



EFFECTS OF FIRING TEMPERATURE ON SOME PHYSICAL PROPERTIES OF BURNT CLAY BRICKS PRODUCED AROUND ADDIS ABABA

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This is to certify that the thesis prepared by Altayework Tadesse, entitled: *Effects of Firing Temperature on some Physical Properties of Burnt Clay Bricks Produced around Addis Ababa* and submitted in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering (Construction Technology and Management) complies with the regulations of the University and meets the accepted standards with respects to originality and quality.

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ABBREVIATIONS

AAiT	Addis Ababa Institute of Technology
AAU	Addis Ababa University
ASTM	The American Society for Testing and Materials.
BF	Brick factory
BS	British standard
CSA	Central Statistical Authority
ESA	Ethiopian Standards Agency.
ES	Ethiopian Standards
LL	Liquid limit
PL	Plastic limit
PI	Plasticity index
SC	Saturation coefficient
VSK	Vertical shaft continuous kiln
WA	Water absorption

ABSTRACT

Controlling the firing temperature during clay bricks production plays a decisive role in both quality and production costs. The principal aim of this research is therefore to study the effects of different firing temperature on the compressive strength, water absorption and saturation coefficients of fired clay bricks produced around Addis Ababa. Moreover, the firing temperature management practices of some brick factories in and around Addis Ababa are also surveyed.

The raw materials for this study were sampled from two quarries and clay bricks are produced from four blended soil samples. The physical property requirements of these clay bricks which are fired at three different firing temperatures and fired for different duration of firing are tested and analyzed.

Interview questionnaires are designed to study the firing temperature management practices of some brick factories in and around Addis Ababa. In addition to the interview, observational based study is conducted by visiting their production processes.

The outputs of this study show that with increment of firing temperature within the optimum 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 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 are their usual lose. 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.

Key words: Physical property requirements, Firing temperature, Compressive strength, Water absorption, Saturation coefficient, Firing temperature management.

CHAPTER ONE

1. 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 [1].

At the time of its invention, clay bricks were shaped with hand and dried with sun light. Kiln-fired clay bricks did not appear until 3000 B.C., long after the art of pottery had demonstrated the effects of high temperatures on clay [1].

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.

The energy required for firing of clay bricks by different kilns is different. Traditional methods of firing consume much energy. In the recent technology of clay bricks production, the application of vertical shaft continuous kiln (VSCK) brings high economic effectiveness but requiring small investment compared to the traditional ones. VSCKs have high capacity and can reduce 50% the amount of energy consumption. Products quality is higher than the standard level [2].

In Ethiopia 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 colour. 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.

1.2 PROBLEM STATEMENT

Most of the clay brick factories in and around Addis Ababa 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 factories.

One of the main 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 factories, 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 OBJECTIVE OF THE THESIS

The objective of this study is to determine the effects of firing temperature on the compressive strength, water absorption and saturation coefficient of burnt clay bricks. And the following question will be addressed with this study.

How the brick factories in and around Addis Ababa control the firing temperature during production of clay bricks?

1.4 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 optimum 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 optimum 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 optimum firing temperature for a known raw material in clay brick production is an important duty to be done.

1.5 REPORT STRUCTURE

This thesis is divided into five major chapters. The first chapter is the introduction part which includes back ground of the problem, objective 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, interview questionnaires, study of the brick factories in and around Addis Ababa and method of reporting the results.

In chapter four, the responses of the interviewee's and the laboratory test results are summarized and discussed. Chapter five includes conclusions, recommendations and recommendations for further studies.

CHAPTER TWO

2. 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. It is treated in a kiln at an elevated temperature to harden, so as to give it mechanical strength and to provide it with resistance to moisture; after being removed from the kiln, the brick is said to be burnt, hard-burnt, kiln-burnt, fired, or hard-fired [3]. 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 [4].

2.2 HISTORY OF CLAY BRICKS PRODUCTION

It has been reported in literatures that the first clay brick was probably made in the Middle East, between the Tigris and Euphrates rivers in Iraq. In other regions it used for permanent structures, early builders relied on the abundant natural materials to make their sun-baked bricks. These, however, were of limited use because they lacked durability and could not be used outdoors; exposure to the elements caused them to disintegrate. The Babylonians, who later dominated Mesopotamia, were the first to fire bricks, from which many of their tower-temples were constructed.

From the Middle East the art of brick making spread west to Egypt and east to Persia and India. Although the Greeks, having a plentiful supply of stone, did not use much brick, evidence of brick Kilns and structures remains throughout the Roman Empire. However, with the decline and fall of Rome, brick making in Europe soon diminished. It did not resume until the twelfth century, when the Dutch made bricks that they seem to have exported to England. In the Americas, people began to use brick during the sixteenth century. It was the Dutch, however, who were considered expert craftsmen [5].

Prior to the mid-1800s, people made bricks in small batches, relying on relatively inefficient firing methods. One of the most widely used was an open clamp, in which bricks were placed on a fire beneath a layer of dirt and used bricks. As the fire died down over the course of several weeks, the bricks fired. Such methods gradually became obsolete after 1865, when the Hoffmann kiln was invented in Germany. Better suited to the manufacture of large numbers of bricks, this kiln contained a series of compartments through which stacked bricks were transferred for pre-heating, burning, and cooling.

Brick making improvements have continued into the twentieth century. Improvements include rendering brick shape absolutely uniform, lessening weight, and speeding up the firing process. For example, modern bricks are seldom solid. Some are pressed into shape, which leaves a frog, or depression, on their top surface. Others are extruded with holes that will later expedite the firing process by exposing a larger amount of surface area to heat. Both techniques lessen weight without reducing strength [5].

Even if there is no recorded production history of clay bricks in Ethiopia, according to the response of the interviews for this study, it is associated with the history of brick factories found in Addis Ababa. The history of clay bricks production in Ethiopia is about 60 years old and is linked with the clay bricks production by George Nicola brick factory which is the oldest brick factory in Addis Ababa [6].

The available brick factories in and around Addis Ababa are:

- i. Ethio and Burayu brick factories which are located in Burayu town along the asphalt road Addis Ababa to the town administration office;
- ii. Asefa & Genbrie brick factory found in Addis Ababa, at a place called Birchiko which is located along the asphalt road Addis Ababa to Asco;

- iii. George Nikola Brick factory found in Addis Ababa, at a place called Birchiko which is located along the asphalt road Addis Ababa to Asco;
- iv. Tatek Brick factory (located near Menagesha town) which was constructed by Chinese but now it is owned by domestic private company and
- v. There is one factory in Alemgena town located along the asphalt road to Jimma, almost 15km from Addis Ababa which is owned by Chinese private company.

Among these factories, three are found in Burayu town and the rest two are found in Addis Ababa, near Burayu town. From this we can say that Burayu town has sufficient raw material sources for brick production.

According to the assessments of locally produced Brick's quality for construction purposes in 2004, the classification of clay bricks produced in Burayu and Ethio brick factories are summarized and listed in Table 2-1 [7].

Table 2-1 Test results of clay bricks produced in Burayu and Ethio brick factories [7].

No.	Types of tests done	Results	Classifications of bricks according to Ethiopian standard
1	Mean compressive strength.	12.35Mpa	C
2	Mean water absorption.	18.83%	A & B

According to this study; the production processes in these factories is 50 years older than the recent technology, there is no proper raw material selection, blending and the burning process is not complete which highly affect the products quality.

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 [8].

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 [9].

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 [2].

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 [10].

In South Africa 4 billion pieces of clay bricks are produced annually [11]. 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. Modern brick production where fuel oil is used covers less than 2% of the total annual brick production [12].

The annual clay bricks produced in factories found in and around Addis Ababa is not more than 30 million pieces. This quantity is very small when compared to the amount produced in other countries as shown on Table 2-2. Most of the brick factories are located in and around Addis Ababa. Moreover, clay bricks are transported hundreds of kilometers from these factories to regional cities. Traditional clay bricks are also produced in Oromia Regional state, around Jimma and recently near Holeta towns. The annual clay bricks produced in some countries are summarized as shown in Table 2-2.

Table 2-2 Annually produced fired clay bricks in some countries.

No.	Country	Annually produced number of fired clay bricks (in billions)	Percentage from the world annual amount of fired clay bricks production (%)
1	China (by 2008 year)	243	54
2	India	140	31.1
3	Vietnam	9.2	2.04
4	UK	2.5	0.56
5	South Africa	4.0	0.89
6	Sudan	2.8	0.62
7	Ethiopia	About 0.03	0.0067

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 in Tables 2-3. Even if this analytical report is presented before 9 years, significant changes are not done until now. Based on this analytical

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 [13].

Table 2-3 - Distribution of Households by Construction Material of Walls of a Dwelling Unit and Place of Residence [13].

<i>Material of walling</i>	<i>Place of Residence</i>		
	<i>Country (%)</i>	<i>Rural (%)</i>	<i>Urban (%)</i>
<i>Wood and Mud</i>	<i>76</i>	<i>74.8</i>	<i>82.4</i>
<i>Wood and Thatch</i>	<i>7.8</i>	<i>9.1</i>	<i>1.0</i>
<i>Reed/Bamboo</i>	<i>3.3</i>	<i>3.9</i>	<i>0.4</i>
<i>Stone and Mud</i>	<i>8.7</i>	<i>9.1</i>	<i>6.3</i>
<i>Stone and Cement</i>	<i>0.7</i>	<i>0.0</i>	<i>4.3</i>
<i>Hollow Blocks</i>	<i>0.5</i>	<i>0.1</i>	<i>3.1</i>
<i>Bricks</i>	<i>0.1</i>	<i>-</i>	<i>0.4</i>
<i>Others</i>	<i>2.8</i>	<i>2.9</i>	<i>2.1</i>

2.3 RAW MATERIALS FOR BURNT CLAY BRICKS MANUFACTURING

2.3.1 Raw materials

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 [1].

2.3.2 Clay Types

According to different literatures, clay soils are classified into surface clays, shale and fire clays. Their unique properties are listed in Table 2-3 [1].

Table 2-4. Types of clay soils and their properties [1].

CLAY SOIL TYPES	PROPERTIES	REMARK
Surface clay	<ul style="list-style-type: none"> - Found close to the earth's surface. - It is the most accessible and simply mined. So, it is the least expensive clay soil. - Has high oxide content, ranging from 10 to 25%. ** 	-This type of clay soils are usually preferred by brick factories due to their least price but require blending with other clay soils which have less oxide content.

Shale	<ul style="list-style-type: none"> -It is a metamorphic form of clay hardened and layered under natural geologic conditions. - It 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	<ul style="list-style-type: none"> - Found at greater depths than either surface clay or shale. - It generally has fewer impurities, more uniform chemical and physical properties, and only 2 to 10% oxides.** - 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 refractory quality makes fire clay best suited to produce brick for furnaces, fireplaces, flue liners, ovens, and chimney stacks. 	<ul style="list-style-type: none"> - Since fire clays are available at greater depth, it is expensive for exploration.

** The significance of the oxide contents of brick clay is described in section 2.3.3 of this chapter.

Therefore, most brick manufacturers use surface clays which have comparatively higher oxide content. Using surface clays reduce raw material exploration cost but blending of these surface clays with other clay soils which have lower oxide content can adjust the

oxide contents of these raw materials within the desired limit. Moreover, it adjusts their physical properties.

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 150+.
- 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 [14].

2.3.3 Clay Mineralogical Composition

As described in sub-section 2.3.1 of this chapter, mineralogical content of a clay soil is one of the most important factors which determine the quality of burnt clay bricks. Clays are mainly composed of silica and alumina with varying amounts of metallic oxides and other minor ingredients and impurities. Even if metallic oxides are impurities, they act as fluxes to promote fusion of clay particles at lower temperatures, influence the range of temperatures in which the material vitrifies, and give burnt clay bricks the necessary strength for structural purposes. The varying amounts of iron, calcium, and magnesium oxides also influence the color of fired clay [1].

So, selection of raw material is an important task to be accomplished. Moreover, the mineralogical composition of brick clay may vary with in a quarry when we go deeper during exploration. Therefore, it requires continuous testing of the raw materials or clay mineralogical compositions in the laboratory during production.

The mineralogical compositions of a good brick raw material or clay are summarized in Table 2-5 [15]:

Table 2-5 Ingredients/oxides of a good clay brick

No.	Ingredients/oxides	Proportions (%)	Remark
1	Silica (SiO_2)	50–60%	
2	Alumina (Al_2O_3)	20–30%	
3	Lime (CaO)	10%	
4	Magnesia (MgO)	< 1%	The sum of these ingredients is less than 20%
5	Ferric oxide (Fe_2O_3)	< 7%	
6	Alkalis (NaOH, KOH, ...)	< 10%	
7	Carbon dioxide (CO_2)		Very small percentage
8	Sulphur trioxide (SO_3)		
9	Water (H_2O)		

The functions of the various ingredients or oxides are [15]:

Silica (SiO_2): It enables the brick to retain its shape and imparts durability, prevents shrinkage and warping. Excess of silica makes the brick brittle and weak on burning. A large percentage of sand or uncombined silica in clay is undesirable. However, it is added to decrease shrinkage in burning and to increase the refractoriness of low alumina clays.

Alumina (Al_2O_3): Absorbs water and renders the clay plastic. If alumina is present in excess of the specified quantity, it produces cracks in brick on drying.

Lime (CaO): Normally constitutes less than 10 per cent of clay. Lime in brick clay has the following effects:

1. Reduces the shrinkage on drying.
2. Causes silica in clay to melt on burning and thus helps to bind it.
3. In carbonated form, lime lowers the fusion point.
4. Excess of lime causes the brick to melt and the brick loses its shape.

Magnesia (MgO): rarely exceeding 1% affects the colour and makes the brick yellow, in burning; it causes the clay to soften at slower rate than in most case is lime and reduces warping.

Iron (Fe_2O_3): Iron oxide constituting less than 7 per cent of clay, imparts the following properties:

1. Gives red colour on burning when excess of oxygen is available and dark brown or even black colour when oxygen available is insufficient; however, excess of ferric oxide makes the brick dark blue.
2. Improves impermeability and durability.
3. Tends to lower the fusion point of the clay, especially if present as ferrous oxide.
4. Gives strength and hardness.

2.4 PROCESSES OF FIRED CLAY BRICKS PRODUCTION

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 [16].

2.4.1 Mining and storage of raw materials

Usually most brick factories are located close to raw material supplies. This is due to the fact that their profitability is mainly dependent on their production costs. The production cost of brick includes [17]:

- Capital Expenditures, including the costs of equipment and its installation;
- Energy Costs, which are the costs for firing of bricks.
- Labor Costs, including the costs associated with employees wages and benefits and
- The Cost of materials, which are the costs of material inputs such as clay minerals, parts, and additives.

Reduction of raw materials mining cost needs a proper planning before and during production. That is the reason why most brick factories are built near the raw material sources. Moreover, continuous brick production regardless of weather conditions is ensured by storing sufficient quantities of raw materials required for many days of operation.

2.4.2 Preparation.

Preparation includes drying with air, blending, mixing and crushing of the raw materials. Crushing of the raw materials is done to reduce the over sized particles of the raw materials. The crushed particles are then sieved to get a well graded raw material. The fineness of the clay influences not only the external appearance of the finished clay bricks but also physical characteristics such as compressive strength and water absorption.

2.4.3 Forming.

Tempering is the first step in the forming processes, produces a homogeneous, plastic clay mass. Usually, this is achieved by adding water to the clay until it becomes plastic which makes it to be shaped to the desired sizes. There are three principal processes for forming clay-bricks: stiff-mud, soft-mud and dry-press [1].

2.4.3.1 Soft-Mud Process – This method is suitable for clays having more index of plasticity and the amount of water used for mixing the clay soils is 20 to 30%.

2.4.3.2 Stiff-Mud Process - In this process, the amount of water used for mixing the clay soils is in the range of 10 to 15%. In the process of mixing, after tempering is done, the tempered clay goes through a de-airing chamber that preserves a vacuum or in manually production, properly mixed plastic sample is compacted in the formwork. 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 mould to produce a column of clay. As the clay column leaves the mould, textures or surface coatings may be applied. An automatic cutter then slices through the clay column to generate the individual brick. Cutter spacing's and mould sizes must be carefully calculated to compensate for normal shrinkage that occurs during drying and firing.

2.4.3.3 Dry-Press Process - This process is chiefly suited to clays of very low plasticity. Clay is mixed with a minimum amount of water (up to 10 percent), then pressed into moulds 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.

Green bricks contain large percentage of moisture, depending upon the forming method. Before the firing process begins, most of this moisture is evaporated in dryer

chambers or they can be dried in open shed where there is sufficient place for drying.

2.4.5 Firing and cooling

2.4.5.1 Definition of firing

Standard terminology of structural clay products of ASTM C 43-98a express firing as follows [18]: -

Firing, - is a process of heating material to elevated temperatures. The temperatures are usually in excess of 930°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 firing temperature should be in excess of 930°C, 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, the greater the extent of bonding and consequently the greater the developed strength and 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.

Since frost resistance generally increases with greater firing temperature, it is advantageous for the industry to optimize the firing conditions [19]. Burning is accomplished by controlled firing in a kiln to achieve fusion of the clay particles and hardening of the bricks. Since so many of the properties of clay-bricks depend on the method and control of firing, the development over the years of more sophisticated kilns have been instrumental in improving the quality and durability of clay bricks.

Different types of kilns are used in the brick industry and their classification is as shown in Table 2-5.

Table 2-6 Classification of Brick kilns [20].

No.	Types of Brick kilns		
	Intermittent (batch) Kilns	Continuous kilns	
		Moving fire annular kilns	Moving ware kilns
1	Clamp	Bull's trench kiln (BTK)	Tunnel
2	Scove	Zigzag etc.	Vertical Shaft (VSBK)
3	Scotch		
4	Downdraught		

2.4.5.2 Firing temperature management in bricks kiln

Clay brick firing is an energy demanding process requiring large quantities of energy

source. The energy sources for firing of clay-bricks includes; old tires, used oil, wood, and all kinds of residential and industrial waste materials, Organic wastes such as sugar bagasse, Old rubbers, coal, etc. Selection of these sources depends on their availability and price.

The firing cost of clay bricks can be optimized by controlling the amount of temperature in the brick kiln. Over burning of clay bricks not only consume much energy which results in increment of production cost but also affect the quality of the clay bricks. Under burning of bricks results in poor quality bricks which makes them to be broken easily. Both over and under burning of bricks are resulted from poor firing temperature management.

Controlling the degree of firing in recent method of production is done by using a temperature sensor or thermocouple in the kiln. But in traditional methods of brick production, the degree firing is decided by the technicians who follow the firing process through the inspection hole on the brick kiln.

2.4.5.3 Stages of firing

The most common stages of clay brick firing are [1]:

- i. Dehydration – In this stage of firing, removal of water occurs.
- ii. Oxidation-Burning of carbonaceous material takes place.
- iii. Vitrification- in this stage, the mixed and shaped clay material is irreversibly changed into a hard, glassy and durable material called fired clay brick. A clay particle does not develop its full strength until it has vitrified. The vitrification range starts at about 900 °C and extends up to the highest temperature the clay can without melting. Depending upon the kind of clay minerals and the impurities present, the upper temperature limit of the vitrification ranges may vary from 1000 °C to 1500°C. During the vitrification period the porosity of the mass decreases and its strength and hardness increases [21].

2.4.5.4 *Physical and Chemical Reactions during clay-brick firing.*

Throughout the process of firing of clay-bricks, a series of physical and chemical changes takes place. The important physical and chemical changes during clay-bricks firing are summarized in Table 2-6.

Table 2-7 Important physical and chemical reactions during clay-brick firing [22].

No.	Firing temperature (°C)	Physical and Chemical reactions
1	30-150	Drying of clay-bricks
2	150-320	Dehydration of clay mineral by removal of combined water
3	350-450	Burn-out of carbonaceous matter
4	500-600	Breakdown of clay mineral structure with simultaneous transformation of quartz accompanying volume expansion
5	538 - 982	Oxidation takes place [9]
6	900- 1000	Sintering and vitrification leading to development of fired strength

Clay, unlike metal, softens slowly and melts or vitrifies gradually when subjected to rising temperatures. Melting of the mixed and shaped clay during firing takes place in three stages [16]:

- a. *Incipient fusion*, when the clay particles become sufficiently soft to stick together in a mass when cooled;
- b. *Vitrification*, when extensive fluxing occurs and the mass becomes tight, solid and nonabsorbent; and
- c. *Viscous fusion*, when the clay mass breaks down and become molten, leading to a deformed shape.

The key to the firing process is to control the temperature in the kiln so that incipient fusion and vitrification occur but viscous fusion should be avoided.

2.4.5.5 Cooling- It is the final stage of firing in which the fired clay brick will be cooled.

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 factories use old machine and methods of production.

2.5 TESTS DONE DURING PRODUCTION

2.5.1 Tests for mineralogical composition of the raw materials

As discussed in this chapter, the quality of clay-bricks is directly dependent on the raw material mineralogical composition. Based on this fact, it becomes essential to test the mineralogical composition of the raw materials. Moreover, to achieve the required mineralogical composition limit of the raw materials, it becomes necessary to blend the raw materials [23].

2.5.2 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 [24].

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 its plastic state.

2.5.3. 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 [25]. 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.

2.5.4 Tests for Specific gravity of the raw materials

Specific gravity is defined as the ratio between the density of a substance and the density of water at 4⁰C. 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 [25]. Values of specific gravity are as high as 3.0 and as low as 2.3 to 2.4 are not uncommon [14].

2.5.5 Tests for fired clay-bricks

2.5.5.1 Tests for compressive strength

Compressive strength is an important property of clay bricks which is used as an indicator of masonry strength and as a result, brick strength has become an important requirement in brickwork design. A considerable amount of past research and studies on masonry indicated that stronger bricks contribute to greater brickwork strength [26]. Compressive strength is the resistant to compression of bricks and is measured in the

laboratory by applying perpendicular load to the largest face.

2.5.5.2 Tests for water absorption

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. Absorption of water depends on clay properties, manufacturing process and burning. Absorption determines the durability of clay bricks. High absorption capacity causes mortar to be dry & results in incomplete hydration of cement in the mortar. So, the bond strength between the mortar and the brick reduced [27].

2.5.5.3 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. [1] 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 [28].

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 [29].

2.6 STANDARD SPECIFICATIONS FOR CLAY BRICKS

The physical property requirements of burnt clay bricks in most specifications are compressive strength, water absorption and saturation coefficient. Moreover, the minimum compressive strength, maximum water absorption and maximum saturation coefficient are used in combination to predict the durability of the clay bricks in use [29].

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.

In different specifications, the main parameter for classifying clay bricks is their physical requirements. For instance, according to ASTM C 62- 97a, clay bricks are classified based on their compressive strength, water absorption and Saturation coefficients. BS also classifies clay bricks based on their compressive strength and water absorption. Likewise Ethiopian standard specification for Clay Bricks - Solid Clay Bricks (ES 86:2001) uses these physical requirements for classifying solid fired clay bricks.

2.6.1 Ethiopian standard specification

The former Ethiopian standard specification for solid clay bricks (ES 86:1990) was formally replaced by another designation ES- 86:2001 [30].

2.6.1.1 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 2-7.

Table 2-8 Minimum compressive strength of solid clay-bricks (ES 86:2001).

<i>Class</i>	<i>Minimum compressive strength</i>	
	<i>Average of 5 bricks</i>	<i>Individual brick</i>
	<i>N/mm²</i>	<i>N/mm²</i>
<i>A</i>	<i>20</i>	<i>17.5</i>
<i>B</i>	<i>15</i>	<i>12.5</i>
<i>C</i>	<i>10</i>	<i>7.5</i>
<i>D</i>	<i>7.5</i>	<i>5.0</i>

2.6.1.2 Tests for water absorption

According to Ethiopian standard, based on their water absorption, bricks are classified as shown in Table 2-8.

Table 2-9 Maximum water absorption of solid clay-bricks (%), (ES 86:2001)

<i>Class</i>	<i>After 24 hour immersion</i>		<i>After 5 hour boiling</i>	
	<i>Average of 5 bricks</i>	<i>Individual brick</i>	<i>Average of 5 bricks</i>	<i>Individual brick</i>
<i>A</i>	<i>21</i>	<i>23</i>	<i>22</i>	<i>24</i>
<i>B</i>	<i>22</i>	<i>24</i>	<i>23</i>	<i>24</i>
<i>C, D</i>	<i>No limit</i>	<i>No limit</i>	<i>No limit</i>	<i>No limit</i>

2.6.1.3 Test for saturation coefficient

According to Ethiopian standard, based on their Saturation coefficients, bricks are classified as shown in Table 2-9.

Table 2-10 Maximum Saturation coefficients of solid clay bricks (ES 86:2001)

<i>Class</i>	<i>Average of 5 bricks</i>	<i>Individual brick</i>
<i>A, B</i>	<i>0.96</i>	<i>0.99</i>
<i>C, D</i>	<i>No limit</i>	<i>No limit</i>

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

According to BS 3921, bricks are classified based on their compressive strength and water absorption as discussed in Table 2-10.

Table 2-11 Classification of clay bricks by compressive strength and Water absorption (BS 3921: 1985) [31].

<i>No.</i>	<i>Classes of clay bricks</i>	<i>Compressive strength (N/mm²)</i>	<i>Water absorption (% by mass)</i>
<i>1</i>	<i>Engineering A</i>	<i>>70</i>	<i><4.5</i>
<i>2</i>	<i>Engineering B</i>	<i>>50</i>	<i><7.0</i>
<i>3</i>	<i>Damp-proof course 1</i>	<i>>5</i>	<i><4.5</i>
<i>4</i>	<i>Damp-proof course 2</i>	<i>>5</i>	<i><7.0</i>
<i>5</i>	<i>All others</i>	<i>>5</i>	<i>No limit</i>

According to this standard specification, damp-proof course 1 bricks are recommended for use in buildings construction whilst damp-proof course 2 bricks are recommended for other external construction works like for masonry construction which fulfills the requirements of BS 5628: Part 3: 1985.

2.6.3 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 in Table 2-11[32].

Table 2-12 Classification of clay bricks based on their physical requirements (ASTM C 62-97a)

<i>Designation</i>	<i>Minimum compressive strength, gross area (MPa)</i>		<i>Maximum water absorption by 5 hr boiling, (%)</i>		<i>Maximum saturation coefficient</i>	
	<i>Average of 5 bricks</i>	<i>Individual bricks</i>	<i>Average of 5 bricks</i>	<i>Individual bricks</i>	<i>Average of 5 bricks</i>	<i>Individual bricks</i>
<i>Grade SW</i>	20.7	17.2	17	22	0.78	0.8
<i>Grade MW</i>	17.2	15.2	22	25	0.88	0.9
<i>Grade NW</i>	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 2-11.

- 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 24 hr.*

2.9 FIELD TESTS FOR FIRED CLAY-BRICKS

In Ethiopian construction industry most 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 [15].

- A good quality brick should be regular in shape and size, with smooth sides and no cracks or defects.
- They possess 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

3. RESEARCH METHODOLOGY

3.1 METHODOLOGY

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.

3.1.1 Data collection and research tools.

3.1.1.1 Data collection

Data for this study are collected from two major sources.

- a. Data source one and
- b. Data source two.

3.1.1.1.1 Data source one

Data source one are responses for interview questionnaires in which a non-participative observation method is used. During this data survey, the brick production process and firing management of some brick factories in and around Addis Ababa 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.

3.1.1.1.2 Data source two

For this data source, relevant literature are reviewed and are described in chapter two of this thesis.

3.1.1.1.3 Research tools

The data retrieval methods for data source one are observation and interview whereas for data source two are publications and internet. The research tools utilized for data source one are review questionnaires and visit of the brick factories, and for data source two are books, journals and websites.

3.2 DESIGN OF INTERVIEW QUESTIONNAIRES

Interview questionnaires were designed and used for this study to interviewing concerned persons in some selected brick factories in and around Addis Ababa. The interview questionnaires include: company profile, raw materials sources, material preparation and blending, production processes, firing during production and general questions.

3.3 DATA ANALYSIS OF INTERVIEWS RESPONSES

The data collected based on the interview questionnaires are analyzed qualitatively and quantitatively using tables. Moreover, based on the non-participative observational data, the brick production processes are studied and the main drawbacks are identified. In addition discussions with the factories management and technicians held to have sufficient data about their firing temperature control mechanism [6].

3.4 SELECTION OF SITES FOR THE RAW MATERIALS

Raw material for this study are planned to be explored from two sites. The first site is Ketchene, which is found in Gulele Sub-city of Addis Ababa where pottery making is a dominant practice in this area. The other site is Burayu town, where most of the brick factories around Addis Ababa are found.

- A. Source of raw material one. The basis for the selection of Kechene area as raw material source "site one" is that in this area pottery making is a dominant practice. So, it is simply hypothesized the possibility to test and use the same raw material used by the pottery technicians for this study.

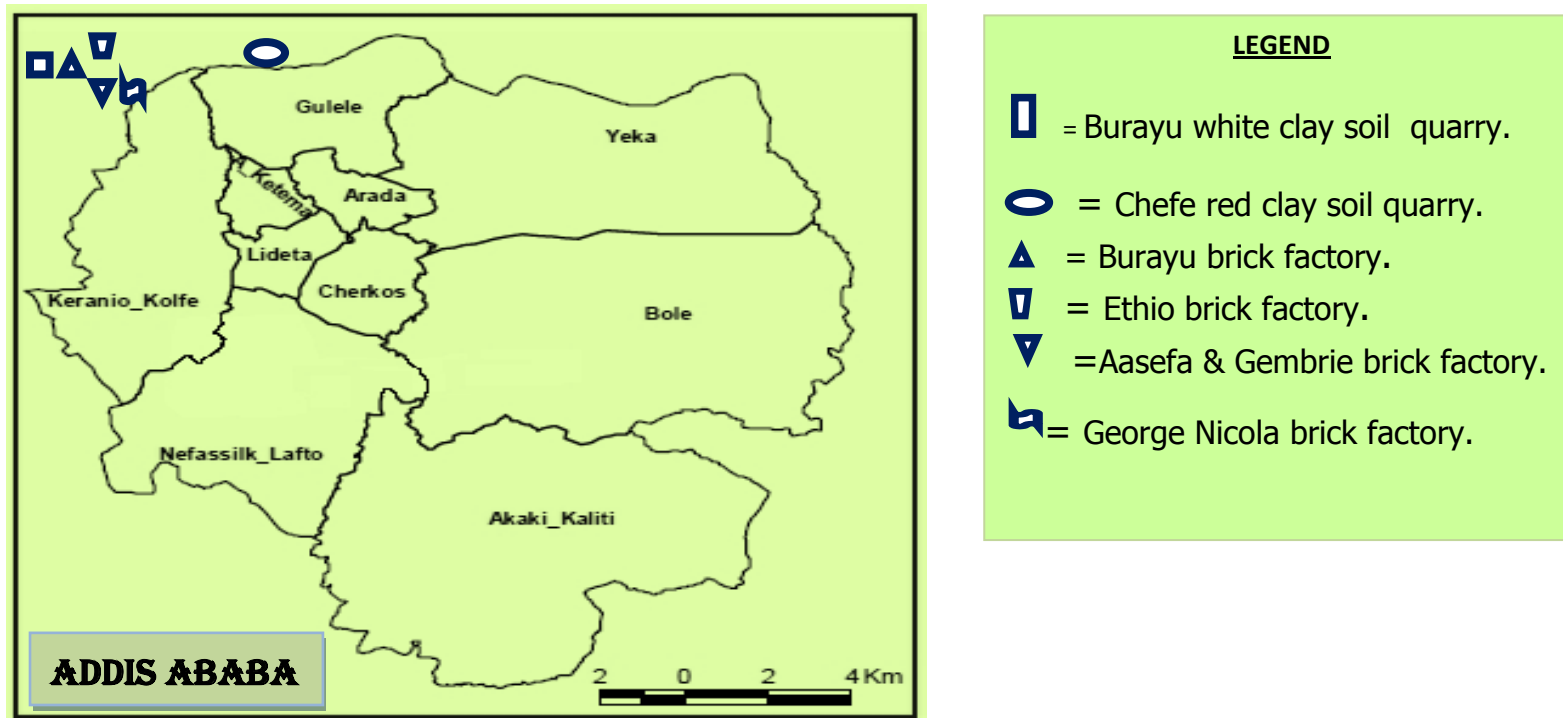
- B. Source of raw material two. Burayu town is located around 13km from Addis Ababa along the asphalt road Addis Ababa - Asco- Ambo. The two largest brick factories formerly owned by the government are located along this line. So, it is planned to use raw materials near the quarry site of Burayu brick factory for this study and this raw material source is designated as raw material source "site two".

The clay soils from raw material source one are red clay soil from chefe area and white soil locally called Gel which is a crushed pottery. The red clay from Chefe area is explored without any cost except exploration and transportation cost but the Gel from this area is sold by private company who has a crushing mill. They collect the broken pottery from the pottery technicians and crush it with their crushing mill.

The white clay soils from Burayu town or "site two" are explored near the quarry site of Burayu brick factory which are still used by the factory as a raw material for brick production.

The four 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 Chefe area and the white soil from Burayu site are used for brick production. The location of the quarry sites of the four soil samples and the studied brick factories is shown on Fig. 3-1.

Fig 3-1 Location of brick factories and raw material quarries used for this study.



3.5 LABORATORY TESTS ON THE SAMPLED SOILS

The chemical or oxide compositions of the four sampled soils are tested in the Ethiopian Geological Survey Laboratory. All the sampled soils do not fulfill the oxide contents of a good clay bricks as stated in the previous chapter. So, blending of these soil samples is necessary to keep their oxide contents within the required limit for the production of clay bricks for this study as discussed in section 2.3.3 of this thesis. So, based on their oxide compositions result, the red soil from Chefe area and the white soil from Burayu quarry are blended with different proportions. The proportions of blending and designations of the blended samples are shown in Table 3-1.

Table 3-1 Designation and percentage of blending of the blended soil samples.

No.	Sampled soils	Percentages of blending proportion by weight (%)	Designation of the blended soils.
1	Burayu white soil	82%	B-1
	Chefe red soil	18%)	
2	Burayu white soil	18%)	B-2
	Chefe red soil	82%)	
3	Burayu white soil	95%)	B-3
	Chefe red soil	5%)	
4	Burayu white soil	50%)	B-4
	Chefe red soil	50%)	

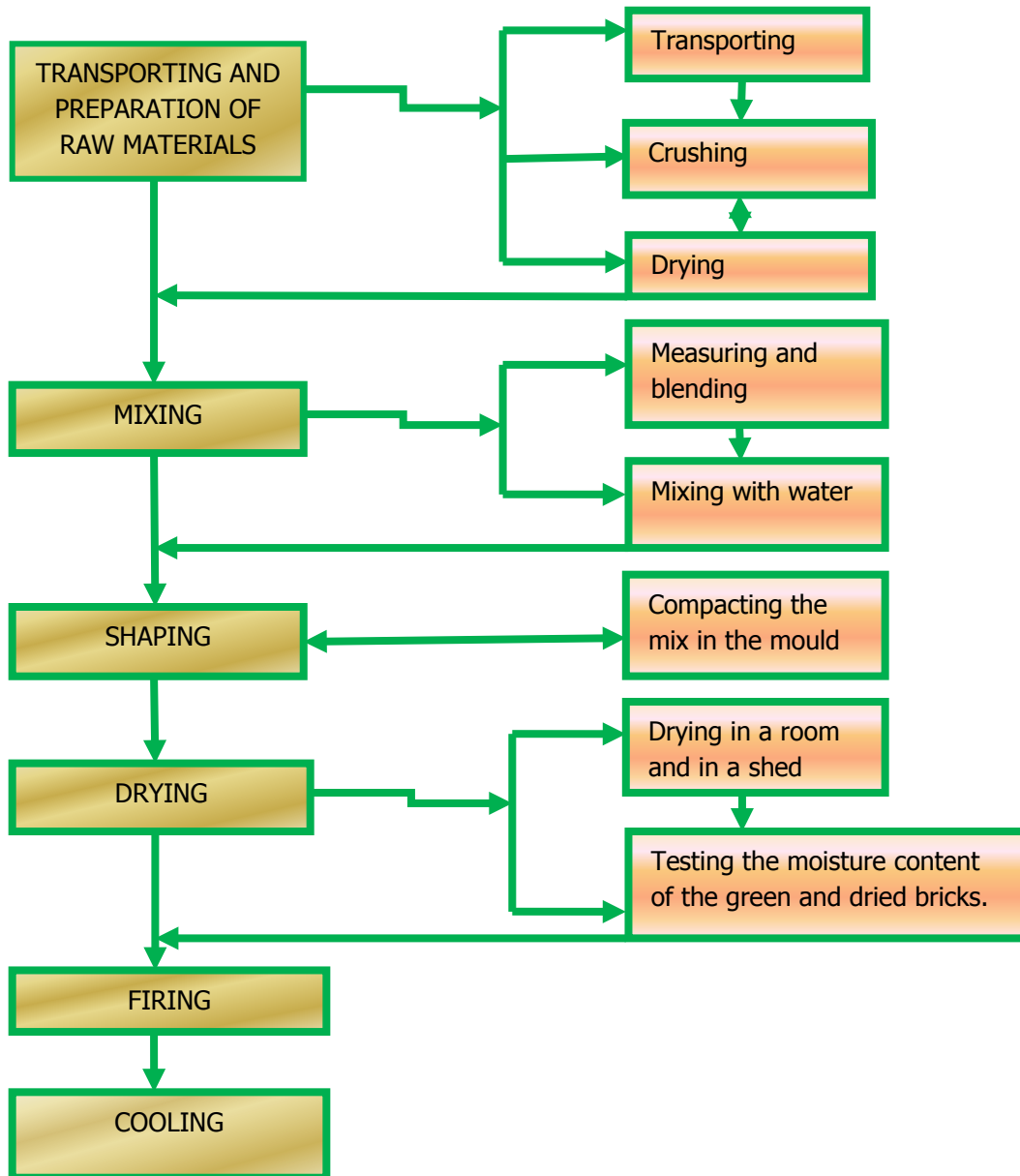
The physical tests of these blended soils including the Atterberg's limit (liquid limit and plastic limit) and the specific gravity are tested in AAiT Geotechnical Engineering Laboratory and the test results are discussed in the next chapter.

3.6 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.

FIG.3-2 Schematic diagram representing the production processes of bricks for this study.



3.6.1 Preparation of the raw materials

The red clay soil and the white clay soil from Chefe and Burayu quarry sites respectively are transported to the production site. The production site for this study is in Burayu 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 and blended with the proportions specified in Table 3-1. The over sized soil particles are manually crushed and sieved again and again.

3.6.2 Forming

For the production of clay bricks from the four blended soil samples, these samples are mixed with water and the amount of water used for mixing each blended soil samples is based on their plastic and liquid limits test results. The amount of water used for mixing these blended soil samples is listed in the next chapter. Mixing of the blended raw materials is done manually. Shaping of the mixed blended soils at their plastic state for this study is done using a mortar mould of size 5cmx5cmX5cm from AAiT Construction Materials Testing Laboratory. Since the available space of the furnace used for firing of the bricks is very small, this small sized bricks mould is selected. Moreover, food oil 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.

3.6.3 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. The time of drying is dependent on the moisture content of the green bricks and the humidity of the production area.

3.6.4 Firing

Firing for this study is done in AAiT Construction Materials Testing laboratory using a furnace. The firing temperatures used for this study are 700⁰C, 950⁰C and 1200⁰C. The bricks from the four blended soils are fired separately for 6 hours with these three different temperatures.

Moreover, the bricks produced from blended soil sample B-4 are fired for 2, 4, 6 and 8 hours separately at a constant temperature of 950⁰C to test the effects of duration of firing temperature on the physical properties of these bricks.

3.7 LABORATORY TESTS DURING THE PRODUCTION PROCESSES.

The moisture content of the green bricks of the four blended soils is determined in the laboratory. In addition to this the moisture contents of the air dried bricks are also tested. The results are discussed in the next chapter.

3.8 LABORATORY TESTS OF THE FIRED CLAY BRICKS.

The fired clay bricks compressive strength, Water absorption and saturation coefficient which are produced from the four blended soil samples are tested in AAiT, 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.

3.9 METHODS OF DATA ANALYSIS

The data analysis for this study is based on the interview questionnaires and the laboratory test results. For the analysis of the response of the interviewee's it required a better planning of the period of interview time and designing the necessary questions. In this regard, the concerned persons from the four brick factories were interviewed after the laboratory works were completed. 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

4 RESULTS AND DISCUSSIONS

Results are achievement of a study and are the basis for answering the objectives of the research. They also show the overall findings of the study which are used to forward conclusions and recommendations. Accordingly, discussions based on the results are included to compare the findings with other literatures and to describe the outcomes of the research activities.

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

4.1 INTERVIEW RESPONSE

During this study, one interviewee from each of the four studied brick factories were interviewed and all of them were volunteers to answer the interview questionnaires. The relevant interviewee's which have long experience in the factories and technical eligibility about the clay brick production were selected by managers of each 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) All the studied brick factories 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 are blended for the production of clay bricks. The proportion of blending of the soil is 80% white clay soil and 20% red clay soil. The 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 all these factories is similar. The stages of clay bricks production includes: exploration and transportation of the raw materials, blending, 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) All these factories 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 factories is poor which results in over and under fired clay bricks. The duration of firing of clay bricks by these factories is 24 hours. Their firing temperature controlling experience is summarized in Table 4-2.
- 2) Since these factories have no owned laboratory, they do not test the fired clay bricks. In addition,
 - Over and under fired clay bricks are common products in all these factories.
 - 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 crushed with a crushing mill in George Nicola brick factory and reused as raw material for clay brick production. But the other factories sell the broken bricks for different uses.

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 all these factories varies and the reason for this is due to their old mechanisms that these factories use for the production.

Table 4-1 Company profile of brick factories surveyed during this study.

NO.	Name of the company	Name of interviewee's	Responsibilities in the factory	Years of establishment of the factory	Present annual brick production capacity(pcs)	No. of employees	
						Male	Female
1	Burayu BF	Ato. Bzuneh Seifu	Senior mechanic	1957 EC	10,500,000	150	170
2	Ethio BF	Ato. Bzuayhu kassa	Senior mechanic	1958 EC	6,000,000	175	190
3	George Nicola BF	Ato. Matwes George	Technical & finance Manager	1945 EC	500,000	40	40
4	Asefa and Genberie BF	Ato. Wuhib Tesema	Technical & finance Manager	1953 EC	157,126	14	16
Total					17157126	795	

N.B. –Burayu BF 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.

-BF means brick factory.

-EC Means Ethiopian calendar.

Table 4-2 Brick factories firing temperature control, raw materials and fired clay-bricks testing.

NO.	Name of brick factory	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	Burayu BF	By experience	No tests.	Shaping	Wood	Not available	By observation
2	Ethio BF	By experience	No tests.	Raw material selection	Wood	Not available	By observation
3	George Nicola BF	By experience	No tests.	Raw material selection	Wood	Not available	By observation
4	Asefa and Genberie BF	By experience	No tests.	Crushing & mixing	Wood	Not available	By observation

4.2 OBSERVATIONAL FINDINGS

Broken bricks resulting from under firing and partly black and partly brown red coloured bricks which have poor aesthetical values resulted from over firing of the bricks are the usual loss of these factories.

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 factories are faced bricks (FB) and solid refractory bricks (by order of customers in Ethio brick factory only) and all these products have sizes of 25cm x 12cm x 6cm.

According to the observation made in these factories and based on the response of the interviewee's, the significance of firing temperature is little understood by all when compared with other stages of brick production. This shows that in these factories there is poor energy utilization causing higher production cost.

4.3 LABORATORY RESULTS

The laboratory test results include; the chemical/oxide compositions of the four sampled soils, physical properties of the four blended soil samples, the moisture content of the bricks during production and the physical properties of the fired clay bricks.

4.3.1 The chemical or oxide composition tests of the sampled soils

The oxide composition tests of the four sampled soils are done by the Ethiopian Geological Survey Laboratory and the results are shown in Table 4-3.

Table 4-3 Oxide compositions of tested soil samples.

SOLIS TYPE	Chemical compositions of soil samples (%)									
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	TiO ₂	MnO	P ₂ O ₅
Burayu-White clay soil one	66.76	17.86	9.53	0.40	0.84	0.22	0.84	0.53	0.08	0.04
Burayu-White clay soil two	67.55	13.66	9.62	0.32	0.73	2.59	2.56	0.47	0.26	0.03
Chefe Red clay soil	48.72	32.10	12.03	0.30	1.13	0.21	1.15	0.94	0.05	0.08
Gel	68.34	15.95	4.93	0.91	1.59	1.76	2.98	0.61	0.11	0.04

The sampled soils except the "Gel" are mined from an average depth of one meter. Therefore, these soils are classified as surface clay. As shown on Table 4-3 the metallic oxides FeO_2 , CaO and MgO are impurities and act as a flux and facilitate fusion of clay particles. These impurities also influence the colour of the fired clay bricks. Particularly the iron content of these soil samples except the "Gel" is comparatively higher which results in brown reddish colour of bricks when fired with higher temperature. In addition to these, the silicon content of the three sampled soils are slightly more accordingly, blending of the selected soil samples are done to keep their oxide content in the required limit. The oxide content of the four blended soil samples are tabulated as shown in Table 4-4.

Table 4-4 Oxide compositions of blended soil samples

Blended soils samples designation	Oxides content (%)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_5
B-1	63.51	20.42	9.98	0.38	0.89	0.22	0.89	0.60	0.075	0.05
B-2	51.97	29.54	11.58	0.32	1.08	0.21	1.09	0.87	0.06	0.07
B-3	65.86	18.57	9.66	0.39	0.85	0.22	0.86	0.55	0.08	0.04
B-4	57.74	24.09	10.78	0.33	0.99	0.20	0.99	0.71	0.07	0.06

Based on the mineralogical composition of the blended sampled soils;

- i. B-1 – has slightly more silica but the alumina content is in the desired limit of good brick clay. So, the cohesion between particles to some extent decreased.
- ii. B-2- has less silica which results in cracking and shrinking of clay bricks. Moreover, this sample has relatively higher content of iron and magnesium oxides causing melting and fusion of the raw materials to take place comparatively at lower temperature.
- iii. B-3- has comparatively more silica and less alumina content compared with the other blended samples. The more silica content reduces the cohesion between particles. This sample has relatively small impure oxides so that fusion of the clay

particles may take place at higher temperature.

- iv. B-4- has slightly less silica but the alumina content is within the desired limit. So, the necessary bond strength between particles may not be developed during fusion.

All the blended soil samples have lower content of lime so that melting of the silica may not be as required.

4.3.2 Physical properties tests

The physical properties test results of the four blended soils are described in Table 4-5. These physical properties of the blended 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.

Table 4-5 Physical properties of sampled soils.

Blended soil sample	LL	PL	PI	Specific gravity	Water used for mixing (% by weight)
B-1	40	30	10	2.56	30
B-2	64	40	24	2.50	45
B-3	41	38	3	2.55	35
B-4	50	28	22	2.45	40

As shown on Table 4-5, the amount of water used for mixing each blended sample is less than its liquid limit. This indicates that the mixed soil sample is in its plastic state.

4.3.3 Tests conducted during production stages

The moisture content of the green bricks and the air dried bricks are tested in a

laboratory and the results are tabulated as shown in Table 4-6.

Table 4-6 Moisture content of green bricks.

Blended raw materials	Moisture content (% by weight)	
	of green bricks	of air dried bricks
B-1	35	10
B-2	54	11
B-3	39	12
B-4	44	9

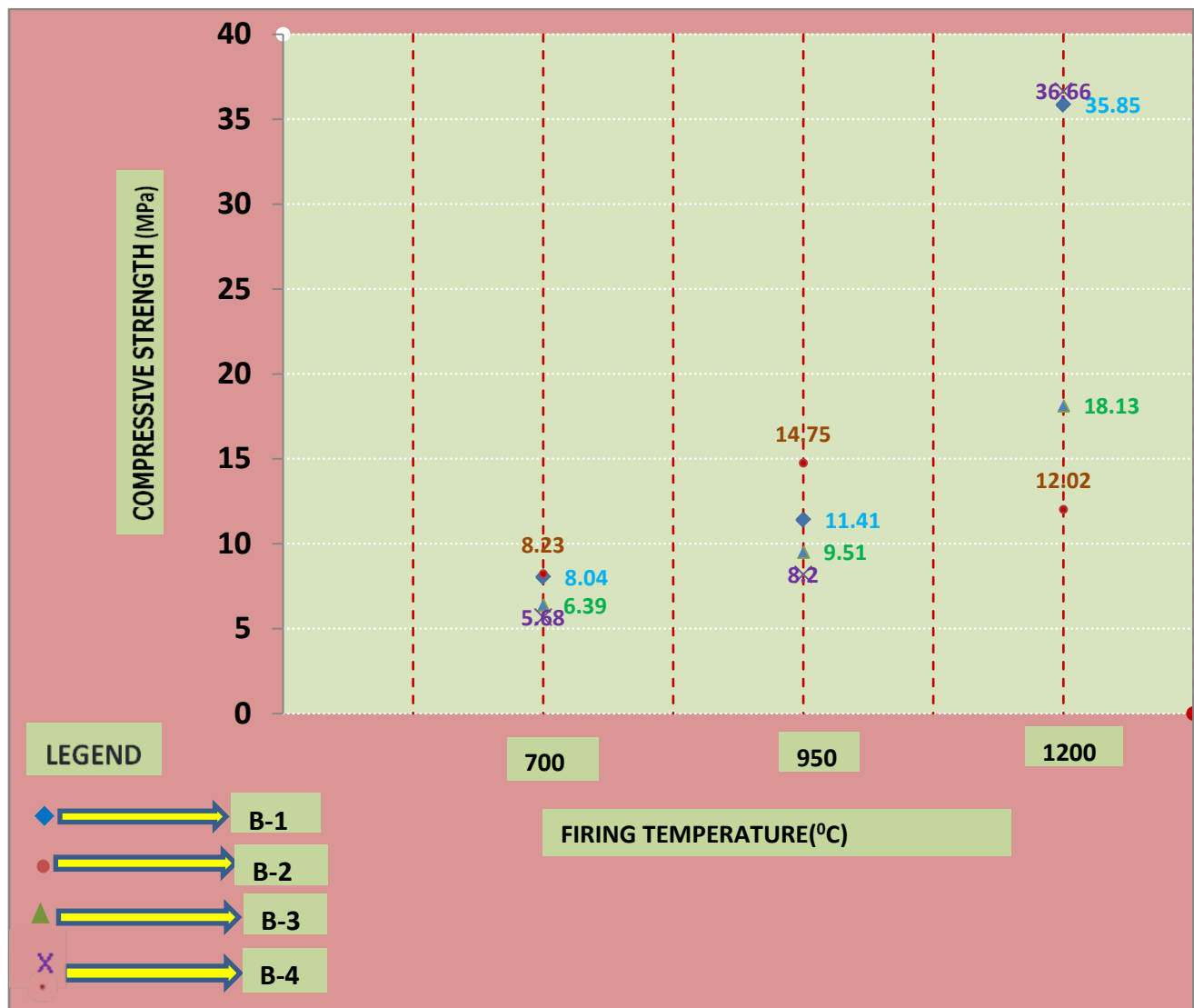
According to the test results, the moisture content at the green bricks stage of all the bricks produced from the four blended soil samples are less than the liquid limits of the raw materials. This shows that the mixed and shaped green bricks are at the plastic stages. Moreover, the moisture content of the air dried bricks are from 9 to 12% these remaining moisture content of the air dried bricks will be removed at the dehydration stage during firing.

4.3.4 Physical properties tests of the fired clay bricks

The physical properties tests of the fired clay bricks are done in AAiT construction materials testing laboratory. The tests include; compressive strength, water absorption and the saturation coefficients.

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

Fig.4-1 Effect of different firing temperature on the mean compressive strength of clay-bricks produced from blended soil sample B-1, B-2, B-3 and B-4.



The average compressive strength of bricks produced from blended soil samples B-1, B-3 and B-4 increases as the firing temperature rises from 700°C to 950°C and 1200°C. Particularly the rapid increment occurs above 950°C where vitrification takes place as shown on Fig. 4-1.

The average compressive strength of bricks produced from blended soil samples B-2, increases as the firing temperature rises from 700°C to 950°C. But above 950°C, the fired clay bricks start cracking because of the small content of silica. In addition, it has comparatively high iron and magnesium oxides content causing melting and fusion of

the raw materials to take place at lower temperature. So, its average compressive strength slightly reduced above this temperature as shown on Fig. 4-1.

Moreover, in this study it is observed that the clay bricks produced from the blended samples containing larger proportion of white clay soils start melting at lower temperature than the one which has larger amount of red clay soils. 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 blended soil samples B-1, B-3 and B-4 is from 950^oC to 1200^oC and with B-2 is from 900^oC to 950^oC.

Table 4-7 Average compressive strength of bricks and their classification.

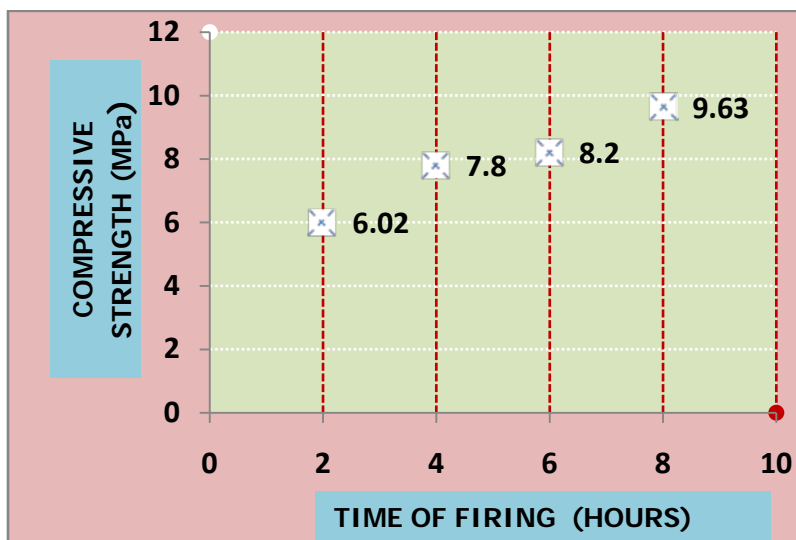
Raw materials	Firing temperature (°C)	Mean compressive strengths of 5 bricks (MPa)	Classification	
			(ES 86:2001)	ASTM
B-1	700	8.04	D	-
	950	11.41	C	NW
	1200	35.85	A	SW
B-2	700	8.23	D	-
	950	14.75	C	NW
	1200	12.02	C	NW
B-3	700	6.39	-	-
	950	9.51	D	-
	1200	18.13	B	MW
B-4	700	5.68	-	-
	950	8.2	D	-
	1200	36.66	A	SW

At 700^oC and 950^oC, bricks produced from blended sample B-2, have maximum compressive strength compared with the compressive strengths of bricks produced from B-1, B-3 and B-4. The possible reason for this result is that this blended sample comparatively has lower SiO₂, higher Al₂O₃ and more metallic oxides. So that during

firing, fusion of the clay particles takes place comparatively at lower temperature and help vitrification to take place early. But when the firing temperature increases, cracking occurs because of the smaller of the silica contents.

At 1200°C , maximum compressive strength is achieved by bricks produced from blended sample B-4. The possible reason for this is that the content alumina of this sample is within the required limit and it has slightly small content of the silica.

Fig. 4-2 Variation of compressive strength with different firing duration of bricks produced from blended soil sample B-4 and fired at 950°C .



The average compressive strength of the bricks produced from blended soil sample B-4, which are fired at a constant temperature of 950°C , slightly increases as the duration of firing increases as shown on Fig 4-2.

During the production processes of the fired clay bricks from the four blended 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 sizes decrease and their mean size of bricks at different stages of productions are listed in Table 4-10.

Table 4-8 Average WA and SC of bricks and their classification.

Blended raw materials	Firing temperature (°C)	Mean Water absorption of 5 bricks and their classification			Mean saturation coefficients of 5 bricks and their classification		
		WA (%)	(ES86:2001)	ASTM	SC	(ES86:2001)	ASTM
B-1	700	17.66	A	MW	0.95	A,B	NW
	950	16.98	A	SW	0.94	A,B	NW
	1200	2.56	A	SW	0.66	A,B	SW
B-2	700	19.10	A	MW	0.84	A,B	MW
	950	18.10	A	MW	0.82	A,B	MW
	1200	6.23	A	SW	0.66	A,B	SW
B-3	700	19.02	A	MW	0.95	A,B	NW
	950	16.74	A	SW	0.90	A,B	NW
	1200	2.74	A	SW	0.30	A,B	SW
B-4	700	19.36	A	MW	0.90	A,B	NW
	950	18.45	A	MW	0.85	A,B	MW
	1200	3.73	A	SW	0.69	A,B	SW

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 4-8; 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 blended raw materials B-1 fired at 700 °C as shown on Table 4-7 and 4-8 are classified as class C, 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 4-9 WA and SC of bricks produced from blended sample B-4 fired at 950°C but different duration of firing.

Blended soil	Firing temperature (°C)	Time of firing (hours)	Mean Water absorption of 5 bricks and their classification			Mean saturation coefficients of 5 bricks and their classification		
			WA (%)	(ES86:2001)	ASTM	SC	Classes of bricks	ASTM
B-4	950	2	23.09	C,D	-	0.94	A,B	NW
		4	19.95	A	MW	0.90	A,B	NW
		6	18.45	A	MW	0.85	A,B	MW
		8	18.07	A	MW	0.76	A,B	SW

As shown in Table 4-8, both the mean water absorption and saturation coefficients are reduced for all the bricks produced from all the four blended soils as the firing temperature increases. Moreover, the results of mean water absorption and saturation coefficients of bricks produced from blended sample B-4 which are fired at constant temperature of 950°C for different duration are as shown in Table 4-9, 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 optimum firing temperature range.

Table- 4-10 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 (°C)	Mean Size of fired Bricks (cm)
B-1	5 x 5x 5	4.80 x 4.80x 4.80	700	4.62 x 4.62 x 4.62
			950	4.52 x 4.52 x 4.52
			1200	4.25 x 4.25 x 4.25

B-2	5 x 5 x 5	4.72 x 4.72 x 4.72	700	4.40 x 4.40 x 4.40
			950	4.28 x 4.28 x 4.28
			1200	3.98 x 3.98 x 3.98
B-3	5 x 5 x 5	4.83 x 4.83 x 4.83	700	4.66 x 4.66 x 4.66
			950	4.58 x 4.58 x 4.58
			1200	4.34 x 4.34 x 4.34
B-4	5 x 5 x 5	4.78 x 4.78 x 4.78	700	4.50 x 4.50 x 4.50
			950	4.34 x 4.34 x 4.34
			1200	4.02 x 4.02 x 4.02

4.4 COST OF CLAY BRICKS

4.4.1 General

All the surveyed brick factories for this study except Ethio brick factory produce only solid face clay bricks of size 25cm x 12cm x 6cm. Ethio brick factory in addition to the face clay bricks, it also produce solid refractory clay bricks of size 25cm x 12cm x 6cm if ordered by its customers. The factories sales price of face clay bricks is almost the same as shown on Table-12.

Based on the sales price of the brick factories, the cost of clay bricks produced for this study is shown in Table-12. This cost estimate is done by considering the volume of the bricks only but the quality of clay bricks has not been considered.

4.4.2 Brick sales price

According to Brick Products Production Share Company, the sales price of clay bricks produced from Burayu and Ethio brick factories is fixed on the basis of the production costs and the profit [33].

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 share company, the profit vary from 18% to 30% of the production cost. The profit vary mainly due to variation of the production costs.

The existing share company price of a piece of Face clay brick produced from Burayu and Ethio brick factories is fixed based on the above listed different costs and profit as summarized in Table 4-11.

Table 4-11 Sales price of a piece of clay brick by Brick Products Production Share Company

NO.	Description		Birr/ one face brick	Remarks
1	Production costs	Fixed costs	0.401	It is 25% of the production costs
		Variable costs	0.962	It is 60% of the production costs
		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	
2	Vat (15%)		0.345	
3	Sales price		2.3	

Table- 4-12 Cost of clay bricks produced in brick factories

Types of bricks and sizes	Factory price(Birr/ one brick)				Remark
	Burayu and Ethio BF	Asefa and Gemberie	George Nicola BF	Bricks produced for this study	
Face brick (25cmx12cmx6cm)	2.3	2.5	2.5		❖ Only face bricks are produced in Asefa and Gemberie and George Nicola BF. ❖ Refractory clay bricks are produced in Ethio BF by special order.
Refractory brick (25cmx12cmx6cm)	3.1	—	—		
Solid clay bricks (4.5cmx4.5cmx4.5cm)				0.2	

Note: The material and labour cost of the produced clay bricks for this study is estimated to be 10 cents per pieces. The increment of this cost is due to the fact that the raw materials are transported from other places. This cost can be minimized when 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 brick factories:
 - a) Have no temperature sensor device or thermocouple to know their kiln firing temperature. But the degree of firing of clay bricks in these factories is decided by their kiln operator's. Which results in over and under fired clay bricks.
 - b) Have no owned laboratory so that they do not test and know the optimum 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 factories is poor so that over and under firing of clay bricks are their usual lose.

2. The optimum firing temperature of clay bricks produced from blended soil sample B-1, B-3 and B-4 is from 950 °C to 1200°C and with B-2 is from 900°C to 950°C. As the firing temperature rises within the optimum 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 samples are reduced.

So, as the firing temperature rises within the optimum firing temperature range of these blended 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 hours, clay bricks produced from blended soil sample B-4 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 optimum 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. All clay bricks produced for this study from the four blended soils at a firing temperature of 950 °C and 1200 °C conform the Ethiopian standard specification for solid clay bricks (ES 86:2001). But clay bricks which are fired at 700°C do not fulfill the different requirements of this specification. Moreover, all 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 hollow clay bricks in addition to the existing standard specification for solid clay bricks and monitor the clay brick factories products accordingly.
2. Production of over and under fired clay bricks in brick factories located in and around Addis Ababa can be minimized by:
 - a) Testing the optimum 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 factories can reduce loses so that their production costs can be optimized.

Performing the above activities play a great role for these brick factories to meet the different requirements of established standard specifications for clay bricks. Accordingly the clay bricks produced from these factories 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 availabilities and potential of brick-clay sources in Ethiopia especially around Addis Ababa is recommended. This will be useful to know the available brick clay sources and encourage investment in this sector.
- 2- Further study is recommended to locally manufacture a temperature sensor device or thermocouple which will be used by brick factories to control the amount of firing temperature in the kiln.

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APPENDIX ONE

1. LABORATORY TEST RESULTS

1.1 COMPUTATION OF MEAN COMPRESSIVE STRENGTH TEST RESULT FOR EACH TYPE OF BRICKS

$$\xi = \frac{F_{\max}}{A} \quad [30]$$

Where, ξ = compressive strength (MPa)

F_{\max} = the force at failure (N)

A = the average bearing area (mm²)

Computation of compressive strength of bricks produced from sample **B-1-700°C**

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4.7	4.7	4.7	21.385	17	7.95
2	4.65	4.65	4.65	20.925	17.8	8.51
3	4.6	4.6	4.6	20.7	17.4	8.41
4	4.6	4.6	4.6	20.93	14.3	6.83
5	4.75	4.75	4.75	21.375	18.2	8.51
Mean						8.04

Computation of compressive strength of bricks produced from sample **B-1-950°C**

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4.55	4.55	4.55	21.39	25	11.69
2	4.5	4.5	4.5	20.93	22.8	10.90
3	4.5	4.5	4.5	20.70	21.3	10.29
4	4.55	4.55	4.55	20.93	27.2	13.00
5	4.5	4.5	4.5	21.38	23.9	11.18
Mean						11.41

Computation of compressive strength of bricks produced from sample **B-1-1200°C**

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4.1	4.1	4.1	16.81	61.2	36.41
2	4.1	4.1	4.1	16.81	65.9	39.20
3	4	4	4	16	62	38.75
4	4.1	4.1	4.1	16.81	61.4	36.53
5	4	4	4	16	45.4	28.38
Mean						35.85

Computation of compressive strength of bricks produced from sample **B-2-700 °C**

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4.6	4.6	4.6	21.16	17.9	8.46
2	4.4	4.4	4.4	19.36	13.1	6.77
3	4.4	4.4	4.4	19.36	12.8	6.61
4	4.35	4.35	4.35	18.92	19.2	10.15
5	4.4	4.4	4.4	19.36	17.7	9.14
Mean						8.23

Computation of compressive strength of bricks produced from sample **B-2-950 °C**

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4.3	4.3	4.3	18.49	23.2	12.55
2	4.2	4.2	4.2	17.64	30.9	17.52
3	4.3	4.3	4.3	18.49	27.4	14.82
4	4.3	4.3	4.3	18.49	24.5	13.25
5	4.3	4.3	4.3	18.49	28.9	15.63
Mean						14.75

Computation of compressive strength of bricks produced from sample **B-2-1200 °C**

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	3.9	3.9	3.9	15.21	18.7	12.29

2	4.1	4.1	4.1	16.81	13.4	7.97
3	4	4	4	16	25.4	15.88
4	3.9	3.9	3.9	15.21	15.5	10.19
5	4	4	4	16	22	13.75
					Mean	12.02

Computation of compressive strength of bricks produced from sample **B-3-700 °C**

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4.8	4.8	4.8	23.04	14.6	6.34
2	4.85	4.85	4.85	23.52	16	6.80
3	4.7	4.7	4.7	22.09	16.3	7.38
4	4.8	4.8	4.8	23.04	11.7	5.08
5	4.7	4.7	4.7	22.09	14	6.34
					Mean	6.39

Computation of compressive strength of bricks produced from sample **B-3-950 °C**

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4.5	4.5	4.5	20.25	17.8	8.79
2	4.55	4.55	4.55	20.02	15.3	7.64
3	4.5	4.5	4.5	20.25	16.5	8.15
4	4.6	4.6	4.6	19.78	20.9	10.57
5	4.55	4.55	4.55	18.2	22.6	12.42
					Mean	9.51

Computation of compressive strength of bricks produced from sample **B-3-1200 °C**

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	3.8	3.8	3.8	14.44	26.8	18.56
2	4	4	4	16	29.4	18.38
3	3.8	3.8	3.8	14.44	26.6	18.42
4	4	4	4	16	25.5	15.94
5	3.75	3.75	3.75	14.06	27.2	19.34

Mean	18.13
------	-------

Computation of compressive strength of bricks produced from sample **B-4-700 °C**

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4.8	4.8	4.8	23.04	13.2	5.73
2	4.85	4.85	4.85	23.52	12.6	5.36
3	4.9	4.9	4.9	24.01	14	5.83
4	4.8	4.8	4.8	23.04	13.6	5.90
5	4.8	4.8	4.8	23.04	12.9	5.60
Mean						5.68

Computation of compressive strength of bricks produced from sample **B-4-950 °C**

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4.75	4.75	4.75	22.56	21.7	9.62
2	4.8	4.8	4.8	23.04	18.3	7.94
3	4.85	4.85	4.85	23.52	17.5	7.44
4	4.8	4.8	4.8	23.04	17.6	7.64
5	4.85	4.85	4.85	23.52	19.7	8.37
Mean						8.20

Computation of compressive strength of bricks produced from sample **B-4-1200 °C**

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4	4	4	16	38	23.75
2	4	4	4	16	62.5	39.06
3	4.1	4.1	4.1	16.81	52.7	31.35
4	4	4	4	16	66	41.25
5	4	4	4	16.00	76.6	47.88
Mean						36.66

Computation of compressive strength of bricks produced from sample fired for 2 hours,

B-4-2hr-950 °C

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4.80	4.80	4.80	23.04	14.00	6.08
2	4.85	4.85	4.85	23.52	14.50	6.16
3	4.75	4.75	4.75	22.56	13.80	6.12
4	4.80	4.80	4.80	23.04	13.50	5.86
5	4.70	4.70	4.70	22.09	13.00	5.89
Mean						6.02

Computation of compressive strength of bricks produced from sample fired for 4 hours,

B-4-4hr-950 °C

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4.7	4.7	4.7	26.79	20.8	7.76
2	4.65	4.65	4.65	22.09	21.2	9.60
3	4.8	4.8	4.8	23.04	16.4	7.12
4	4.8	4.8	4.8	23.04	13.8	5.99
5	4.8	4.8	4.8	23.04	19.6	8.51
Mean						7.80

Computation of compressive strength of bricks produced from sample fired for 6 hours,

B-4-6hr-950 °C

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4.75	4.75	4.75	22.56	21.7	9.62
2	4.8	4.8	4.8	23.04	18.3	7.94
3	4.85	4.85	4.85	23.52	17.5	7.44
4	4.8	4.8	4.8	23.04	17.6	7.64
5	4.85	4.85	4.85	23.52	19.7	8.37
Mean						8.20

Computation of compressive strength of bricks produced from sample fired for 8 hours,
B-4-8hr-950 °C

No	Dimension (cm)			Area [cm ²] L*W	Failure load [KN]	Compressive strength [MPa]
	L	W	H			
1	4.8	4.8	4.8	23.04	22.9	9.94
2	4.65	4.65	4.65	21.62	22.3	10.31
3	4.75	4.75	4.75	22.56	23	10.19
4	4.75	4.75	4.75	22.56	21.8	9.66
5	4.8	4.8	4.8	23.04	18.5	8.03
					Mean	9.63

1.2 WATER ABSORPTION AND SATURATION COEFFICIENT RESULT OF EACH TYPE OF BRICKS

$$WA (\%) = \frac{100(W_2 - W_1)}{W_1} \quad [30]$$

$$SC = \frac{(W_2 - W_1)}{W_3 - W_1} \quad [30]$$

Where, W_1 is the dry mass of sample,

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

W_3 is the mass of saturated sample after 5 hour 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 B-1 fired at 700°C

NO.	W_1 (gm)	W_2 (gm)	W_3 (gm)	WA(%)	SC
1	161	192	193	19.25	0.81
2	162	192	193	18.52	0.80
3	162	190	192	17.28	0.61
4	162	190	191	17.28	0.83

5	163	189	191	15.95	0.83
Mean				17.66	0.95

Water absorption and saturation coefficients of bricks from sample B-1 fired at 950°C

NO.	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	162	189	191	16.67	0.93
2	163	190	191	16.56	0.96
3	163	191	192	17.18	0.97
4	164	191	194	16.46	0.90
5	161	190	192	18.01	0.94
Mean				16.98	0.94

Water absorption and saturation coefficients of bricks from sample B-1 fired at 1200°C

NO.	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	158	160	163	1.27	0.40
2	155	158	159	1.94	0.75
3	154	163	164	5.84	0.90
4	162	165	166	1.85	0.75
5	156	159	162	1.92	0.50
Mean				2.56	0.66

Water absorption and saturation coefficients of bricks from sample B-2 fired at 700°C

NO.	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	126	153	158	21.43	0.84
2	128	157	160	22.66	0.91
3	130	153	161	17.69	0.74
4	133	157	159	18.05	0.92
5	134	155	160	15.67	0.81
Mean				19.10	0.84

Water absorption and saturation coefficients of bricks from sample B-2 fired at 950°C

NO.	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	132	155	164	17.42	0.72
2	129	153	163	18.60	0.71
3	133	158	160	18.80	0.93
4	125	153	155	22.40	0.93

5	121	145	149	19.83	0.86
Mean				19.41	0.83

Water absorption and saturation coefficients of bricks from sample B-2 fired at 1200°C

NO.	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	120	130	132	8.33	0.83
2	124	128	129	3.23	0.80
3	124	129	131	4.03	0.71
4	121	128	144	5.79	0.30
5	123	135	141	9.76	0.67
Mean				6.23	0.66

Water absorption and saturation coefficients of bricks from sample B-3 fired at 700°C

NO.	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	146	173	175	18.49	0.93
2	146	174	175	19.18	0.97
3	147.5	173	174	17.29	0.96
4	146	174	176	19.18	0.93
5	143	173	174	20.98	0.97
Mean				19.02	0.95

Water absorption and saturation coefficients of bricks from sample B-3 fired at 950°C

NO.	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	145	168	169	15.86	0.96
2	144	172	174	19.44	0.93
3	144	164	166	13.89	0.91
4	145	165	171	13.79	0.77
5	140	169	171	20.71	0.94
Mean				16.74	0.90

Water absorption and saturation coefficients of bricks from sample B-3 fired at 1200°C

NO.	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	148	150	152	1.35	0.5
2	153	155	159	1.31	0.33
3	144	152	156	5.56	0.67
4					

5					
			Mean	2.74	0.30

Water absorption and saturation coefficients of bricks from sample B-4 fired at 700°C

NO.	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	158	188	189	18.99	0.97
2	153	183	191	19.61	0.79
3	158	190	196	20.25	0.84
4	157	187	188	19.11	0.97
5	159	189	191	18.87	0.94
			Mean	19.36	0.90

Water absorption and saturation coefficients of bricks from sample B-4 fired at 950°C

NO.	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	151	181	190	19.87	0.77
2	154	184	191	19.48	0.81
3	155	185	186	19.35	0.97
4	155	182	186	17.42	0.87
5	155	180	185	16.13	0.83
			Mean	18.45	0.85

Water absorption and saturation coefficients of bricks from sample B-4 fired at 1200°C

NO.	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	137	142	144	3.65	0.71
2	136	144	145	5.88	0.89
3	139	141	143	1.44	0.50
4	139	145	144	4.32	1.20
5	119	123	144	3.36	0.16
			Mean	3.73	0.69

Water absorption and saturation coefficients of bricks produced from soil sample B-4 and fired for two hours at 950°C

NO.	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	155	189	193	21.94	0.89

2	157	193	194	22.93	0.97
3	139	172	175	23.74	0.92
4	156	192	194	23.08	0.95
5	143	177	179	23.78	0.94
Mean				23.09	0.94

Water absorption and saturation coefficients of bricks produced from soil sample B-4 and fired for four hours at 950⁰C

NO	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	185	189	19.35	0.88	0.88
2	182	184	17.42	0.93	0.93
3	187	190	21.43	0.92	0.92
4	186	191	20.78	0.86	0.86
5	186	189	20.78	0.91	0.91
Mean				19.95	0.90

Water absorption and saturation coefficients of bricks produced from soil sample B-4 and fired for six hours at 950 0⁰C

NO	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	151	181	190	19.87	0.77
2	154	184	191	19.48	0.81
3	155	185	186	19.35	0.97
4	155	182	186	17.42	0.87
5	155	180	185	16.13	0.83
Mean				18.45	0.85

Water absorption and saturation coefficients of bricks produced from soil sample B-4 and fired for eight hours at 950⁰C

NO	W ₁ (gm)	W ₂ (gm)	W ₃ (gm)	WA(%)	SC
1	153	179	190	16.99	0.70
2	154	182	188	18.18	0.82
3	153	180	190	17.65	0.73
4	151	180	190	19.21	0.74
5	153	181	188	18.30	0.80
Mean				18.07	0.76

1.3 SAMPLED SOILS OXIDE COMPOSITION TEST RESULTS

The oxide compositions of the four selected soil samples are tested by the Ethiopian Geological Survey Laboratory. Even if the two soil samples from raw material source site two have field No. "Burayu Red Clay Soil" and "Burayu White Clay Soil" on the laboratory test results; both soils are White clay soils. These soils are designated as "White clay soil one" and "White clay soil two" with Lab. No. 7777-12 and 7778-12 respectively as shown on the laboratory test result. For this study White and red clay soils with Lab. No. 7777-12 and 7779-12 respectively are used. The laboratory test results are attached here with.

Table 4-3 Oxide compositions of tested soil samples.

SOLIS TYPE	Chemical compositions of the soil samples (%)									
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	TiO ₂	MnO	P ₂ O ₅
Burayu-White clay soil one	66.76	17.86	9.53	0.40	0.84	0.22	0.84	0.53	0.08	0.04
Burayu-White clay soil two	67.55	13.66	9.62	0.32	0.73	2.59	2.56	0.47	0.26	0.03
Chefe Red clay soil	48.72	32.10	12.03	0.30	1.13	0.21	1.15	0.94	0.05	0.08
Gel	68.34	15.95	4.93	0.91	1.59	1.76	2.98	0.61	0.11	0.04

APPENDIX TWO

QUESTIONARRIES 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_____

Years of establishment_____

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?

- ❖ How do you know/test the mix proportions?

Table 2A Raw materials types and their proportions

No.	Types of pottery to be done	Raw material types				Proportions of raw materials. (1:2:3:4)
		(1)	(2)	(3)	(4)	
1						
2						
3						
4						

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 Drying of red clay soil in the brick production site.



Photo-2 Drying of white clay soil in the brick production site.



Photo-3 Measuring of soil samples for blending.



Photo-4 Painting the form works with food oil during shaping stage of brick production.



Photo-5 Fired clay bricks produced from the four blended soil samples.



Photo-6 Fired clay bricks produced from the blended soil sample B-1.



Photo-7 Fired clay bricks produced blended soil sample B-2.



Photo-8 Fired clay bricks produced from the blended soil sample B-3.



Photo-9 Fired clay bricks produced from the blended soil sample B-4.



Photo-10 Fired clay bricks produced from the blended soil sample B-1 which starts melting at a firing temperature of 1200°C.



Photo-11 Wood for firing in Burayu brick factory.



Photo-12 Inspection hole for controlling the degree of firing of bricks in Burayu brick factory kiln.



Photo-13 Over burnt clay bricks in Ethio brick factory.



Photo-14 Over burnt bricks in Burayu brick factory.



Photo-15 Broken bricks in Burayu brick factory.

SIGNED DECLARATION SHEET

This thesis is my original work, and has not been presented for a degree in any other university and that all sources of material used for the thesis have been dually acknowledged.

Candidate

Name: ALTAYEWORK TADESSE

Signature: _____