sample Askola shows small increment on the mean compressive strength and a small reduction on the average water absorption and saturation coefficients. So, this slight improvement on these physical properties of the clay bricks is achieved by extending the duration of firing which causes wastage of more energy. Therefore, rising the firing temperature within its allowable firing temperature range of the raw materials brings a rapid improvement of these physical properties with an economical production cost than extending the duration of firing.

4) Both clay bricks produced for this study from the two soils at a firing temperature of 970 and 1200 ^{0}C conform the Ethiopian standard specification for solid clay bricks (ES 86:2001). But clay bricks which are fired at 700^{0}C do not fulfill the different requirements of this specification. Moreover, both the clay bricks produced with different amounts of firing temperatures have different values of compressive strength, water absorption and saturation coefficients. Which prove that the physical properties of clay bricks are dependent on the degree of firing temperature below the melting points of their raw materials.

5.2 Recommendations

Based on the findings of this research the following recommendations are forwarded:

1. The concerned governmental body is better to set detail standard specification for traditional clay bricks produced around jimma and throughout Ethiopia in addition to the existing standard specification for solid clay bricks and monitor the traditional clay brick production products accordingly.

2. Production of over and under fired clay bricks in traditional brick production located in and around Jimma can be minimized by:

a) Testing the allowable firing temperature of the raw materials to achieve target physical properties of clay bricks and;

b) Using a temperature sensor device helps to know the amount of firing temperature in the brick kiln. Which minimize under firing, over firing and even melting of the clay bricks. And by implementing these activities, these traditional production kilns can reduce loses so that their production costs can be optimized.

Performing the above activities play a great role for these brick production kilns to meet the different requirements of established standard specifications for clay bricks. Accordingly the clay bricks produced from these production kilns can be used as engineering bricks which are used for the construction of civil structures.

3. In Ethiopia traditional clay bricks are produced in Jimma and recently near Holeta towns only. So, the concerned stakeholders should do much to encourage production of traditional clay bricks in the rural areas. Thus it creates job opportunities and can reduce deforestation for the construction of walls of residential houses.

4. Encouraging both domestic and foreign investment in this sector plays a decisive role for the development of the clay brick sector in Ethiopia. Moreover, it creates competition in terms of quality and cost in this sector.

5.3 Recommended Further Studies

The following further studies are recommended which have their constructive role for the development of the clay brick sector in Ethiopia.

1) Further study to survey the mineralogical content, of clay soil available around Jimma used to make clay bricks. This will be useful to know the exact characteristics and classification of clay bricks available around Jimma.

2) Further study is recommended to locally manufacture a temperature sensor device or thermocouple which will be used by brick productions to control the amount of firing temperature in the kiln.

REFERENCES

A.Bown, P. a. (2013). Sustainability of masonry in construction. *Leeds Metropolitan University, UK.*

Abebe Dinku Adil Zekaria, &. T. (2004.). Assessments of locally produced brick's quality for construction purposes,. *EACE Bulletin Volume.6.No.1,* .

Abebe Dinku. (2002). *Construction materials laboratory manual.* AAU Printing Press.

Abebe Dinku, A. Z. (2004.). Assessments of locally produced brick's quality for construction purposes,. *EACE Bulletin Volume.6.No.1,* .

Adeola, J. (1977). *Areview of masonery block/brick types used for building in nigeria* . university of benin,benin city: unpublished M.Eng.Thesis,.

ASTM C67-90. (1996). *Standard test method fothe properties of fired clay bricks " Annual book of American society for testing and materials.*

Brick making enterprises in Hai Duong, H. Y. (2004.). *vertical shaft continuous kiln (VSCK) in brick making industry,.* Vietnam's thermology science and technique institute.

Brick Products Production Share Company. (2013.). *Verbal communication with Finance and Administration Head of Brick Products.* Addis Ababa,.

brick Specifications for and classification of. (2007.). *Technical notes on brick construction.* Reston, Virginia,: Brick industry association,.

British Standard Institution. (1985.). *British Standard Specification for clay bricks (BS 3921),.*

Companies, T. M.-H. (2004). Masonry design and detailing for Architects and Contractors. *Retrieved from: http://www.digitalengineeringlibrary.com* .

Ethiopian Standards Agency (ESA). (2011). *Solid clay bricks, ES 86:2001, Ethiopian standard, Second edition 2001-06-27,.*

Ethiopian Standards Agency(ESA). (2011.). Solid clay bricks ES 86:2001 Ethiopian standard Second edition. 2001-06-27,.

Franke L and Schoppe I. (1989). deterioration of historical brick buildings. *european symposium on science ,thecnology* , 418-21.

from, R. (dated on February, 4, 2012). *www.answers.com › Library › Technology.*

G. Cultrone E. Sebastian M. J. De la Torre, 1. ((2005)39). Constr. Build. Mater.

Hendry, A. (1991). *Reinforced and Prestressed Concrete.* New York.: Longman.

Hung Yen, D. N. (2004.). *vertical shaft continuous kiln (VSCK) in brick making industry, Brick making enterprises.* Vietnam's thermology science and technique institute.

Jeorge J. Venta, P. (1998.). *Life cycle analysis of brick and mortar products", the ATHENATM Sustainable Material.* Canada, Ottawa,.

Joseph E.Bowles. *Foundation analysis and design.* fifth edition.

Karaman. (2006). Firing Temprature and time influence on clay bricks properties. *Journal of Scietific & Industrial research* , 154-155.

Mbumbia I, D. W. ((2000)). performance characteristics of lateritic soil bricks fired at low tempratures. *case study of cameroon,const Build Mat,* , 121-131.

Mbumbia I, D. W. (14(2000)). performance characteristics of lateritic soil bricks fired at low tempratures. *case study of cameroon,const Build Mat,* , 121-131.

National research council of Canada. (1984). Frost durability of clay bricks - evaluation criteria and quality control,. *division of building research* .

Reston Virginia. (2007). *Technical notes on brick construction.* Specifications for and classification of brick, Brick industry association,.

Retrieved, T. (2012.). *Technology.* www.answers.com › Library ›.

Rimpel, E. (2011.). *Modernization of the Indian brick industry.* Indian: Essen (Germany),.

Rounak Attri2, R. K. (2015). UTILIZATION OF WTP SLUDGE & TEA WASTE IN. *International Journal of Advanced Technology in Engineering and ScienceVolume No 03, Special Issue No. 01,* , 2348 – 7550.

Rounak Attri2, R. K. (March 2015). UTILIZATION OF WTP SLUDGE & TEA WASTE IN. *International Journal of Advanced Technology in Engineering and ScienceVolume No 03, Special Issue No. 01,* , 2348 – 7550.

S.K. Duggal. (2000.). *Building materials, Third edition, Motilal Nehru institute of technology Allahabad (U.P.),.* New Delhi,: New age international (p) Ltd. publishers.

sedat karaman, s. E. (2006). firing time and temprature influence on mechanical and physical properties of clay bricks. *scientific and industrial research* , 153-159.

Syed Ashraful Alam. (2006.). *Use of biomass fuels in the brick-making industries of Sudan.* Finland: Implications for deforestation and greenhouse gas emission, Thesis submitted for M. Sc. Degree in forest ecology, University of Helsinki.

The ASTM Committee on standards. (1999.). *Annual book of ASTM standards, Volume 04.05, " Standard Specification for building bricks (Solid Masonry units made from Clay or Shale)",.* ASTM C 62-97a,.

The brick industry association. (2006.). Technical notes on brick construction. *Centennial Park Drive, Reston, Virginia 20191 / www.gobrick.com/* , 703-620-0010.

The federal Democratic republic of Ethiopia. (2004). *Central Statistical Authority.* Welfare monitoring survey, analytical report.

U.S. Department of the interior bureau of reclamation. (1998). *earth manual.* earth manual, part 1,.

United States government printing Office. (1998). *Earth manual, Part 1, Earth sciences and research laboratory, Geotechnical research technical service center, Third edition.*

wang, X. (2010). *Environmental pollution from rural brick-making operations and their health effects on workers.* China: Northwestern University for nationalities, West of China, Institute of environmental health.

APPENDIX ONE

LABORATORY TEST RESULTS

Computation of Mean Compressive Strength Test Result for Each Type of Bricks

$$\xi = \frac{F_{max}}{A}$$ (Ethiopian Standards Agency(ESA), 2011.)

Where, ξ= compressive strength (MPa)

F= the force at failure (N)

A= the average bearing area (mm^2)

Computation of compressive strength of bricks produced from sample **Bedabuna-700^{0}C**

`No	Dimension(cm)			Area(cm^2)	Failure load (KN)	Compressive strength(Mpa)
	L	**W**	**H**			
1	22.5	10.5	5.4	56.7	80.2	14.14
2	22.5	10.5	6	63	97.4	15.46
3	23	10.8	5.5	59.4	104.5	17.59
4	22	10.4	5.8	60.32	95.6	15.85
5	23	10.7	5.3	56.71	88.9	15.68
					Mean	15.74

Computation of compressive strength of bricks produced from sample **Bedabuna-970^{0}C**

\`No	Dimension(cm)			Area(cm^2)	Failure load (KN)	Compressive strength(Mpa)
	L	**W**	**H**			
			5	52.5	140.4	26.74
2	22.5	10.5	5	52.5	169.9	32.36
3	23.5	10.5	5.5	57.75	160.6	27.81
4	23	10.8	5.2	56.16	130.8	23.29
5	22.5	10.4	6	234	155.4	6.64
Mean						23.37

Computation of compressive strength of bricks produced from sample **Bedabuna-1200^{0}C**

\`No	Dimension(cm)			Area(cm^2)	Failure load (KN)	Compressive strength(Mpa)
	L	**W**	**H**			
1	22.5	10	5.2	52	154.5	29.71
2	22.9	10	5.2	52	170.9	32.87
3	22.3	10.3	5.3	54.59	170.3	31.20
4	23	10	5.3	53	160.5	30.28
5	22.4	11	5.8	63.8	155	24.29
Mean						29.67

Computation of compressive strength of bricks produced from sample **Askola -970^{0}C**

No	Dimension(cm)			Area(cm^2)	Failure load (KN)	Compressive strength(Mpa)
	L	**W**	**H**			
1	22.5	10.2	5.2	53.04	34.2	6.45
2	23	10.9	5.4	58.86	36.4	6.18
3	22.2	10.7	5.3	56.71	27.6	4.87
4	22.7	10.4	5.5	57.2	32.4	5.66
5	22.6	10.5	5.6	58.8	38.1	6.48
					Mean	5.93

Computation of compressive strength of bricks produced from sample **Askola -970^{0}C**

\`No	Dimension(cm)			Area(cm^2)	Failure load (KN)	Compressive strength(Mpa)
	L	**W**	**H**			
1	23.2	10.6	5.5	58.3	45.8	7.86
2	22.1	10.4	5.5	57.2	72.9	12.74
3	23	10.5	5.4	56.7	51.4	9.07
4	22.6	10.8	5.2	56.16	58.2	10.36
5	22.4	10.2	5.8	59.16	66.3	11.21
					Mean	10.25

Computation of compressive strength of bricks produced from sample **Askola -1200^{0}C for 6h**

\`No	Dimension(cm)			Area(cm^2)	Failure load (KN)	Compressive strength(Mpa)
	L	**W**	**H**			
1	23	10.8	5.3	57.24	57.1	9.98

2	22.5	10.6	5.3	56.18	71.2	12.67
3	22.8	10.7	5.4	57.78	84.3	14.59
4	22.6	10.4	5.7	59.28	62.3	10.51
5	22.2	10.5	5.5	57.75	84.5	14.63
Mean						11.82

Computation of compressive strength of bricks produced from sample **Bedabuna -970^{0}C for 2h**

`No	Dimension(cm)		Area(cm^2)		Failure load (KN)	Compressive strength(Mpa)
	L	**W**	**H**			
1	22.7	10.5	5.2	54.6	72.7	13.32
2	22.5	10.7	5	53.5	70.9	13.25
3	22.5	10.1	5.1	51.51	56.3	10.93
4	23	10.2	5.5	56.1	60.2	10.73
5	22.8	10.3	5.8	59.74	65	10.88
Mean						12.48

Computation of compressive strength of bricks produced from sample **Bedabuna -970^{0}C for 4h**

`No	Dimension(cm)		Area(cm^2)		Failure load (KN)	Compressive strength(Mpa)
	L	**W**	**H**			
1	22.4	10.5	5	52.5	147.8	28.15
2	22.4	10.4	4.9	50.96	170.8	33.52
3	22.5	10.3	5	51.5	167.4	32.50
4	22.8	10.8	5.5	59.4	150.2	25.29
5	23	10.6	5.7	60.42	172.1	28.48

Mean	29.59

Computation of compressive strength of bricks produced from sample **Bedabuna -970^{0}C for 6h**

`No	Dimension(cm)			Area(cm^2)	Failure load (KN)	Compressive strength(Mpa)
	L	W	H			
1	22.5	10.5	5	52.5	140.4	26.74
2	22.5	10.5	5	52.5	169.9	32.36
3	23.5	10.5	5.5	57.75	160.6	27.81
4	23	10.8	5.2	56.16	130.8	23.29
5	22.5	10.4	6	62.4	155.4	24.90
					Mean	27.02

Computation of compressive strength of bricks produced from sample **Bedabuna -970^{0}C for 8h**

`No	Dimension(cm)			Area(cm^2)	Failure load (KN)	Compressive strength(Mpa)
	L	W	H			
1	22.6	10.3	5.2	53.56	168.6	31.48
2	22.4	10.1	5.5	55.55	225	40.50
3	22.2	10.5	4.9	51.45	209.7	40.76
4	22.5	10.8	5.5	59.4	190	31.99
5	22.8	10.6	5.8	61.48	215	34.97
					Mean	35.94

Computation of compressive strength of bricks produced from sample **Askola -970^{0}C for 2h**

`No	Dimension(cm)			Area(cm^2)	Failure load (KN)	Compressive strength(Mpa)
	L	**W**	**H**			
1	22	10.2	5.3	54.06	26.7	4.94
2	23.2	10.4	5.3	55.12	42	7.62
3	22.8	10.6	5.4	57.24	29.6	5.17
4	22.6	10.3	5.6	57.68	26.5	4.59
5	22.4	10.5	5.1	53.55	41.5	7.75
					Mean	6.01

Computation of compressive strength of bricks produced from sample **Askola-970^{0}C for 4h**

`No	Dimension(cm)			Area(cm^2)	Failure load (KN)	Compressive strength(Mpa)
	L	**W**	**H**			
1	22.7	10.6	5	53	42.5	8.02
2	22.2	10.5	5.1	53.55	38.5	7.19
3	23.3	10.4	5.2	54.08	39.5	7.30
4	22.5	10.5	5.5	57.75	37.2	6.44
5	22.8	10.2	5.4	55.08	43.1	7.82
					Mean	7.36

Computation of compressive strength of bricks produced from sample **Askola -970^{0}C for 6h**

`No	Dimension(cm)	Area(cm^2)	Failure load (KN)	Compressive strength(Mpa)

	L	W	H			
1	23.2	10.6	5.5	58.3	45.8	7.86
2	22.1	10.4	5.5	57.2	72.9	12.74
3	23	10.5	5.4	56.7	51.4	9.07
4	22.6	10.8	5.2	56.16	58.2	10.36
5	22.4	10.2	5.8	59.16	66.3	11.21
					Mean	10.25

Computation of compressive strength of bricks produced from sample **Askola -970^{0}C for 8h**

`No	Dimension(cm)		Area(cm^2)		Failure load (KN)	Compressive strength(Mpa)
	L	W	H			
1	22.9	10.2	5	51	133.5	26.18
2	23.4	10.5	5.1	53.55	70.6	13.18
3	21.9	10.1	4.9	49.49	70.1	14.16
4	22.5	10.4	5.5	57.2	82.5	14.42
5	22.6	10.6	5.3	56.18	74.6	13.28
					Mean	16.25

Water Absorption and Saturation Coefficient Result of Each Type of Bricks

$$WA(\%) = 100\frac{(W2-W1)}{W1}$$ (Ethiopian Standards Agency(ESA), 2011.)

$$SC = \frac{(W2-W1)}{W3-W1}$$ (Ethiopian Standards Agency(ESA), 2011.)

Where, W_1 is the dry mass of sample,

W_2 is the mass of saturated sample after 24 h immersion in cold water (gm),

W_3 is the mass of saturated sample after 5 h immersion in boiling water (gm),

WA is the water absorption of the bricks and (gm), SC is the saturation coefficient.

Water absorption and saturation coefficients of bricks from sample **Bedabuna** fired at 700^0C

No.	W1(gm)	W2(gm)	W3(gm)	WA (%)	SC
1	1.675	1.815	1.855	8.36	0.78
2	1.59	1.725	1.755	8.49	0.82
3	1.65	1.78	1.8	7.88	0.87
4	1.6	1.78	1.78	11.25	1.00
5	1.62	1.75	1.756	8.02	0.96
			Mean	8.80	0.88

Water absorption and saturation coefficients of bricks from sample **Bedabuna** fired at 970^0C

No.	W1(gm)	W2(gm)	W3(gm)	WA (%)	SC
1	1.645	1.765	1.805	7.29	0.75
2	1.6	1.7	1.755	6.25	0.65
3	1.61	1.71	1.76	6.21	0.67
4	1.58	1.705	1.753	7.91	0.72
5	1.62	1.7	1.751	4.94	0.61
Mean				6.52	0.68

Water absorption and saturation coefficients of bricks from sample **Bedabuna** fired at 1200^0C

No.	W1(gm)	W2(gm)	W3(gm)	WA (%)	SC
1	1.645	1.765	1.805	7.29	0.75
2	1.605	1.725	1.76	7.48	0.77
3	1.58	1.65	1.71	4.43	0.54
4	1.61	1.745	1.75	8.39	0.96
5	1.63	1.7	1.72	4.29	0.78
Mean				6.38	0.76

Water absorption and saturation coefficients of bricks from sample **Askola** a fired at 700^0C

No.	W1(gm)	W2(gm)	W3(gm)	WA (%)	SC
1	1.5	1.775	1.785	18.33	0.96
2	1.495	1.73	1.835	15.72	0.69
3	1.49	1.78	1.8	19.46	0.94
4	1.52	1.772	1.782	16.58	0.96
5	1.5	1.75	1.825	16.67	0.77
Mean				19.64	0.84

Water absorption and saturation coefficients of bricks from sample **Askola** fired at 970^0C

No.	W1(gm)	W2(gm)	W3(gm)	WA (%)	SC
1	1.49	1.715	1.805	15.10	0.71
2	1.6	1.695	1.76	5.94	0.59
3	1.5	1.71	1.8	14.00	0.70
4	1.55	1.705	1.79	10.00	0.65
5	1.56	1.7	1.77	8.97	0.67
Mean				17.35	0.86

Water absorption and saturation coefficients of bricks from sample **Askola** fired at 1200^0C

No.	W1(gm)	W2(gm)	W3(gm)	WA (%)	SC
1	1.46	1.915	1.97	31.16	0.89
2	1.625	1.72	1.78	5.85	0.61
3	1.5	1.9	1.95	26.67	0.89
4	1.54	1.85	1.9	20.13	0.86
5	1.6	1.83	1.85	14.38	0.92
Mean				10.8	0.66

Water absorption and saturation coefficients of bricks from **Bedabuna** site fired at 970^0C for 2h

No.	W1(gm)	W2(gm)	W3(gm)	WA (%)	SC

1	1.59	1.8	1.81	13.21	0.95
2	1.61	1.73	1.76	7.45	0.80
3	1.65	1.82	1.85	10.30	0.85
4	1.52	1.71	1.79	12.50	0.70
5	1.67	1.78	1.79	6.59	0.92
Mean				10.01	0.84

Water absorption and saturation coefficients of bricks from **Bedabuna** site fired at 970^{0}C for 4h

No.	W1(gm)	W2(gm)	W3(gm)	WA (%)	SC
1	1.62	1.75	1.81	8.02	0.68
2	1.595	1.72	1.765	7.84	0.74
3	1.61	1.74	1.8	8.07	0.68
4	1.6	1.73	1.79	8.12	0.68
5	1.59	1.71	1.77	7.55	0.67
Mean				7.92	0.69

Water absorption and saturation coefficients of bricks from **Bedabuna** site fired at 970^{0}C for 6h

No.	W1(gm)	W2(gm)	W3(gm)	WA (%)	SC
1	1.59	1.71	1.74	7.55	0.80
2	1.6	1.7	1.755	6.25	0.65
3	1.61	1.71	1.76	6.21	0.67
4	1.58	1.705	1.753	7.91	0.72
5	1.62	1.7	1.751	4.94	0.61
Mean				6.57	0.69

Water absorption and saturation coefficients of bricks from **Bedabuna** site fired at 970^{0}C for 8h

No.	W1(gm)	W2(gm)	W3(gm)	WA (%)	SC
1	1.68	1.81	1.855	7.74	0.74
2	1.6	1.695	1.74	5.94	0.68
3	1.67	1.8	1.85	7.78	0.72

4	1.65	1.69	1.73	2.42	0.50
5	1.62	1.685	1.7	4.01	0.81
Mean				5.58	0.69

Water absorption and saturation coefficients of bricks from **Askola** site fired at 970^0C for 2h

No.	W1(gm)	W2(gm)	W3(gm)	WA (%)	SC
1	1.64	2.35	2.38	43.29	0.96
2	1.655	2.25	2.3	35.95	0.92
3	1.71	2.19	2.21	28.07	0.96
4	1.68	2.35	2.37	39.88	0.97
5	1.66	2.33	2.34	40.36	0.99
Mean				37.51	0.96

Water absorption and saturation coefficients of bricks from **Askola** site fired at 970^0C for 4h

No.	W1(gm)	W2(gm)	W3(gm)	WA (%)	SC
1	1.62	2.09	2.105	29.01	0.97
2	1.52	1.695	1.75	11.51	0.76
3	1.35	2.05	2.1	51.85	0.93
4	1.42	1.65	1.8	16.20	0.61
5	1.48	1.82	1.9	22.97	0.81
Mean				26.31	0.82

Water absorption and saturation coefficients of bricks from **Askola** site fired at 970^0C for 6h

No.	W1(gm)	W2(gm)	W3(gm)	WA (%)	SC
1	1.49	1.8	1.805	20.81	0.98
2	1.6	1.695	1.76	5.94	0.59
3	1.55	1.71	1.8	10.32	0.64
4	1.56	1.7	1.79	8.97	0.61
5	1.52	1.75	1.77	15.13	0.92
Mean				12.23	0.75

Water absorption and saturation coefficients of bricks from **Askola** site fired at 970^{0}C for 8h

No.	**W1(gm)**	**W2(gm)**	**W3(gm)**	**WA (%)**	**SC**
1	1.43	1.62	1.685	13.29	0.75
2	1.525	1.72	1.79	12.79	0.74
3	1.48	1.64	1.7	10.81	0.73
4	1.5	1.66	1.73	10.67	0.70
5	1.51	1.69	1.76	11.92	0.72
Mean				11.89	0.72

APPENDIX TWO

QUESTIONNAIRES FOR INTERVIEW

Introduction

I. You are kindly requested to give detailed information.

II. You are not obliged to answer questions, which you do not want to.

1-Company Profile

Name of the company________________________________

Average number of worker for the recent 5 years:

Total____________

Female__________

Male____________

Annual production capacity: Total production capacity________________________

Types of brick produced ____________, ___________, _________ _____________,

______________, _________________.

2- Material

- What are the raw materials you used for the brick manufacturing?

  ____

- Where is the source of materials? ___________________________________
- How do you select and test the raw materials?

  ____

- Please list any problem related to material production and utilization?

  ____

- Is there any cost that you pay for the raw materials?

  If yes, what is the amount?

____

If no, ____

3- Material Preparation, Blending, Proportion

- ❖ What are the main activities to be done in raw materials preparation**?**
- ❖ How do you blend the raw materials and what is their proportion?

  ____

- ❖ What proportion of water you use for mixing the blended raw materials how do you blend the raw materials and what is their proportion?

  ____

4- Production Processes

- ❖ What are the steps for brick production? ______________________________

  ____

- ❖ Which step is a critical step in brick production? Why?

  ____

5- Firing during Production

- ❖ What are the steps of firing the bricks?

  ____

- ❖ What are the energy sources for firing?

  ____

- ❖ How long you fire bricks during production? __________________________
- ❖ How do you control the amount of temperature during firing?

  ____

- ❖ What is the effect of firing temperature in brick production?

  ____

6. **General questions:**

- ❖ What are the social, political and economical problems you encountered?

  ____

  ____

- ❖ Is there any market problem?

  ____

  ____

- ❖ Do you test the quality of the end product?

  If yes, what types of tests are done? __________, ___________, _________

  _________________, ______________________,___________________

- ❖ What is your opinion about the quality of bricks produced in Ethiopia?

  ____

This is the end of the Questionnaire: THANK YOU!!

APPENDIX THREE

LISTS OF PHOTOS

Photo-1 Inspection of fired Bricks in production kiln

photo-2 measuring compressive strength

Photo-3 Inspection of traditional brick kilns

Photo-4 soil sampling for physical property test

Photo-5 Immersion of bricks for 24h in to water

Photo-6 firing of clay bricks in furnace

Photo-7 under burned brick kilns

Photo-8 over burned clay brick kilns

Photo-9 Traditional piling of brick for firing

photo-10 high temperature furnace

Photo-11 Naming of bricks for identification

Photo-12 Askola soil sample for physical test

Photo-13 Broken bricks in Askola bricks production kilns

Photo-14 Wood molding of Brick

Photo-15 Air dried Bricks

Photo-16 Cooling traditional fired brick