Jimma University

School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Construction Engineering and Management Chair

Suitability of Mixing Spent Coffee Grounds and Plastic Waste with Clay for Brick Production

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

By: Tarekegn Belay

September, 2017

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Advisor: Dr. -Ing. Fekadu Fufa

Co- Advisor: Eng. Alemu Mosisa

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CONSTRUCTION ENGINEERING AND MANAGEMENT STREAM

Suitability of Mixing Spent Coffee Grounds and Plastic Waste with Clay for Brick Production

BY: TAREKEGN BELAY

APPROVED BY BOARD OF EXAMINERS:

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Declaration

"I declare that this research report entitled "**Suitability of Mixing Spent Coffee Grounds and Plastic Waste with Clay for Brick Production**" is original work of my own, has not been presented for a degree of any other university and that all sources of material used for the thesis have been duly acknowledged".

Candidate:

Mr. Tarekegn Belay

Signature: ________________________

As Master Research Advisors, we here by certify that we have read and evaluate this MSc research prepared under our guidance, by Mr. Tarekegn Belay entitled: -

"Suitability of Mixing Spent Coffee Grounds and Plastic Waste with Clay for Brick Production"

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

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Abstract

The conventional method of bricks production using clay soil has brought natural resource depletion. In Jimma City and around Jimma there are high amount of Spent coffee ground and Plastic Waste thrown everywhere in the city. The aim of the study was to investigate the suitability of the mixture of clay soil, spent coffee ground and plastic waste for production of bricks. The specific objective of the study were evaluating index properties of clay soil and general properties of poly ethylene terephthalate and spent coffee ground, examine the physical and mechanical properties of the produced bricks, determine adequate firing temperature of produced bricks and determine the optimum percentage replacement of coffee ground and plastic waste as brick raw materials.

According to this research methodology, control bricks and four other different percentages of spent coffee ground and plastic waste with clay soil were replaced 2, 4, 6 and 8% and 1.5, 3, 4.5 and 6% by weight respectively manufactured. The laboratory test result of mean compressive strength for this study, the 2, 4, 6 and 8% spent coffee ground and 1.5, 3, 4.5 and 6% plastic waste and control bricks at 800^{0}C firing temperature were 16.51, 20.62, 14.42, 13.52 and 23.43Mpa respectively. The maximum compressive strength was at 3% Plastic Waste and 4% Spent Coffee Ground replacement fired at 600, 700, 800, 900 and 1000^{0}C which were 13.72, 16.31, 20.62, 16.72 and 16.37MPa respectively. The produced Bricks were fulfills Ethiopia standard and America society for testing and materials standard.

Based on the 800^{0}C firing temperature, Water absorption for all percentage replacement and control bricks were 21.44, 21.62, 22.15, 22.35 and 20% respectively. The efflorescence test results show that, all of the produced Bricks were not effloresced and the dimension tolerance test result was satisfied for construction purpose as Ethiopia standard and America society for testing and materials standard.

Finally incorporated spent coffee ground and plastic waste with clay bricks were better for construction purpose by fulfilling the standard in addition to giving safety for environment and natural resource depletion. Therefore, the concerned government bodies, society, Small and micro enterprises and the user shall adopt the mixing spent coffee ground and plastic waste with clay for brick production.

Keywords: *spent coffee ground, plastic waste, clay soil, physical and mechanical properties, firing temperature*

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Abbreviations

3Rs	Reducing, Reusing and Recycling
ASTM	American Society for Testing and Materials
BS	British Standard
CS	Clay Soil
CW	Coffee Waste
ES	Ethiopian Standard
HDPE	High-Density Polyethylene
LDPE	Low Density Poly ethylene
LL	Liquid Limits
LOI	Loss on Ignition
MDD	Maximum Dry Density
MSW	Municipal Solid Waste
OMC	Optimum Moisture Content
PE	Polyethylene
PET	Poly-Ethylene Teryphthalate
PETP	Polyethylene Terephthalate and Polystyrene
PI	Plastic Index
PL	Plastic Limits
PP	Poly propylene
PPM	Parts Per Million
PW	Plastic Waste
SCG	Spent Coffee Ground
UV	Ultraviolet
WA	Water Absorption

1. INTRODUCTION

Brick is one of the most important construction materials for the construction industry in many countries in the world. The production of bricks by using conventional method has brought undeniable shortcomings. During the production of bricks, the consumption of earth-based materials such as clay, shale and sand were resulted in resource depletion and environmental degradation (Alaa *et al.*, 2013). By using industrial wastes, which are no commercial values (Edward and Robert, 2011); into usable materials for construction applications, the demand for virgin quarry materials and landfill space will decline the natural resource depletion (Aselina, Hermawati and Noor, 2015).

The brick was anciently produced by mixing the known natural resources, forming the bricks, drying them and then firing those (Edward and Robert, 2011) and (Jeorge and Venta,1998).
According to Arul *et al.* (2014), Waste materials are defined as material by-products from human and industrial activities which have no lasting value. Waste materials are constantly being generated as by-products of commercial, industrial, construction and demolition activities. In recent years, several researchers have reported on the engineering properties of various by-products of commercial, industrial, construction and demolition activities as well as their sustainable reuse in engineering infrastructure applications such as pavements, embankment fill and pipe-bedding materials.
The increase in the number of agricultural industries supports economic growth positively but it affects the environment negatively by generating large amounts of agriculture wastes. As a result, agriculture wastes are generated in large quantities throughout the world. Those coffee producing countries, coffee wastes constitute a source of severe contamination and a serious environmental problem. For this reason, since the middle of the last century, efforts have been made to develop methods for its utilization as a raw material for the production of feeds, beverages, vinegar, biogas, caffeine, pectin, pectin enzymes, protein, and compost (Aselina, Hermawati and Noor, 2015).
Agro-industrial residues/wastes are generated in large quantities throughout the world. Their non-utilization results in loss of valuable nutrients and environmental pollution (Asrat, Belay and Bhagwan, 2015).

The use of processed CW has been the subject of numerous studies which, in general, lead to the conclusion that coffee by-products and wastes can be used in a variety of ways. Many research studies have been conducted for the replacement, reusing and recycling of CW but there is lack attention has been diverted to utilizing in manufacturing bricks. Nevertheless, from previous research, many types of waste material have been successfully utilized in manufacturing bricks, for example, cigarette butts (Kadir and Mohajerani, 2015).

Plastic waste can cause water, air and soil contamination. Shuffling and mixing the trash increases the difficulty and cost of recovering and recycling it. Most plastics take at least 240 years to degrade and consequently are a source of pollution (Angle *et al.*, 2015).

Ethiopia is one of the country growing coffee plantations from the world and the waste of the coffee such as SCG waste is high in amount and it is thrown everywhere in the cities and towns, especially those zone mostly producing coffee, the SCG waste was one of environmental pollution and it hasn't commercial value by reusing. This research investigated the utilization of SCG waste incorporating into clay for brick productions as construction materials.

The quantity of plastic waste in the cities and towns of Ethiopia are increased time to time. The one of it estimated that the rate of incremental expansion is because; it is not used as construction materials recycling. The PW and SCG incorporating with clay as raw materials of clay brick and also can reduce depletion of natural resource of clay brick materials and reduce environmental pollution.

1.1 Statement of Problem

Most of the house constructed in Jimma city is made up of the clay bricks and so many enterprises were actively producing clay bricks in Jimma city and around Jimma city to satisfying the demand. But these enterprises were not tried to replace partially by wastages to reduce natural resource depletion and environmental impact happened due to wastages. Jimma, as one of rapid urbanizing city, is far from satisfying its inhabitants by protecting the environment wastages. Now days and previously, the clay brick production consume the known natural resource materials to produce brick. For the production of clay brick, there is consumption of natural resources clay soil and if it is used continuously without replacing other wastes, the depletion of natural clay soil will be occurred. So for this solution, high amount of SCG and plastic waste (PET) are thrown everywhere in the Jimma city and which are disturbing the environment. These SCG and PW haven't commercial values in case of applying for construction purpose. Jimma city municipality has lost cost which spent for cleaning wastes are those of the problems. To overcome these problem this research was carried out by incorporating SCG and PW with clay for brick production.

According to Siti, Sullyfaizura and Norlia (2015), Disposal of large quantity of plastic bottle has emerged as an important environmental challenge, and it's recycling is facing a big problem due to non-degradable nature. Due to plastic does not decompose biologically; the amount of plastic waste is steadily increasing. According to Aselina, Hermawati and Noor (2015), in coffee producing countries, coffee wastes constitute a source of severe contamination and a serious environmental problem.

1.2 Research Questions

The research questions that this study explained; are as follows:

i. What are the index properties of clay soil and some general properties of PW and SCG used for brick production?
ii. What are the physical and mechanical properties of produced bricks?
iii. What is the optimum firing temperature of produced bricks?
iv. What is the optimum ratio of SCG and PW will be replaced during the production of clay bricks?

1.3 General Objectives

To Investigating the Suitability of Mixing Spent Coffee Grounds and Plastic Waste with Clay for Brick Production

1.4 Specific Objectives

i. To evaluate the index properties of clay soil and general properties of PET and SCG
ii. To examine the physical and mechanical properties of the produced bricks
iii. To determine adequate firing temperature of produced bricks
iv. To determine the optimum percentage replacement of SCG and PW as brick raw materials

1.5 Significance of the Study

This study is to investigate SCG and PW as brick raw materials and utilization of SCG and PW with clay for brick production around Jimma zone will provide helpful information to various stake holders:

It is used for reducing the depletion of natural resource of brick raw materials. Jimma city like other developing cities has poor solid waste management. In Jimma city SCG and PW are big challenges adversely affecting the Environment. So, this study reduces the environmental impact affected by SCG and PW.

Jimma city administration will benefit from the study as a source of information and foundation for the construction industry that can help to improve and control qualities of the materials regarding to standard and specifications and in addition to reduce the environmental pollution.

The Owners, contractors and consultants will benefit from the study as a source of materials for building construction projects and the study will provide lessons that will help the concerned body can come up with appropriate measures to address problems resulting from using of SCG and PW with clay for brick production. Other researchers may use the findings as a reference for further research on SCG and PW as a raw materials bricks.

1.6 Scope of the Study

The research focuses on the brick production which was incorporated CS with SCG and PW. In this study, chemical and physical properties of raw materials of bricks, physical and mechanical properties of harden tests were conducted. Incorporating other raw materials into clay for bricks production except SCG and PW such as PET (drinking water bottles) were out of the scope of this study. Various attempts were made to incorporate various waste material in bricks production such as natural fibers, textile laundry wastewater sludge, foundry sand, granite sawing waste, perlite, processed waste tea, sewage sludge, structural glass waste, fly ash, sugar cane bagasse ash, organic residue, steel dust, bottom ash, rice husk ash, silica fume, marble and granite waste, municipal solid incineration fly ash slag (Alaa *et al.*, 2013).

1.7 Limitation of the study

The following major limitations were faced during this study:

Mineralogical composition of CS and SCG were not conducted in this study due to the mineralogical machine test not give function during the time of this study conducted.

Depending on weather condition brick may be defected due to hot and cold weather condition exchange. Therefore, to check this defect, freezing and thawing test will be applied. Due to time constraint freezing and thawing test for brick is not conducted.

The mould and furnace were limitations of the study. In this study, the wooden mould was applied due to lack of standard mould. When the mixture paste of CS, SCG and PW were poured in the wooden mould, dimension of the mould was changed; this was changing the dimensional accuracy and shape of bricks. The availability of furnace and high temperature furnace were big challenges during this study.

2 LITERATURE REVIEW

2.1 Definition of Clay Bricks

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. 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 (Altayework., 2013).

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 for 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 (Altayework., 2013).

Construction materials for wall and distribution of households by construction material have not been well studied and complied in a data base in the country, However, around 76.0% 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%) than rural (74.8%). Slightly more than 9% of rural and 1% of urban households dwell in wood and thatch houses. Households living in housing units with walls constructed of stone and mud constitute 9.1% in rural and 6.3% in urban areas. Dwelling units with wall constructed by other types of materials are uncommon (< 10%) in both the urban and the rural areas. According to the study, 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 low (Eshetu, Alemu and Fekadu, 2017).

2.3 Theoretical Review

The increase in the popularity of using environmental friendly, low cost and lightweight construction materials in building industry has brought about the need to investigate how this can be achieved by benefiting the environment as well as maintaining the material requirements affirmed in the standard. Recycling of waste generated from industrial and agricultural activities as building materials appears to be viable solution not only to such pollution problem but also to the problem of economic design of buildings. Brick belongs to the wide family of construction materials since it is mainly used for the construction of outer and inner walls in buildings. The brick industry is the most indicated technological activity sector to absorb solid waste due to the large quantity of raw material used by the sector as well as by the large volume of final products in construction (Alaa *et al.*, 2013).

In many countries the compositions of waste is different, that it is affected by the socioeconomic characters, waste management programs and consumption patterns. But generally, the level of plastic in the waste composition is high. One of the largest component of plastic waste is polyethylene which is followed by polypropylene. The large volume of materials required for construction is potentially a major area for the reuse of waste materials. Recycling the plastics has advantages since it is widely used and has a long service life, which means that the waste is being removed from the waste stream for a long period. Because the amount of clay required to make bricks is large, the environmental benefits are not only related to the safe disposal of bulk waste, but also to the reduction of environmental impacts that arise due to burning of plastics.

Plastic waste which is increasing day by day becomes eyesore and in turn pollutes the environment. High-density polyethylene (HDPE) and polyethylene (PE) bags are cleaned and added with sand and aggregate at various percentages to obtain high strength bricks that possess thermal and sound insulation properties to control pollution and to reduce the overall cost of construction, this is one of the best ways to avoid the accumulation of plastic waste which is an on-degradable pollutant. This alternatively saves the quanta of sand/clay that has to be taken away from the precious river beds/mines. The plastic waste is naturally available in surplus quantity and hence the cost factor comes down (Dinesh *et a.l,* 2016).

At present, the need for a progressive reduction in human produced waste has been reasserted by both social pressure for preserving the environment and high cost for the final disposition of waste. This implies a newly generated interest in using products whose raw material is waste, which may lead to product diversification and final cost reduction, as well as to provide some industrial sectors with an alternative material. These factors explain why appreciation towards waste materials is an increasingly important current issue, which is necessary to clear up problems derived from current development.

Once waste has been generated, a wide range of techniques must be applied for its reintegration. The European Union and, in general, developed countries tend to the so called '3Rs' waste hierarchy: reducing the amount of waste one produces and recovering waste which can be reused, recycling by means of multiple available techniques and reusing, directly or indirectly, materials.

Building is an excellent industry for the absorption of considerable amounts of solid waste material, not only in the form that they are found, but also after being adapted. Building offers several advantages, among which are as follows: being able to absorb huge amounts of material and admitting an enormous range of qualities, which allows setting a wide range of materials, each showing its standardized quality and suitability for a specific use (Eliche *et al.*, 2011).

2.4 Effect of Temperature on Brick Firing

In the modern brick production fuel oil is used and covers less than 2% of the total annual brick production. The annual clay bricks production in Ethiopia is not more than 30 million pieces. This quantity is very small when compared to the amount produced in other countries. Clay bricks are transported hundreds of kilometers from the factories to regional cities in Ethiopia. Traditional clay bricks are widely produced in Jimma and Hollata, Oromia Regional National State, Ethiopia *(*Eshetu, Alemu and Fekadu, 2017).

Fire brick is a generic name that encompasses any brick that can withstand repeated heating and cooling at various temperature ranges. Additionally, fired bricks must be able to withstand different atmospheres, provide various structural or insulating qualities, and due to the difficulty in cutting them, must be available in a variety of shapes to add flexibility to kiln design and construction. Composite refractory brick has been identified as a solution to obtain both chemical and physical properties needed to be possessed by a good refractory brick (Davies *et al.*, 2015).

According to Johari *et al.* (2010), the firing of fired clay brick, a series of transformation occurs which determine the final properties of the brick product. The main factors involved in manufacturing bricks are the type of raw materials, fabrication method, drying procedure, firing temperature and firing profile. These factors will affect the quality of the final product. However, suggested that the durability and strength of bricks are related to their microstructure and mineralogy. In unfired clay bricks, the strength and water permeability are related to the size and shape of the particles present and the forming process, but upon heating, the nature of the mineral comprising the mass has a very important influence because of the chemical reactions and partial fusing which occur then the porosity in brick unit depends on the type of clay used in manufacturing and temperature of firing. The porosity of the brick influences its compressive strength, water absorption and permeability.

Most of the traditional clay brick production system in and around Jimma is obsolete and produce limited type and amount of clay bricks when compared with other countries. Furthermore, over and under fire clay bricks production is the regular practice of these traditional factories. One of the major contributing factors for this problem is poor kiln firing temperature controlling mechanism. So, besides assessing the kiln firing temperature controlling mechanism of traditional clay bricks production systems, determination of the effect of firing temperature on the compressive strength, water absorption and saturation coefficient of clay bricks could be vital input in improving the quality of traditionally produced clay bricks throughout the country (Eshetu, Alemu and Fekadu, 2017).

2.4.1 Physical and Chemical Changes 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 the Table 2.1.

Table 2.1: Important physical and chemical changes during clay-brick firing (Altayework., 2013)

No.	Firing temperature (^{O}C)	Physical and Chemical changes
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
6	900-1000	Sintering and vitrification leading to development of fired Strength

2.5 Materials of Bricks

2.5.1 Plastic Waste

By definition the plastics can be made to different shapes when they are heated. In closest environment it exists in the different forms such as cups, furniture's, basins, plastic bags, food and drinking containers, and they are become waste material. Accumulation of such wastes can result into hazardous effects to both human and plant life. Therefore, need for proper disposal, and, if possible, use of these wastes in their recycled forms, occurs. This can be done through process of plastic management. Waste management in respect to plastic can be done by recycling. If they are not recycled then they will become big pollutant to the Environment as they not decompose easily and also not allow the water to percolate in to the soil and they are also poisonous (Davies *et al.*, 2015) .

The quantity of plastic waste in Municipal Solid Waste (MSW) is expanding rapidly. It is estimated that the rate of expansion is increased from time to time; this is due to rapid growth of population, urbanization, developmental activities and changes in life style which leading widespread littering on the landscape. Thus disposal of waste plastic is a serious problem globally, since they are non-biodegradable and also researchers have found that the plastic materials can remain on earth for 4500 years without degradation (Amit *et al.*, 2012). Looking forward the scenario of present life style a complete ban on the use of plastic cannot be put even though the waste plastic is taking the face of devil for the present and future generation. But plastic is an effective raw material because of its large scale production witnessed after the industrial revolution. Today, it is impossible for any vital sector of the economy to work efficiently without usage of plastic starting from agriculture to packaging. Automobile, electronics, electrical, building construction, communication sectors has been virtually revolutionized by the applications of plastics. Thus we cannot ban the use of plastic but the reuse of plastic waste in building construction industry is considered to be the most feasible applications. Plastic have many good characteristics which include versatility, lightness, hardness, and resistant to chemicals, water and impact (Maneeth *et al.*, 2014).

According to Puttaraj *et al.* (2014), Poly ethylene terephthalate belongs to the polyester family of polymers, one of the largest and most diverse of the polymer families. This family of polymers is linked by the common feature of having an ester (-COO-) link in the main chain, but the range of polyester materials is probably the largest of all the polymer families. And also the chemical structure of the PET is having only atomic species that are carbon, hydrogen and oxygen. Also from the properties of the PET it can be understood that it has got good chemical resistance and better resistance to UV rays.

Waste plastic utilization in asphalting of roads" and the techniques to use plastic waste for construction purpose of roads and flexible pavements, which were developed by various researchers has been reviewed. And collectively emphasizes the concept of utilization of waste plastic in construction of flexible road pavement (Amit *et al.,* 2012).

Table 2.2: type of waste plastics (Puttaraj *et al.*, 2014)

Waste plastic	Available as
Poly ethylene terephthalate (PET)	Drinking water bottles etc.
High Density Poly ethylene (HDPE)	Carry bags, bottle caps, house hold articles etc.
Low Density Poly ethylene (LDPE)	Milk pouches, sacks, carry bags, bin linings, Cosmetics and detergent bottles.
Poly propylene (PP)	Bottle caps and closures, wrappers of detergents,
Urea formaldehyde	Electrical fittings, handles and knobs
Polyester resin	Casting, bonding fibers (glass, kevlar, carbon fiber)

2.5.1.1 Chemical structure of a waste plastic (polyethylene terephthalate) PET

The monomer for the production of PET is ethylene teryphthalate and this consists of the ethylene molecule (-CH2 - CH2-), two ester molecules (-COO-), and the terephthalate ring molecule. The only atomic species present in PET are therefore hydrogen, oxygen, and carbon. Burning PET generates only carbon dioxide (CO_2) and water (H_2O). So there is no potential danger of harmful gas emission. The structure of the PET monomer is shown in Figure 2.1 (Maneeth *et al.*, 2014).

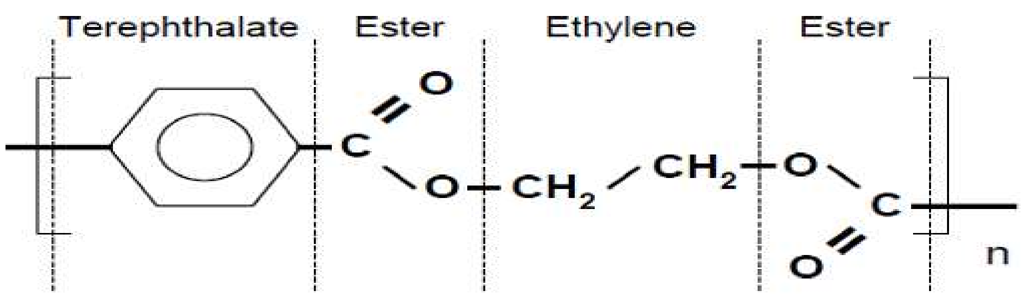

Figure 2.1: Chemical structure of PET of the monomer (Maneeth *et al.*, 2014)

2.5.2 Spent Coffee Ground

Spent Coffee grounds are a solid organic residue, widely generated by the service sector, which, at present, is not recycled or is used as a fertilizer in agriculture or for compost production. Therefore, it is necessary to research new applications on this kind of residue. Porous ceramic production may be a significant application for SCG. Besides, SCG may contribute to auto thermal combustion due to its high heating power, which involves lower fuel consumption during firing. Uses of organic residues in brick production in order to obtain porous ceramic bodies with better insulating properties have been studied by other authors studied the feasibility of reducing the thermal conductivity of ceramic material by incorporating lightening additives like agricultural residues: olive oil waste, paper industry waste, sewage and coke. By incorporating different proportions of organic residue into the ceramic matrix, the required thermal and acoustic insulation levels may be achieved. Consequently, a lightening, pore forming residue like SCG may provide economic benefits for the building industry and ecological benefits due to the lack of problems regarding residue depletion (Eliche *et al.*, 2011).

2.5.3 Clay Soil

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 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 (Altayework., 2013).

2.5.3.1 Clay Soil Types

According to different literatures, clay soils are classified into surface clays, shale and fire clays. Their unique properties are listed in the Table 2.3.

Table 2.3: Types of clay soils and their properties (Altayework., 2013)

Clay Soil Types	Properties	Remark
Surface clay	- -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	- -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	- 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. An d this refractory quality makes fire clay best suited to produce brick for furnaces, fireplaces, flue liners, ovens, and chimney stacks.	- Since fire clays are available at greater depth, it is expensive for exploration.

2.6 The Characteristic Clay Soil (CS) and Coffee Waste (CW)

The majority chemical compositions were higher in CS than CW. Silicon Dioxide (SiO_2) and Aluminum Oxide (Al_2O_3) in CS have the highest percentages of chemical composition than CW. Meanwhile, Barium Oxide (BaO) obtained the lowest percentages in CS. In terms of CW, highest percentages of chemical composition are Iron Oxide (Fe_2O_3) and Calcium Oxide (CaO) than CS. Besides, Molybdenum Trioxide (MoO_3) represents the lowest percentages in CW. Although the chemical composition is different, due to clay soil flexibility, various types of waste materials and origins are successfully incorporated inside clay brick and the properties obtained are still within the limits set by the required standards (Viruthagiri, Sathiyapriya and Shanmugam, 2014).

2.7 Manufacturing Process of Bricks

Although the basic principles of manufacture are fairly uniform, individual manufacturing plants tailor their production to fit their particular raw materials and operation. Essentially, brick are produced by mixing ground clay with water, forming the clay into the desired shape, and drying and firing. In ancient times, all molding was performed by hand. However, since the invention of brick-making machines during the latter part of the 19^{th} century, the majority of brick produced in the United States have been machine made (Bricks Industry Association, 2004).

2.7.1 Phases of Bricks Manufacturing

According to Altayework (2013), the manufacturing process has six general phases: 1) mining and storage of raw materials, 2) preparing raw materials, 3) forming the brick, 4) drying, 5) firing and cooling and 6) de-hacking and storing finished products

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: 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.

Preparation: - Preparation includes drying with air, blending, mixing and crushing of the raw materials. Crushing of the raw materials is done to reduce the oversized 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

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.

Drying: - Green brick are contains 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

Definition of firing: - Standard terminology of structural clays product of (ASTMC43-98a, 1999) express fires as follows:

Firing, - is a process of heating material to elevated temperatures. The temperatures are usually in excess of 930^0C. The firing temperature should be in excess of 930^0C. 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 color 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.

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

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 of ASTM standard (Bricks Industry Association, 2004).

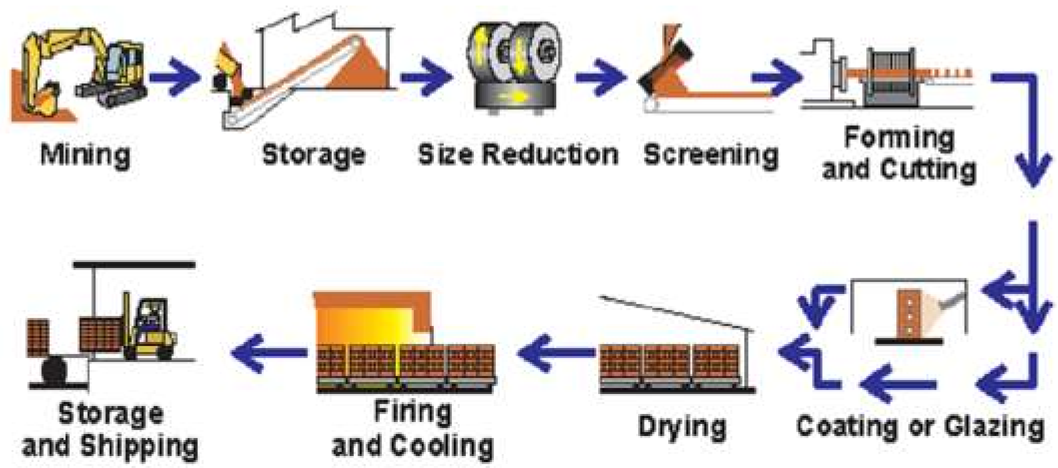

Figure2.2: Diagrammatic Representation of Manufacturing Process (Bricks Industry Association, 2004)

2.8 Laboratory Tests Done During Production Bricks

2.8.1 Chemical composition of clay soil

The elements that are found in soils in the highest quantities are O (oxygen), Si (silica), Al (aluminium), Fe (iron), C (carbon), Ca (calcium), K (potassium), Na (sodium), and Mg (magnesium). These are also major elements found in the Earth's crust and in sediments. Oxygen is the most prevalent element in the Earth's crust and in soils. It comprises about 47% of the Earth's crust by weight and more than 90% by volume. In any representative soil variety, the clay content may vary from 15 to 80% (alumina (Al_2O_3) content of this clay might vary from 10 to 30%), the free silica or sand from 5 to 80%, the oxides of iron from 1 to 10%, the carbonates of lime and magnesia together, from 1 to 5%, and the alkalis from 1 to 4% (Heinrich *et al*., 2008).

Table 2.4: Comparison of chemical analysis of good and ordinary soil sample for vertical shaft brick kiln firing (Heinrich *et al*., 2008)

No	Test parameters on dry basis (% by mass)	Good sample	Ordinary Sample	Effects on fired brick property in a vertical shaft brick kiln firing system
1	Loss of Ignition	3.2	7.7	Measure of organic matter in soil. Too high LOI is deleterious, giving high porosity, shrinkage and chances of black coring increases due to fast firing system in vertical shaft brick kiln.
2	Silica as SiO_2	61.8	80	Structural silica within clay mineral gives strength in the fired brick whereas free silica gives strength and rigidity to the green brick. Silica is the primary constituent of any soil. Gives strength in a green brick and helps in maintaining the shape and size when fired at vitrification temperatures. Silica (structural silica) present within the clay reacts with Alumina to form mullite, which is also responsible for giving the required strength in a fired brick.
3	Iron as Fe_2O_3	> 3	0.9	Gives a strong red color to the brick when fired at appropriate temperatures.
4	Alumina as Al_2O_3	23	14.6	In combination with silica forms mullite ($2Al_2O_3.3SiO_2$) at high temperatures. The mullite is in the form of criss-crossing needles which are responsible for developing strength in a fired brick. An increased strength of a fired brick will only happen if the amount of alumina content is being equalized with silica in the ratio of 2:3.
5	Sodium as Na_2O	0.1	0.2	Indication of montmorillonite clays. More than 1% content will affect the fired brick properties giving a white scum in the fired bricks when in contact with water

6	Potassium as K_2O	2.76	Trace	Indication of Illitic clays. Higher quantities present in the clay will lead to lower vitrification temperatures but with a high firing shrinkage.
7	Calcium as CaO	Trace	Trace	In lump form is extremely deleterious resulting in lime bursting. However in fine state and more than 2% will mask the red color given by iron, resulting in a buff coloured fired brick.
8	Magnesium as MgO	1.2	1.2	Indication of Illitic clays. Is beneficial for fired brick properties since it acts as a catalyst during the vitrification stage and aids in a denser and stronger brick.
9	Organic carbon as C	0.82	0.66	Measure of heat producer within the soil. Acts as an internal fuel thus reducing the external fuel consumption. Higher amounts will result in black coring, warpage, cracks due to the fast firing pattern in vertical shaft brick kiln.

According to Izwan *et al.* (2011), the LOI reported for clay soil less than 8.75% due to the reason of LOI test is ideal for bricks productions and as Akinshipe and Kornelius (2017) Finding, the LOI in clay during firing is happen due to the burning out of carbonaceous matter and combustible Sulfur in the clay, breakdown of carbonates present in the clay to give off carbon dioxide, CO_2 and release of combined water from the clay.

As Council of Scientific and industrial Research (2011) report, the clay soil has less amount is the LOI due to the high amount of free silica and LOI less than 10% important for clay soil and recommended for brick production.

2.8.2 Grain Size of Clay Soil

This test was to know the particle size distribution of the soil and the percentage of pass through sieve No. 200(0.075mm sieve size) to determine whether the soil coarser or finer and the percentage of coarser and finer of the soil. The classification of the soil and method were as per (ASTM D422, 1998).

Table 2.5: soil classification according to ASTM standard (ASTM D422, 1998)

Classification	Size particles
Gravel	76.2 – 4.75 mm
Sand	4.75 – 0.075 mm
Coarse sand	4.75 – 2 mm
Medium sand	2 - 0.425 mm
Fine sand	0.425 – 0.075 mm
Silt size	0.074 to 0.005 mm
Clay size	< 0.005 mm
Colloids	< 0.001 mm

The Sieve analysis test was carried out to determine the particle size distribution of the soil samples. The Particle Size distribution of the soil gives a view on the grading, mechanical properties, soil composition and strength of the soil particles. Poor Particle Size distribution affects the density, permeability, shear strength and the ultimate bearing capacity of the soil (Expedito, Baraka and Arthur, 2015).

2.8.3 Liquid Limit Test of Clay Soil

According to Expedito, Baraka and Arthur (2015), the liquid limit is the minimum moisture content at which the soil will flow under its own weight or is the water content at which the soil passes from the plastic to the liquid state. At this moisture content the soil ceases to be liquid and becomes plastic.

2.8.4 Plastic limit Test of Clay Soil

According to ASTM D4318 (2000), ref. number 4.2, Plastic limit (PL) is determined by the minimum moisture content at which the soil can be rolled into thread of 3mm diameter without breaking up. 20g of sieved soil was mixed thoroughly with water. The plastic limit was calculated using the following expression.

2.8.5 Plasticity Index Test of Clay Soil

Plasticity index is the range of moisture content at which a soil is in plastic state. From the plastic index the soil plasticity can be rated as low, medium, high or extremely high (Expedito, Baraka and Arthur, 2015).

According to V. N. S.Murthy (2002), the soil classified cording to plasticity index as shown in Table 2.7.

Table 2.6 : Soil classifications according to Plasticity Index

Plasticity index	Plasticity
0	Non-plastic
< 7	Low plastic
7 – 17	Medium plastic
> 17	Highly plastic

PI = LL – PL---2.2

Where, PI = Plastic index; LL = Liquid limit; and PL = Plastic limits

2.8.6 Linear Shrinkage

linear shrinkage is the difference of the original length of wet soil before oven dry and the length after oven dry (Expedito, Baraka and Arthur (2015).

The following table shows the Soil classification quality according to percentages of shrinkages could be Good, Medium good, Poor and Very poor.

Table 2.7: Soil classification according to degree of shrinkage (V. N. S. Murthy, 2002)

shrinkage %	Quality of soil
< 5	Good
5 – 10	Medium good
10 – 15	Poor
> 15	Very poor

2.8.7 Specific Gravity of Clay Soil

Specific gravity is the relative density of the soil particle. Specific gravity of the soil samples were assessed in order to assist in analysis of the volume occupied by soil solids and voids, which in turn helps to determine the porosity, void ratio and the mass of soil solids. Three tests were carried out for each sample and the average value was then calculated (Expedito, Baraka and Arthur, 2015).

2.8.8 Compaction Test of Clay Soil

According to Akaninyene and Jonathan (2016), compaction test is specifically carried out to determine the range of moisture content at which maximum compaction can be achieved provided the moisture content obtained during test is not exceeded. The stability of the compacted layer can always be achieved. It ensures that no further deformation occurs provided the imposed load does not exceed that obtained during laboratory test.

2.8.9 Compressive Strength Test of Bricks

The compressive strength of brick is measured by loading brick in compression. Conventional tests require a brick to be loaded normal to its bed face and the faces are capped or packed before testing to reduce the effects of roughness, Soft packing has the advantage of a reduction in the time of preparation for testing and it was claimed that soft capping produced a more representative strength than hard capping (Obam *et al.*, 2015).

$$\text{Compressive Strength} = \frac{\text{Maximum Crushing Load}}{\text{Surface Area}} \quad \text{---} 2.1$$

2.8.10 Water Absorption of Bricks

Absorption of brick is its capacity to absorb water to saturation. The rate of absorption or suction of bricks has an important effect on the adhesion of brick and mortar because if the brick absorbs too quickly from the mortar, the mortar will set too soon and adhesion will be poor. All bricks with absorption of 19.85g/min should be wetted sufficiently so that the rate of absorption does not exceed this amount (Abebe, 2002).

2.8.11 Test for Saturation Coefficient of Bricks

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 (Altayework, 2013).

2.8.12 Dimensional Tolerance

Dimensions of bricks are changed, Because of the shrinkage during drying and firing. The amount of variation in shrinkage depends on many factors, such as variations in raw materials and manufacturing techniques. Brick manufacturers attempt to control these factors. Variations in brick size are compensated for by the mortar joint thickness to achieve fixed dimensions of the masonry (ASTMC216-10, 2010).

Table 2.8: ASTM standards on dimension tolerance of bricks (ASTMC216-10, 2010)

Specified dimension or average brick size(mm)	Maximum permissible variation in (mm) plus or minus from				
	Column A(for specified)		Column B(for average bricks size in job lot sample)		
	Type FBX	Type FBS	Type FBX	Type FBS(smooth)	Type FBS (rough)
76 and under	1.2	2.4	1.6	1.6	2.4
76 to102	2.4	3.2	1/6	2.6	3.2
102 to 152	3.2	4.8	2.4	2.4	4.8
152 to 203	4.0	6.4	2.4	3.2	6.4
203 to 305	5.6	7.9	3.2	4.8	7.9
305 to 406	7.1	9.5	4.8	6.4	9.5

Note: FBX: Brick for general use in exposed exterior and interior walls where a high degree of mechanical perfection, narrow colour range and minimum permissible variation in size are required.

FBS: Brick for general use in exposed exterior and interior masonry walls where wider colour ranges and greater variation in sizes are permitted than are specified for type FBX.

For making a wooden mould the final size of the fired brick and the overall (both green and fired) shrinkage of the soil needs to be determined. Once the fired brick size has been decided, the interior dimensions of the mould can be calculated based on the shrinkage rates during the brick bat testing. In brick making the clay shrinkage rate varies between 4-10%. Soils with shrinkage lesser than 4% will not develop any binding properties making the brick weak and fragile. Soils with shrinkage higher than 10% will be more susceptible to drying shrinkage cracks and also the fired dimensions will be difficult to control. More over the greater the shrinkage, the higher the chances of the green brick warping during drying. For any brick production to get a balance between reasonable strength and productivity with minimal green brick rejection a shrinkage rate between 6-8% is ideal (Heinrich *et al*., 2008).

2.8.13 Efflorescence in Bricks

Usually sulphate of magnesium, calcium, sulphate and carbonate (and sometimes chloride and nitrates) of sodium and potassium are found in efflorescence. These salts may be traced to the brick itself, sand used in construction, the foundation soil, ground water, water used in the construction and loose earth left over in contact with brick work. Bricks with magnesium sulphate content higher than 0.05 percent should not be used in construction. Soluble salt content in sand (chloride and sulphate together) should not exceed 0.1 percent (Sharmistha, Joyanta and Richi, 2013).

The absence of gray or white deposits on the surface of the bricks after the test indicates absence of soluble salts. If the white deposits cover about 10% of the surface, the efflorescence is said to be slight. The efflorescence is considered as moderate when the white deposits cover about 50% of the surface. If gray or white deposits are found on more than 50% of surface, the efflorescence becomes heavy. And the efflorescence is treated as serious when the deposits are converted into powdery mass (Lieiva *et al.,* (2015).

2.9 Different Standard specification for Clay Bricks

In different standard specifications, the main parameter for classifying clay bricks is their physical and mechanical requirements. To classify burnt clay bricks used mainly by their mean compressive strength and other quality properties such as water absorption.

Clay bricks were classified based on their compressive strength, water absorption and Saturation coefficients, British Standard Specification for Clay bricks (British Standard BS 3921, 1985) also classifies clay bricks based on their compressive strength and water absorption and Ethiopian standard specification for Clay Bricks- also uses these physical requirements for classifying solid fired clay bricks (ASTM C62-97a, 1999).

2.9.1 Ethiopian standard specification

Bricks are classified according to the laboratory test results means and individuals of compressive strength, water absorption and saturation coefficient, according to Ethiopian standard ES 86 (2001) given in the Table 2.9.

2.9.1.1 Compressive Strength

Table 2.9: Minimum compressive strength of solid clay-bricks

Class	Minimum compressive strength	
	Average of five Bricks (N/mm^2)	Individuals of five bricks (N/mm^2)
A	20	17.5
B	15	12.5
C	10	7.5
D	7.5	5

2.9.1.2 Water absorption Test

According to Ethiopian standard, based on laboratory test results of their water absorption, bricks are classified as shown in Table 2.10.

Table 2.10: Maximum water absorption of solid clay-bricks (%)

Class	After 24 hour immersion		After 5 hour boiling	
	Average of five bricks	Individual of Five bricks	Average of Five bricks	Individual of five bricks
A	21	23	22	24
B	22	24	23	24
C,D	No limit	No limit	No limit	No limit

2.9.1.3 Saturation coefficient Test

According to Ethiopian standard ES 86 (2001), saturation coefficient of clay bricks is given in the Table 2.11

Table 2.11: Maximum Saturation coefficients of solid clay bricks

Class	Average of five bricks	Individuals of five bricks
A,B	0.96	0.99
C,D	No limit	No limit

2.9.2 British Standard Specification for Clay bricks

As stated in British Standard BS 3921 (1985), bricks are categorized based on their compressive strength and water absorption as listed in the Table 2.12.

Table 2.12: Classification of clay bricks by compressive strength and Water absorption

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

2.9.3 The American Society for Testing and Materials; Standard Specification for Building Bricks

According to ASTM C62-97a (1999), standard specification for building bricks, clay bricks are classified based on their compressive strength, water absorption and saturation coefficient as shown in the Table 2.13.

Table 2.13: Classification of clay bricks based on their physical requirements

Designation	Minimum compressive strength, gross area (MPa)		Maximum water Absorption by 5 hr. boiling, (%)		Maximum saturation Coefficient	
	Average of Five bricks	Individual of five Bricks	Average of Five bricks	Individual of five Bricks	Average of Five bricks	Individual of five Bricks
Grade SW	20.7	17.2	17	22	0.78	0.8
Grade MW	17.2	15.2	22	25	0.88	0.9
Grade NW	10.3	8.6	No limit	No limit	No limit	No limit

According to this standard specification, classification brick are based on their resistance to damage by freezing when the weather wet as defined in note 1. On this specification, three grades are enclosed and the requirements are listed in Table 2.13.

1. 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.
2. 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.
3. 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.

3 MATERIALS AND METHODS

3.1 Sampling Area

The samples were collected from Jimma Zone, southwestern Ethiopia which is located 346 km from southwest of Addis Ababa. Its geographical coordinates are between 7° 13'- 8° 56'N latitude and 35°49'-38°38'E longitude with an estimated area of 19,506.24. The city is found in an area of average altitude of about 1780 m above sea level. It is laid in the climatic zone locally known as Woyna Daga which is considered ideal for agriculture as well as human settlement.

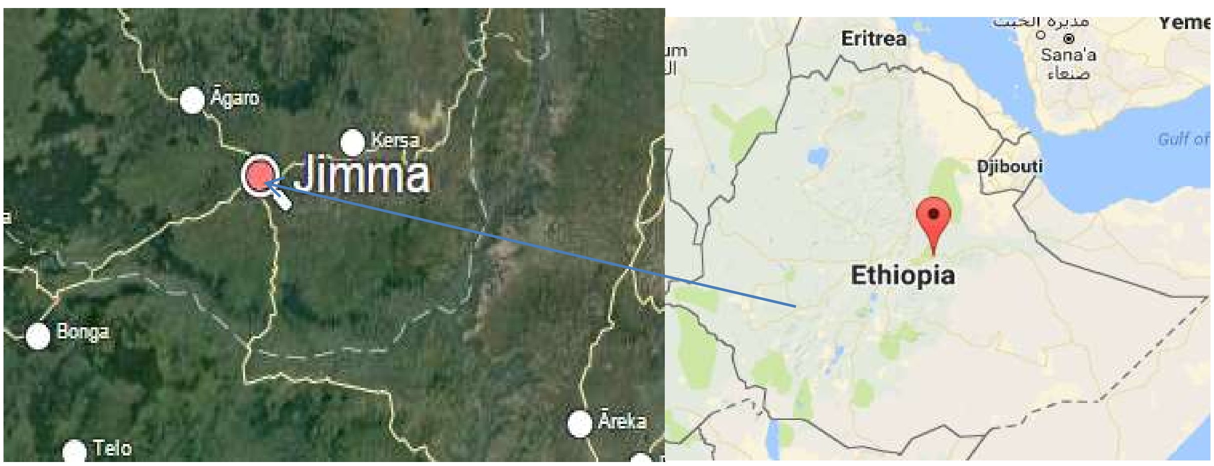

Figure 3.1: Sampling

3.2 Study Period

The research study took seven Months and it was started on March 2017 and ended September 2017, which was including from data collection up to final of paper submission.

3.3 Experimental procedure

This Experimental procedure is based on a purposive sampling selection process in terms of which a representative sample of SCG, PW such as PET (drinking water bottles) and CS materials have been surveyed and the research was conducted by using both descriptive and analytical methods, which mean that the methodology used in the research was laboratory analysis of sample data and the data have been collected from the site (Kilole) and cafeterias.

The laboratory test for physical and mechanical properties of materials of bricks and produced bricks were conducted according Ethiopian standard (ES) and ASTM for one of the tests and the mean of result was taken.

The following diagram represents the schematic diagram over view of methodologies sequences carried out in the study.

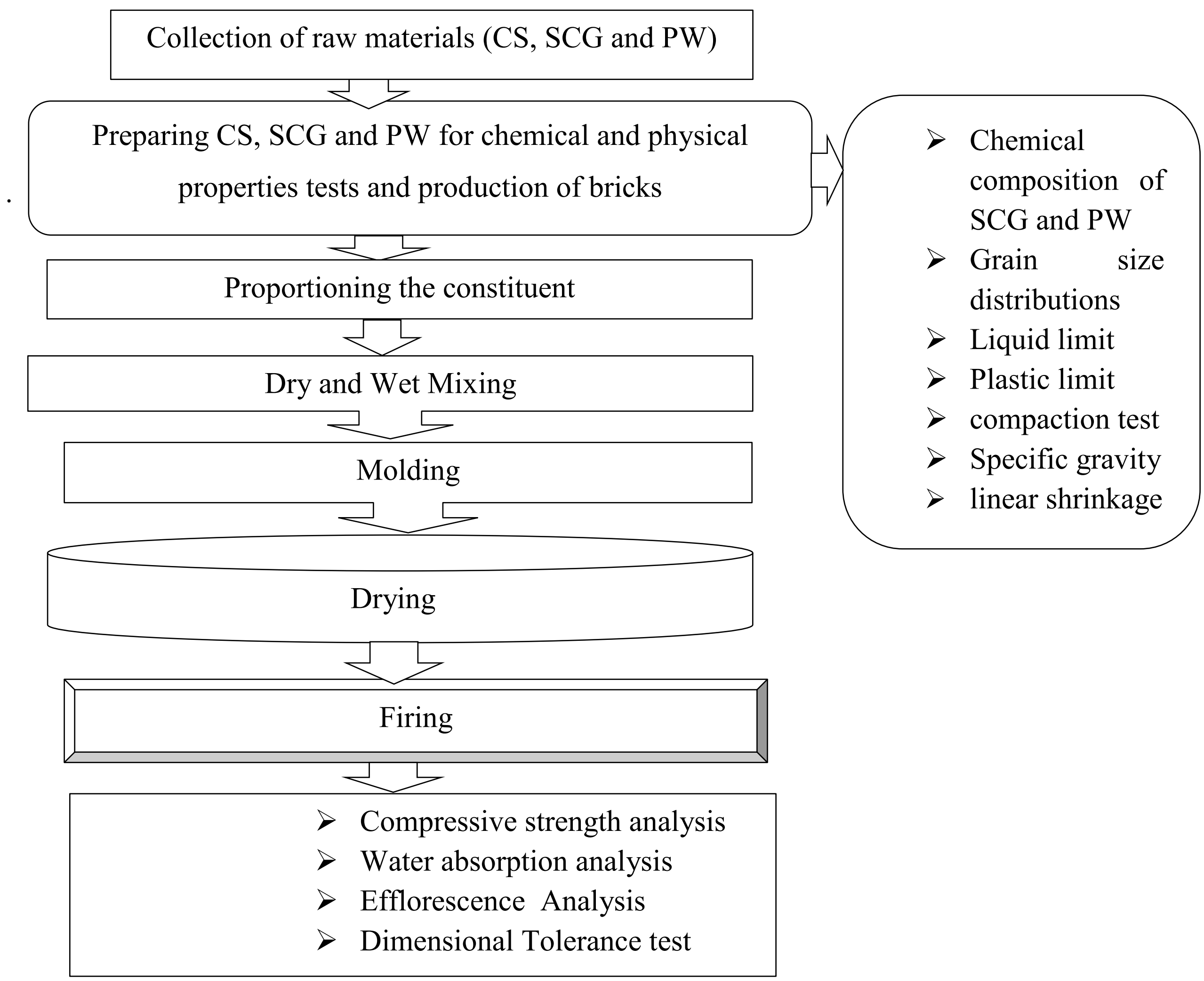

Figure 3.2: Schematic diagram of experiment

1.3.1 Materials preparation for experiment

Clay soils (CS), spent coffee ground (SCG) and plastic waste (PW) are raw materials that were used in this research. The CS, SCG and PW were obtained from Agaro (Kilole), cafeterias and garbage in Jimma city respectively. Here in Jimma city PW type especially PET such as Drinking water bottles and SCG are high in amount and this type of plastics are better than the other for this study, because of they are abundantly available and free from any previously carried chemicals.

3.3.1.1 Clay soil

Clay soil used for this study was white clay soil and it was mined by man power from Agaro specific place kilole as shown in Figure 3.3 and it was taken at the depth of one meter for production of Bricks. The initial preparation conducted during the study were consists of drying by sun light and milling in order to obtained good particle size distribution for brick production and physical tests such as Index properties of clay soil.

Figure 3.3: Picture taken during the collection of soil sample

3.3.1.2 Spent Coffee Ground

Definition of spent coffee ground: - SCG is made after the coffee is roasted and milled/grinded, then the milled coffee was soluble in water and the SCG remains behind the cup or jug after the main soluble compounds have been extracted.

SCG was collected from different cafeterias those are making coffee for drink and transported to laboratory. After that the initial preparation consists of drying by sun light in order to easily dry mix with other constituent and passed through different sieve size for grain size distribution to related proportion size with CS and PW as shown in Figure 3.4.

Figure 3.4: Picture taken during the collecting and drying of Coffee Ground

3.3.1.3 Plastic waste

Plastic waste was collected from garbage and taken to the laboratory as given in Figure 3.5. Then removing any impurities from plastic waste and burning in open space and crushing manually by hammer in order to obtained suitable particle size distribution passed through different sieve size with CS and SCG as a good filler.

Figure 3.5: Picture taken during the collecting, burning and milling by hammer of PW

3.3.2 Tests for Physical and chemical Properties of raw materials of Bricks

The materials used for this study were CS, SCG and PW. Before producing bricks sample, physical and chemical properties of CS, SCG and PW were tested to identify the suitability of materials for brick production.

3.3.3 Chemical composition of CS and SCG

The chemical composition of the CS and SCG were determined at Ethiopian Geological survey. These tests were to identify chemical composition available in CS and SCG, and suitability for the production of bricks. The soil sample was mined at an average of one meter depth, the same as the soil sample taken for brick production. Two kilograms for each of CS and SCG samples were taken to the laboratory and chemical composition concentration percentages available in the SCG and CS were analyzed. The Chemical composition analyses were done by LiBO2 FUSION, HF attack, Gravimetric, Colorimetric and Atomic Absorption Spectrophotometry (AAS) test method of analysis.

3.3.3.1 Index Properties Tests of Clay Soil

These tests were conducted to identify the classification and suitability of clay soil as per different standards for brick production.

Particle size analysis of Clay soil: For coarse grained soil (larger than 0.075 mm sieve size) the mechanical method of analysis was done, for grains finer than 0.075 mm sieve size the process of sedimentation by Hydrometer method was used, for the analysis to determine the particle size distribution of a clay soil sample by applying the particle size analysis using the mechanical method (Sieve analysis), To draw the grain size distribution curve.

Sieving can be performed in either wet or dry condition. Dry sieve analysis is suitable for cohesion less soils with little or no fines, and wet sieve analysis is for soil containing a substantial of fine particles.

In this study, sieving was performed in wet and dry condition. The soil sample taken for this test was 500g. The amount of clay soil pass through 0.075 mm sieve size was checked as greater than 35%, which shows the soil was finer and the analysis was carried out by the process of sedimentation hydrometer method (ASTM 152H) and the remaining particles on 0.075 mm was carried out by mechanical method (sieve analysis) by oven drying for 24hr at 110 ± 5^0c.

In the sedimentation analysis, only those particles which are finer than 75 micron size are included. Hence soil sample is washed through a 75 micron sieve. In this test the volume of suspension is 1000 ml and 50g dry soil specimen was taken.

To remove organic matter from the soil by oxidation and accomplished by mixing the soil sample with a solution of 30% hydrogen peroxide. To have the proper dispersion of soil, the dispersion agent is added to the soil to increase specific gravity of suspension. ASTM D422 (1998), recommends the use of dispersing solution sodium-hexametaphosphate and sodium carbonate in distilled water to make 1000 ml of solution. The sedimentation jar is shaken vigorously and then kept vertical over a solid base and watch was simultaneously started. The hydrometer and thermometer are slowly inserted in the jar and hydrometer readings and temperature readings are taken in 1, 2, 5, 15, 30, 60, 120, 240, 480, 960 and 1440 minutes as given in Figure 3.6.

Figure 3.6: picture taken during the analysis oh hydrometer test

Grain size analysis expresses quantitatively, the proportion by weight of the various sizes of particles present in the soil. Grain size analysis is mathematical analyzed by given in equation 3.1 for sieve analysis and combined the hydrometer and sieve analyses, the amount of each soil classification were known.

$$\text{Percentage of Retained on any Sieve} = \frac{\text{Weigth of Soil Retained}}{\text{Total Soil of Weight}} * 100 \text{----------------------------} 3.1$$

Liquid Limit Test:. The soil which was specified to liquid limit test was passed through No.40 (425 µm Sieve) and 250 g was taken. The liquid limit is identified in the laboratory as that water content at which the groove cut into the soil pat in standard liquid limit device requires 25 blows (drops) from a height of 1cm to close along a distance of 13 mm (casagrande method). The water content at which the groove closed was done. A graph of moisture content against number of blows in logarithmic scale was done. The moisture content corresponding to 25 blows was taken as the liquid limit of the sample. The first trial was closure between 25 to 35 blows; the second trial was between 20 and 30 blows; and the third trial was between 15 to 25 blows (ASTM D4318, 2000) as given in Figure 3.7.

Figure 3.7: Picture taken during the liquid limit by using casagrande apparatus

Plastic Limit Test: Plastic limit was done by taking 250 grams of clay soil which was air dried and passed through 425 µm sieve was mixed with distilled water until it became like a ball. Some amount soil samples from the ball was taken and rolled into threads with fingers. Rolling and remoulding was done between the fingers and glass plate until the thread crumbled at diameter of three millimeters. The water content of the crumbled thread was determined.

..

Figure 3.8: Plastic limit test

Plasticity index (PI): plasticity index (PI) is the range of water content over which a soil behaves plastically. Numerically, it was the difference between the liquid limit and the plastic limit. PI = LL – PL.

Linear Shrinkage (LS): This test was conducted to determine shrinkage due to drying and it is happen more in clay soil during the drying process is prolonged after the plastic limit has been reached and the volume of the soil continue to decrease and the reverse condition is happen during wet. For this study, the test method was carried out as per (ASTM D4943-08, 2017) and the sample was prepared by mixing with water until it was reached for liquid limit test. In this test, linear shrinkage was measured along linear measurement and the soil sample was passed through 425 micro test sieves, originally having the moisture content of the liquid limit and oven dried at 110 ± 5^{0}C for 24hrs as shown in Figure 3.9.

Figure 3.9: Picture taken during the linear shrinkage

Specific gravity:. The particular specific gravity of a soil actually denoted the specific gravity of the solid matter of the soil and refers, therefore, to the ratio of the mass of solid matter of a given soil sample to the mass of an equal volume (i.e. equal to the volume of the solid matter) of water.

This test was conducted to determine the volume occupied by the soil solids and voids, which help to determine the porosity of the soil, void ratio and mass of the soil as per (ASTM D854, 2002) by using pcynometer apparatus. The soil sample taken for this test was 10 g which passed through 2 mm sieve size. For this test, three tests were done and the averages of the three results were taken. The test results were attached in the appendix one.

$$G_s = K[\frac{M_s}{M_s + M_{pw}(at T_x) - M_{pws}}] \text{---} 3.2$$

Where*:* G_s = specific gravity of soil at 20^{o}c; K = conversion factor and specific gravity of water at T_x/specific gravity of water at 20^{o}c; Ms = mass of sample of oven dried soil (i.e M_{ps}-M_p) g;

M_{pw} (at T_x) = mass of pycnometer filled with water at temperatureT_x,g; T_x = temperatur of contents of pycnometer when M_{pws} was taken in ^{0}c; M_{pws}= mass of pycnometer plus water and soil (at T_x),g.

Compaction test: This test was conducted to determine optimum moisture content (OMC) and maximum dry density of the soil samples and to make dense by removing the air void at given moisture the pressure made dense soil as per ASTM D698-91 (2015)**,** Optimum water content is used to decide amount of water required for mixing the soil sample even it was used during brick production except some changes below and above water content gotten from compaction test at the materials dense due to workability. The soil sample taken for compaction test was 16 kg which passed through 4.75 mm sieve size for five test points and mean result was taken. The mathematical calculations are given below equations:

$$Wet\ Density = \frac{Weight\ of\ Wet\ Soil}{Mould\ Volume} \text{--} 3.3$$

$$Weight\ of\ Dry\ Soil = (Weight\ of\ Dry\ Soil + Can) - Weight\ of\ Can \text{-----------------------} 3.4$$

$$Weight\ of\ Water = (Weight\ of\ Wet\ Soil + Can) - (Weight\ of\ Soil + can) \text{--------------} 3.5$$

$$Moisture\ Content(\%) = \frac{Weight\ of\ Water}{Weight\ of\ Dry\ Soil} X\ 100 \text{---} 3.6$$

$$Density\ of\ Dry\ Soil = \frac{Bulk\ Density\ of\ Soil}{1+Moisture\ Content} \text{---} 3.7$$

Figure 3.10: photo taken during compaction test

3.3.3.2 Physical Properties Tests of SCG and PW

Grain Size Analysis of SCG and PW: Particle size analysis of SCG and CS were conducted to determining particle distribution of SCG and PW. For each of materials 500 g of samples were taken and by arranging the sieve according to their size from big to small size, top to down up to pan and the shaker was applied for 10 minutes. After that, the mass of any SCG and PW retained on any sieve was balanced and percentage of finer was determined. Depending on the amounts of SCG and PW passed through 0.075 mm sieve size were greater/less than 35%, the samples percentage were divided coarser and finer.

$$Percentage\ of\ Retained\ on\ any\ Sieve = \frac{Weigth\ of\ SCG\ or\ PW\ \ Retained}{Total\ SCG\ or\ PW\ Weight} * 100 \text{------3.8}$$

Specific gravity of SCG and PW: Specific gravity of SCG and PW were to determine the ratio of the mass of a given volume of materials to the mass of an equal volume of water as per (ASTM D792 – 08, 2008) for PW. But for SCG the same procedure used for clay soil applied as per (ASTM D854, 2002). In effect, it tells us how much the material was heavier than (or lighter) than water as given in the equations below.

In these tests, the amount of samples taken for the two materials were 10 g which passed through 2 mm sieve size and then specific gravity were applied by using pcynometer apparatus.

Calculate the specific gravity of the PW was as follows according to (ASTM D792 – 08, 2008).

$$Sp.gr\ @23℃ = \frac{a}{(a+w-b)} \text{--3.9}$$

Where: *a* = apparent mass of specimen, without sinker, in air, *b* = apparent mass of specimen (and of sinker, if used) completely immersed and of the partially immersed in liquid, and *w* = apparent mass of totally immersed sinker (if used) and of partially immersed.

Calculate the specific gravity of the SCG was as follows:

$$G_{SCG} = K[\frac{M_{SCG}}{M_{SCG} + M_{pw}(at T_x) - M_{PW(SCG)}}] \text{--3.10}$$

3.3.4 Production of bricks specimen

In this research, five types of brick specimen were produced which were control brick (0%) and different percentage of SCG 2, 4, 6 and 8% and PW 1.5, 3, 4.5 and 6% were added into clay for brick production by weight with 24cm x 12cm x 6cm size. The constituent have been replaced as taking reference point according to Aselina, Hermawati and Noor (2015).

There were four major steps has been involved in producing bricks for test specimens. These included, Proportioning of constituents, mixing (dry and wet), moulding/pressing of bricks, air-curing or drying and firing.

3.3.5 Sample Size

Table 3.1 shows that, the sample size of bricks produced for physical and mechanical tests. These samples were produced according to the percentage replacement including control bricks (0%) by considering the amount bricks needed for each of testes.

Table 3.1: Mixing ratio and amount of sample produced

PW : SCG : CS Ratio (%) in Weight					
Temperature in ^{0}C	control bricks	1.5 : 2: 96.5	3 : 4 : 93	4.5 : 6 : 89.5	6 : 8 : 86
600	20	20	20	20	20
700	20	20	20	20	20
800	20	20	20	20	20
900	20	20	20	20	20
1000	20	20	20	20	20
Total brick produced	100	100	100	100	100

3.3.6 Sources of Data

Both primary sources and secondary data sources were used. Secondary data used for this research was collected from different journals, book, website and standards during the literature review and primary sources data for this study were laboratories or experimental output.

3.3.7 Proportioning the Ingredients of Brick

Proportioning of three types of constituent (CS, SCG and PW) were done as per the percentage by weight and control bricks for comparison purpose.

3.3.8 Mixing of the Ingredients Brick

Mixing is done to make the CS, SCG and PW homogeneous and smooth. The mixing of constituent materials was performed in two stages. First, the dry materials (SCG, PW, CS) were mixed thoroughly using a manually. The second stage was involved the addition of water. During manual moulding of green bricks the minimum moisture content varies between 25 to 35%. The moisture content is a factor of the ease of workability of the paste of CS, SCG and PW and moulder habits. This is done gradually until the mixtures were uniform and moldable consistency.

Figure 3.11: Dry mixing the during the production of the bricks sample

3.3.8.1 Moulding

A wooden mould was made according to Ethiopian standard (ES) with the 24cm X 12cm X 6 cm with internal dimension. The mould was open at the top to produce the bricks as easily.

The CS, SCG and PW mixture paste were prepared. After the preparation of the paste, it was thrown into the mould box by generate a natural force, it was thrown from approximately a height of 35 - 45 cm above the mould. It was compacted by hand into the box by force carefully and cutting by thin wires/thread the excess paste above the mould. This was to get the correct angle, shape and avoid air void. The freshly produced bricks were carefully stored in the open air in rows as give in Figure 3.12.

Figure 3.12: Green bricks

3.3.8.2 Drying

Water was added during paste preparation to increase workability of the mixture, but in drying it was removed for case of decreasing crack in fired bricks with less water content and the other was for time consumption. Proper drying of bricks was involved by rotating the bricks to different exposure.

3.3.8.3 Firing

During production of fired bricks, a high temperature furnace was used. An initial study was carried out to find the effect of firing temperature on the physical and mechanical properties of bricks. The bricks were fired at 600, 700, 800, 900 and 1000^{0}C by preheat in 5hours constant at Burka Gibe Metals and Metals Spare Part Share Company respectively by taking physical and mechanical properties of bricks gradually to get the adequate firing temperature as shown in the Figure 3.13. The starting point of firing temperature was fixed according to different literatures and ending of firing temperature was fixed due to the result got from laboratory.

The aim of firing: - firing is the main process in the production of bricks, as it controls several important properties of bricks such as mechanical strength, water absorption resistance, abrasion resistance, dimensional stability and chemical resistance.

Figure 3.13: picture taken during Firing dried Bricks

3.3.9 Physical and Mechanical Properties of Burnt Bricks

3.3.9.1 Compressive strength of bricks

The aim of this test was to determine the compressive strength of bricks and Compressive strength was the only mechanical property used in normal brick specification; it is the failure stress measured normal to the bed face. Compressive strength of fired brick was done by following the test method of bricks on (Ethiopian standard ES 86 , 2001) and (ASTM C62-97a, 1999). For the fired clay bricks the bricks taken to the laboratory of china communication construction company industry by using the compression testing machine, each types of bricks were inserted between the upper and lower plates by kept the center line of the compression machine plates and on the machine as indicated in Figure 3.14.

For each type of brick specimen produced was fired at different firing temperatures, five bricks were taken for compressive strength test and the results were taken average and individual according to the Equation 3.10.

$$compressive\ strength = \frac{\text{Crushing load (KN)}}{\text{Area of Brick}} \text{---} 3.11$$

Figure 3.14: Breaking Bricks by using compression machine

3.3.9.2 Water Absorption of bricks

This test was to determine WA of bricks by following the (Ethiopian standard ES 86 , 2001) and (ASTM C62-97a, 1999) and the specimens were oven dried at 110 ± 5^{o}c for 24hrs and cool the specimen and the mass were taken (W1). The specimen were Immersed in clean water at a 20^{o}c for 24hrs, after that the specimen were taken out of water and wiped by damp cloth to remove water on the surface of bricks and the mass of the specimen was taken (W2).

For each type of bricks specimen produced at different temperatures, five bricks were taken for water absorption test and the results were taken both in average and individual. This was to get the rate of absorption or suction percentages of bricks according to the Equation 3.11.

$$\% \text{ of water absorption} = \frac{(W2-W1)*100}{W1} \qquad 3.12$$

Where: W1 = weight of oven dry bricks; W2 = weight of saturated surface dry brick, after 24hrs of submersion in cold water

Figure 3.15: Immersing bricks in cold water for 24hrs

3.3.9.3 5hrs Boiling test

This test was done as per the (Ethiopian standard ES 86 , 2001) and (ASTM C62-97a, 1999), to determine the water absorption of bricks by 5hrs boiling. Five specimens were used for this test for each replacement and temperature. The specimen were returned, which were saturated for 24hrs in cold water at 20^{o}c for 5hrs boiling test. The water within 1hr and continuously boiling for 5hrs and cool at 20^{o}c for 18 hrs. The specimen were removed from the water and wiped by damp cloth and the weight was taken within 5 min (W3).

$$\%\ of\ water\ absorption = \frac{(W3-W1)*100}{W1} \qquad \text{-----3.13}$$

Where: W3= saturated weight of the specimen after 5hrs submersion in boiling water.

Figure 3.16: Boiling bricks for 5hrs to test water absorption

3.3.9.4 Saturation coefficient

The saturation coefficient was the ratio of absorption after 24hrs immersion in cold water to that after 24hrs immersion and 5hrs boiling.

$$\text{Saturation coefficient} = \left(\frac{(W2-W1)}{(W3-W1)}\right) * 100 \text{---} 3.14$$

Where: W1, W2, W3 are define above.

3.3.9.5 Efflorescence Test

Bricks may contain soluble salts that come to the surface when the brick dries. The source of these soluble salts is the raw materials used in the brick production process.

The efflorescence test of bricks was conducted as per (ASTM C 67- 94, 1995). Ten bricks of the dimension tolerance test from each type of bricks were taken to determine the presence of salt on the bricks. The bricks were rated as 'effloresced' and /or 'not effloresced' as the standard on ASTM C 67 stated. The test samples were immersed in water for seven days and oven dry for 3 days at 110 ± 5^{o}c and the rating was done by observing the surface of the bricks if they have white dots on the bricks.

3.3.9.6 Dimension tolerance

The dimension tolerance test for this study conducted as per the procedures of (ASTMC216-10, 2010). For this study all the bricks are considered as FBS (brick for general use in masonry) as indicated in Figure 3.17, ten bricks from each types were taken and the test was conducted by measuring the length, width and height of each brick and the dimension was checked if it's within the (ASTMC216-10, 2010) standard limit.

Figure 3.17: Picture taken during the dimension tolerance

4 RESULTS AND DISCUSSIONS

In this part, the physical and chemical properties of raw materials of bricks, mechanical and physical properties of harden bricks results and discussions were discussed.

4.1 Chemical composition of CS and SCG

Chemical composition of CS result was given in

Table **4.1**, major component of the clay soil more composed of Silicon Dioxide (SiO_2), Aluminum Dioxide (Al_2O_3) and Iron Oxide (Fe_2O_3) which were 70.66%, 9.40% and 3.80% respectively. These major oxides had their own role on the bricks quality; therefore, Silicon Dioxide (SiO_2) was increased the brick's strength and durability, prevents shrinkage and warping. Aluminum Dioxide (Al_2O_3) was Absorbs water and renders the clay plastic, Iron Oxide (Fe_2O_3) was change the brick color to red after firing with oxygen, improves impermeability and durability of bricks, gives strength and hardness for bricks and other minor composition which had a role on the bricks were, the lime (CaO) was Reduces the shrinkage during drying, during burning causes silica as it was melt and bind together and excess amount of CaO causes the bricks as it melt loss its shape, MgO most of the time not more than 1%, and change the color of brick into yellow during burning.

Table 4.1: oxide composition of soil from Kilole

Chemicals composition of soil samples (%)												
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	SO_3
70.66	9.40	3.80	0.40	0.76	1.12	1.36	0.04	<0.01	0.88	2.65	7.20	0.45

Loss on Ignition is one way of knowing the loss during firing of bricks. The reason of high or low amount of loss on ignition was high amount of water in its grain nature or low amount of water in its grain nature and it is evaporated during LOI test. As stated in Table 4.1, the loss on ignition for this study was 7.20%.

Table 4.2 shows that, the oxide composition and Loss on Ignition (LOI) of SCG. Chemical composition of SCG has more related with CS, the difference between the two materials were only the percentage amount of oxides.

As stated in the Table 4.2, the chemical composition of SCG was high amount of percentage in MgO, K_2O, P_2O_5, CaO and Na_2O (20.8%, 19.04%, 18.16%, 12.67% and 8.42% respectively) and the other oxides such as SiO_2, Fe_2O_3 and Al_2O_3 (5.97%, 3.46%and 2.37%) respectively were low from the composition of SCG when compared to the clay soil samples. These were the same function for bricks as clay soil composition except the amount of difference. These results show that, the composition of clay soil and SCG were relatively the same chemical composition rather than the percentage content difference.

Table 4.2: Oxide composition of SCG

Chemical Composition of Coffee Ground in %													
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	P_2O_5	Na_2O	TiO_2	MnO	SrO	SO_3	LOI	CuO
5.97	2.37	3.46	12.67	20.8	19.04	18.16	8.62	0.17	0.47	0.09	3.06	4.8	0.24

4.1.1 Laboratory test results for the index properties of soil

The index properties of clay soil results and discussions were indicated, which are more applicable for production of bricks such as grain size analysis, Liquid Limits, Plastic limits, specific gravity, linear shrinkage and compaction test.

4.1.1.1 Grain size Distribution of soil

Particle distribution of the sample of clay soil is given in Figure 4.1. Particle size distribution result show that 91.48% passed through 0.075 mm sieve. This shows that the soil was fine grain and according to ASTM D422 (1998), classification of soil shown in Figure 4.1, 30% was clay soil, 60% was silt, 3.92% was fine sand, 2.07% was medium sand and 1.9% was coarse sand.

According to Tara (2014), a soil which contains Clay& silt content of 40% - 65% is suitable for brick making. The result of grain size distribution on this study shows, standard specification give for grain size distribution and previously studied result shows that the grain size distribution was clay soil and it was suitable for brick production.

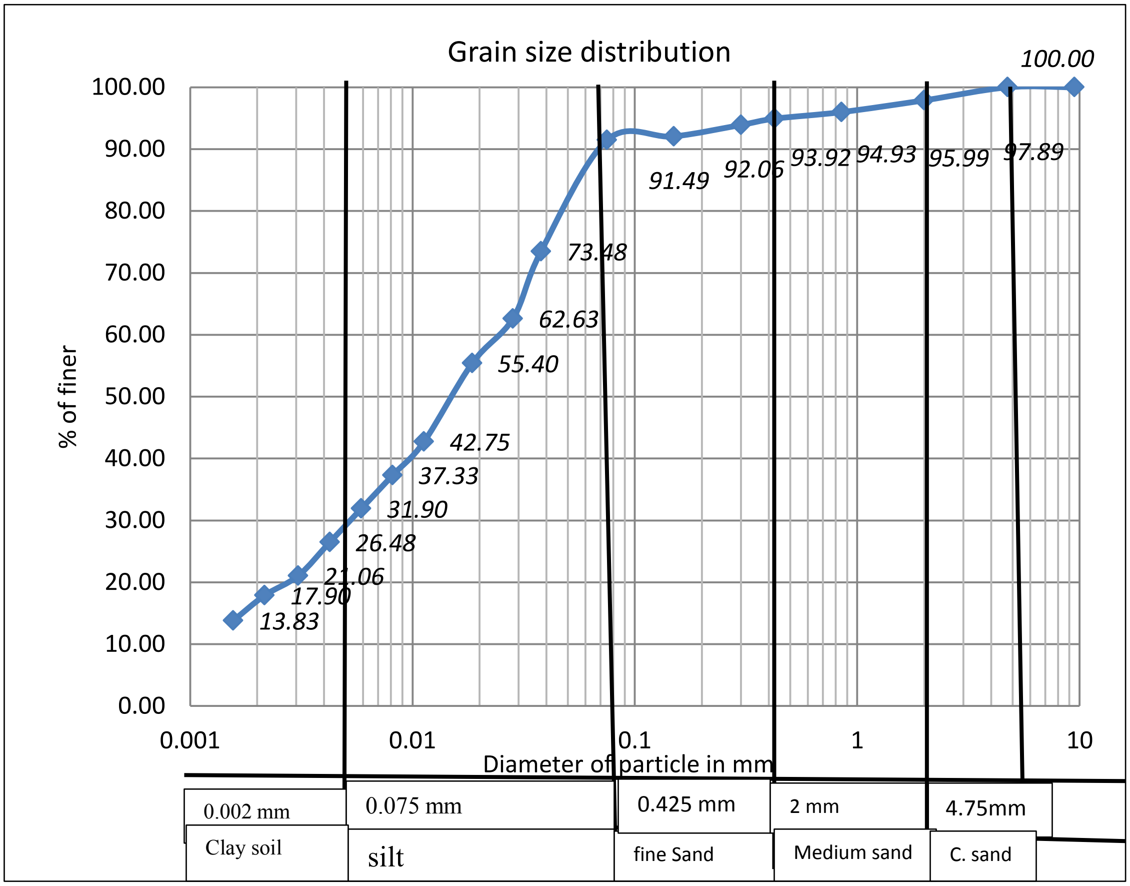

Figure 4.1: Particle size distribution of soil sample

4.1.1.2 Grain Size Distribution of SCG and PW

Particle size distribution of SCG and PW were given in Figure 4.2. The particle size distribution result passed through 0.075 mm sieve size for the PW and SCG test result were 40% and 44.8% which are greater than 35%, so grain size particles were finer. According to ASTM D422 (1998), written for classification of soil, a particle size passed through 0.075 mm sieve, which is greater than 35% is fine grain. So, the present SCG and PW used for brick production were fine particles.

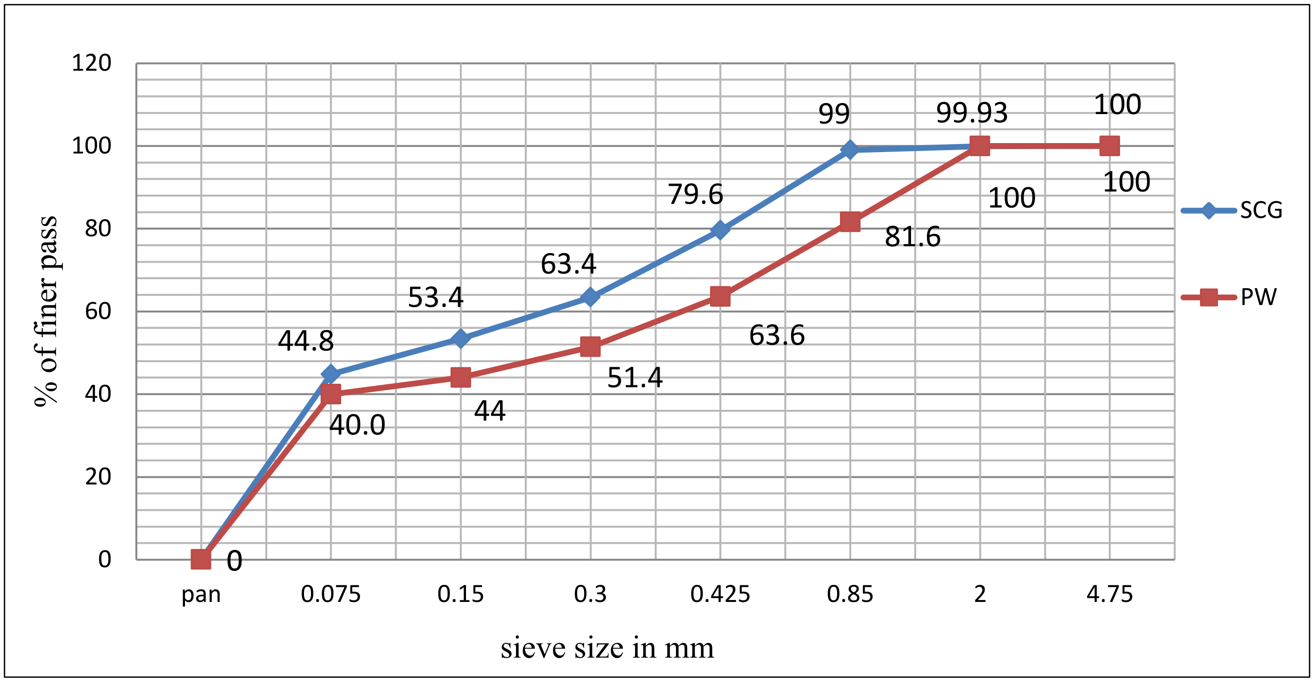

Figure 4.2: particle distribution of SCG and PW

4.1.1.3 Liquid limit

As indicated in Figure 4.3 water content of the soil at 25 blows was 49% and the soil classification was already determined depending on the percentage of passed through 0.075 mm sieve size as it was silt and clay. According to Head (2006) stated that low plastic clays, the liquid limit is less than 30%, in intermediate plastic clays, the liquid limit ranges from 30% to 50% and in high plastic clays, the liquid limit is more than 50%. So, the soil used in this study was in intermediate plastic clays. Liquid limit result shows that the soil is clay soil and it was fulfill the criteria of clay soil used for brick production.

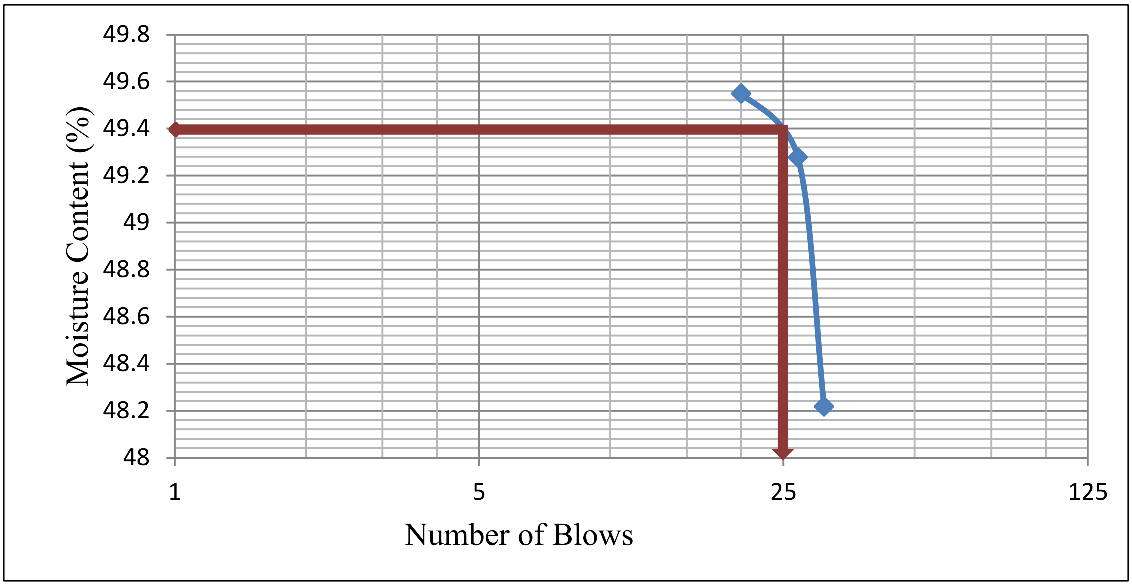

Figure 4.3: moisture content of soil sample

4.1.1.4 Plastic Limit

Plastic limit of the sample clay soil was given in Table 4.5. The plastic limit of clay soil sample result was 33%. This result show, characteristics of clay soil plasticity when took the water wet and plasticized and plastic index of the present clay soil used was 16%. According to V. N.S Murthy (2002), soil plasticity index varies between 7 – 17% medium plasticity. The result of the plasticity index for this study was 16%**,** so the soil is categorized under medium plasticity.

According to Council of Scientific and industrial Research (2011) report, the quality of clay soil for plasticity was the capacity of wet with water and the result of moulded mass at the correct water, after that the dried and get normal strength to handling. To know the plasticity of clay for brick production, there are so many factors such as chemical constitution of clay, the physical nature, presence of impurities, fineness, presence of organic content and absence of large quantity of free silica.

A soil which has plastic index 7%-16% ranges is more suitable for brick production (Tara, 2014). From the result of this test and the previously founding, the present soil used categorized under clay silt.

Table 4.3: plastic limit of soil sample

TRIAL	1	2	3
Can code	R1	R2	R3
Mass of Can	6.18	5.57	6.44
Mass of can with wet soil	14.12	10.47	10.49
Mass of can with Dry soil	12.13	9.38	9.495
Mass of water	1.99	1.10	0.99
Mass of Dry Soil	5.94	3.81	3.10
Water Content (%)	34.55	32.69	32.43
Plastic limit average (%)	33		

4.1.1.5 Specific gravity of soil

The result of this study, the specific Gravity of the soil sample was 2.71; the soil was already clay soil based on the particle size distribution analysis test results. According to Braja (2002), the specific Gravity of clay is 2.67-2.9.

According to Tanveer *et al.* (2012) founding, the specific gravity clay soil used for brick production depends on their mineral composition, particle size distribution of components, texture, resulting void ratio and moisture contents. From the result got and according to standard specification given for clay soil specific gravity the present used soil was clay.

4.1.1.6 Specific Gravity of SCG and PW

Specific gravity of the SCG and PW were 1.26 and 1.14 respectively. These show that SCG and PW were less density and fineness than clay soil in this study. As it discussed under grain size distribution SCG and PW, the percentage passed through 0.075 mm sieve were shows less fine than clay soil. According to ASTM D792 – 08 (2008) specific gravity of plastics were varies 0.9 to 1.34 g/cm^3. According to Arul *et al*. (2014), specific gravity SCG was 1.36 – 1.37. The result variance occurred between the present and the previous might be from the fineness the materials used.

4.1.1.7 Linear Shrinkage

The linear shrinkage of the soil was 4.05%. This result shows that the difference between wet and after dried in oven dry. According to Tanveer *et al* (2012), linear shrinkage less than 5% are non-critical and as Council of Scientific and industrial Research (2011) report, linear shrinkage less than 10% is recommended for bricks and tiles. Thus, soil used in this study was suitable for brick production as the result shows and previously research finding.

4.1.1.8 Compaction Test

The OMC and MDD of the soil sample were 27.18% and 1.33 g/cm^3 respectively. This OMC of the soil sample show that, the soil was plastic at above given OMC. The MDD of soil sample was at a point the soils dried and harden to handle. During manual moulding of green bricks the minimum moisture content varies between 25 to 35%. The moisture content is a factor of the ease of workability of the soil and moulder habits.

These results were According to Expedito, Baraka and Arthur (2015), the high values of optimum moisture content of the soil samples is due to the presence of greater amount of clay soil of high plasticity.

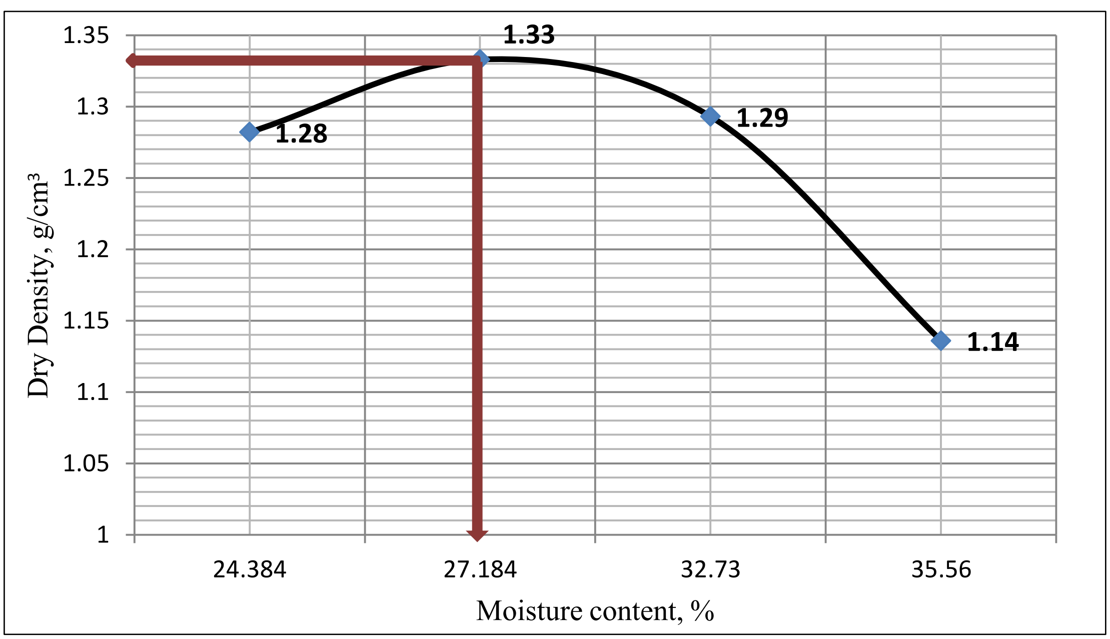

Figure 4.4: OMC and MDD of Soil Sample

4.2 Harden Properties of Produced Bricks

4.2.1 Compressive strength the Bricks

Table 4.4 Mean compressive strength of the bricks (MPa) at different temperature

Temperature in ^{0}C	Control brick	PW : SCG : CS Ratio (%)			
		1.5 : 2 : 96.5	3 : 4 : 93	4.5 : 6 : 89.5	6 : 8 : 86
600	14.42	13.68	13.71	12.73	12.46
700	18.48	16.20	16.31	13.92	13.32
800	23.43	16.51	20.62	14.42	13.52
900	20.82	16.33	16.72	13.27	12.10
1000	20.16	16.06	16.37	13.10	12.13

Table 4.4 shows the effect of temperature, the amount of SCG and PW replaced the soil on the compressive strength of the bricks. When the firing temperature increased from 600 up to 800 ^{0}C, compressive strength increased for all compositions. Maximum compressive strength was got at 800^{0}C for all types of bricks, 23.43MPa for control bricks, 16.51MPa for 1.5%PW and 2% SCG, 20.62MPa for 3% PW and 4% SCG, 14.42MPa for 4.5% PW and 6% SCG and 13.52MPa for 6%PW and 8% SCG. From 900 up to 1000^{0}C, compressive strength is decreased due to high firing temperature except 6% PW and 8% SCG fired at 1000^{0}C. This might be due to the shape of bricks, less accuracy of compression machine and mistake dimensional measurement. During high firing temperature, the particles of the composition were melting and evaporated. This phenomenon causes the porosity and the porosity increase from the 900 up to 1000 ^{0}C and the compressive strength was decreased.

On the other side, the compressive strength is increased with increment of replacement PW and SCG from 1.5 and 2% up to 3 and 4% respectively. This increment of compressive strength with increment of PW and SCG was due to high bonding between particles of greater percentage of CS and high amount of SiO_2, Fe_2O_3 and Al_2O_3 in the CS. From 4.5 and 6% up to 6 and 8% replacement of PW and SCG respectively compressive strength decreased due to the less amount of bond between the particles and less amount of SiO_2 and Al_2O_3 in the SCG, beside this, there is no all in all in the Plastic waste. It was satisfied the minimum compressive strength of ES 86: 2001 and ASTM C 62- 97a as given in Table 4.5. The maximum compressive strength was at 3%

PW and 4% SCG replacement fired at 600, 700, 800, 900 and 1000^0C which were 13.72, 16.31, 20.62, 16.72 and 16.37MPa respectively.

The average compressive strength and their classification according to (Ethiopian standard ES 86 , 2001) and (ASTM C62-97a, 1999) Table 4.5 shows. As the result all the replacement including control bricks fulfilled the standard.

Table 4.5: Average compressive strength of Bricks and their classification

Replacement	Temperature in (^{0}C)	Mean compressive strength in (MPa)	Classification	
			ES (86:2001)	ASTM C 62-97a
Control Bricks	600	14.42	C	NW
1.5% PW & 2% SCG		13.68	C	NW
3% PW & 4% SCG		13.71	C	NW
4.5% PW & 6% SCG		12.73	C	NW
6% PW & 8% SCG		12.46	C	NW
Control Bricks	700	18.48	B	MW
1.5% PW & 2% SCG		16.20	B	NW
3% PW & 4% SCG		16.31	B	NW
4.5% PW & 6% SCG		13.92	C	NW
6% PW & 8% SCG		13.32	C	NW
Control Bricks	800	23.43	A	SW
1.5% PW & 2% SCG		16.51	B	NW
3% PW & 4% CG		20.62	A	MW
4.5% PW & 6% SCG		14.42	C	NW
6% PW & 8% SCG		13.52	C	NW
Control Bricks	900	20.82	A	SW
1.5% PW & 2% SCG		16.33	B	NW
3% PW & 4% SCG		16.72	B	NW
4.5% PW & 6% SCG		13.27	C	NW
6% PW & 8% SCG		12.10	C	NW
Control Bricks		20.16	A	MW
1.5% PW & 2% SCG		16.06	B	NW

3% PW & 4% SCG	1000	16.37	B	NW
4.5% PW & 6% SCG		13.10	C	NW
6% PW & 8% SCG		12.13	C	NW

4.2.2 Water Absorption

The effect of firing temperature, the amount of SCG and PW replaced the soil upon the water absorption of bricks were shown in Figure 4.5. When the firing temperature increased, water absorption decreased, in the opposite side, when the amount of SCG and PW increased for the same temperature, water absorption increased. This shows that, they didn't have linear relationships. From the result, the porosity happened in brick was closed porosity, because of when the temperature increased, water absorption decreased. The reason of water absorption increment with increment of SCG and PW was high content of organic matter in the SCG and PW. According to Ethiopian standard ES 86 (2001) and ASTM C62-97a (1999), it fulfilled the maximum water absorption and saturation coefficient as shown in Figure 4.5.

During firing, organic matter content in composition was burned, form CO_2 and made pores and the other made densification. Water absorption more occurs, when the bricks have porosity. The porosity either closed porosity or open porosity. When the porosity was closed, no more water absorption was occurred rather than open porosity. As it was seen from data, the water Absorption was not that much high. Therefore, the porosity might be closed.

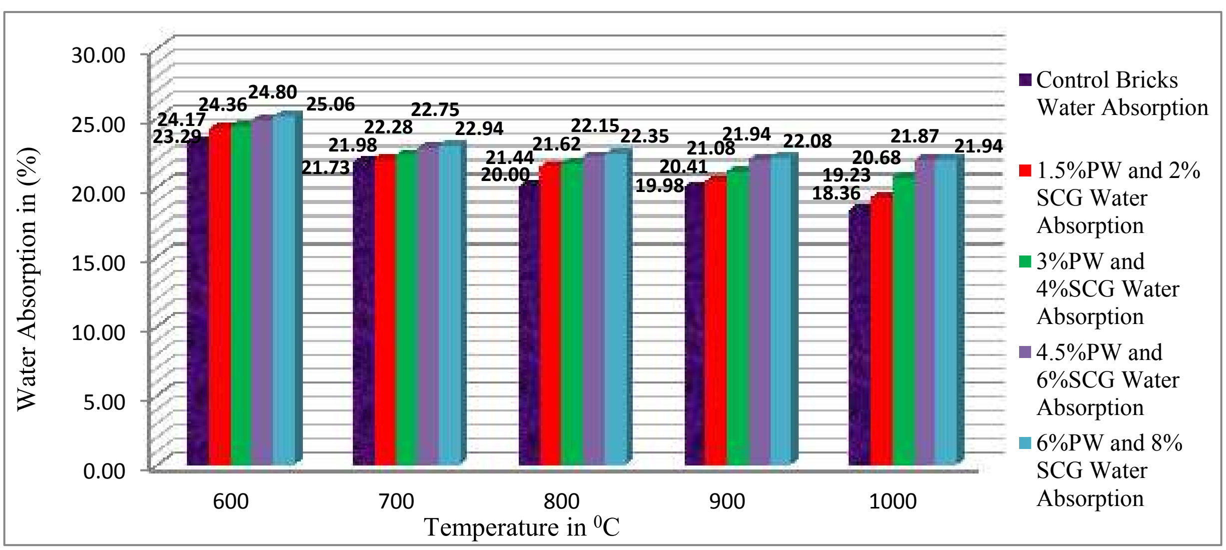

Figure 4.5: effect of firing temperature, SCG and PW upon the water absorption of brick

Table 4.6 show that each of mean water absorption and saturation coefficient of produced bricks according to ES and ASTM standards. From the result got each mean water absorption and saturation coefficient of bricks were satisfied by the two standards.

Table 4.6: Average Water Absorption for 24hrs cold water immersed and 5hrs boiling and Saturation Coefficients of bricks and their classification

Replacement	Temperature (^{0}C)	Mean Water Absorptions of 5 bricks (%) and their classification			Mean Saturation Coefficients of 5 bricks (%) and their classification		
	600	WA (%)	ES86:2001	ASTM	Saturation Coefficient	ES86:2001	ASTM
Control bricks		23.29	C,D	NW	0.97	C, D	NW
1.5% PW & 2% SCG		24.17	C,D	NW	0.95	A, B	NW
3% PW & 4% SCG		24.36	C,D	NW	0.97	C, D	NW
4.5% PW & 6% SCG		24.80	C.D	NW	0.95	A, B	NW
6% PW & 8% SCG		25.06	C,D	NW	0.97	C, D	NW
Control bricks	700	21.73	B	MW	0.97	C, D	NW
1.5% PW & 2% SCG		21.98	B	MW	0.96	A, B	NW
3% PW & 4% SCG		22.28	C,D	NW	0.95	A, B	NW
4.5% PW & 6% SCG		22.75	C, D	NW	0.96	A, B	NW
6% PW & 8% SCG		22.94	C,D	NW	0.96	A, B	NW

Control bricks	800	20.00	A	MW	0.92	A, B	NW
1.5% PW & 2% SCG		21.44	B	MW	0.97	C, D	NW
3% PW & 4% SCG		21.62	B	MW	0.93	A, B	NW
4.5% PW & 6% SCG		22.15	A	NW	0.94	A, B	NW
6% PW & 8% SCG		22.35	C, D	NW	0.95	A, B	NW
Control bricks	900	19.98	A	MW	0.97	C. D	NW
1.5% PW & 2% SCG		20.41	A	MW	0.97	C. D	NW
3% PW & 4% SCG		21.08	B	MW	0.97	C, D	NW
4.5% PW & 6% SCG		21.94	B	MW	0.97	C, D	NW
6% PW & 8% SCG		22.08	C, D	NW	0.96	A, B	NW
Control bricks	1000	18.36	A	MW	0.95	A, B	NW
1.5% PW & 2% SCG		19.23	A	MW	0.95	A, B	NW
3% PW & 4% SCG		20.68	A	MW	0.95	A, B	NW
4.5% PW & 6% SCG		21.87	B	MW	0.94	A, B	NW
6% PW & 8% SCG		21.94	B	MW	0.93	A, B	NW

4.2.3 Dimensional tolerance test result of bricks

The dimension tolerance test was conducted on the bricks which are ready to use after their firing stage. This test is to determine the effect of dimension change due to drying and firing from its original dimension. The relationship of bricks dimension before firing and after firing is carried out according ASTM C62-97a (1999), by taking ten bricks and measuring in millimeter along all sides (length, width and height). During firing, the brick was shrinking due to the remove of moisture content and organic matter content burned the dimension variance occurred between original and after firing.

When the temperature increased, the shrinkage of bricks increased. This is due to the removing of moisture content and organic matter by gradually increment of temperature. In the opposite side, when the amount of SCG and PW increased, shrinkage decreased from the firing temperature was 600 to 800^0C. This shows that, organic content in the SCG and PW didn't removed all in all at 600 to 800^0C and firing temperature didn't damage the bricks and from 900 to 1000^0C, when SCG and PW increased, shrinkage increased. In this case, organic matter is removed for the case of high temperature.

The brick dimension tolerance fired at 600^0C along the all sides was shown on Table 4.9. The dimension of mold along the length (inner dimension) is 240 mm and (ASTMC216-10, 2010) permissible variation along the length is 7.9 mm. As it shown in table 4.8 control bricks and 1.5% PW and 2% SCG bricks didn't fulfill the (ASTMC216-10, 2010) permissible variation because of discussed in the above paragraph and the rest were fulfilled the standard because, they have high amount of SCG and PW waste and organic content is didn't removed at low temperature.

For along width, the dimension of the mold (inner dimension) is 120mm and for along height, the dimension of mold (inner dimension) is 60 mm and ASTM permissible variation along width and height is 4.8 mm and 2.4 mm respectively, except control brick along the width the other satisfied the ASTM permissible variation.

Table 4.7: Results of Dimension Tolerance Tests Fired @ 600 C

Types of Bricks or Replacements	Average variation Result of ten bricks along Length (mm)		Average variation Result of ten bricks along Width (mm)		Average variation Result of ten bricks along Height (mm)	
	Length (mm)	ASTM C216 permissible maximum variation in(mm)for size (203 mm - 305 mm)	Width (mm)	ASTM C216 permissible maximum variation in(mm)for size (102 mm - 152 mm)	Height(mm)	ASTM C216 permissible maximum variation in (mm) for size (76 mm and under)
Control brick	8.1	7.9	5.00	4.8	1.40	2.4
1.5% PW & 2% SCG	8.0	7.9	4.8	4.8	1.6	2.4
3% PW & 4% SCG	7.5	7.9	2.8	4.8	1.5	2.4
4.5% PW & 6% SCG	6.7	7.9	2.8	4.8	1.3	2.4
6% PW & 8% SCG	6.5	7.9	2.1	4.8	1.3	2.4

The dimension tolerance of bricks fired at 700^0C was given in Table 4.10. As (ASTMC216-10, 2010) permissible variation, except control brick along length (9.10 mm which is greater than 7.9 mm), the all along width and height were satisfied according to ASTM C216 as discussed in above section. In this, the reason of control bricks were no fit the standard, there is no organic matter in clay than SCG and PW. So at low temperature organic matter didn't remove.

Table 4.8: Dimension Tolerance results Fired @ 700 C

Types of Bricks or Replacements	Average variation Result of ten bricks along Length (mm)		Average variation Result of ten bricks along Width (mm)		Average variation Result of ten bricks along Height (mm)	
	Length (mm)	ASTM C216 permissible maximum variation in (mm) for size (203 mm – 305 mm)	Width (mm)	ASTM C216 permissible maximum variation in(mm)for size (102 mm - 152mm)	Height(m)	ASTM C216 permissible maximum variation in (mm) for size (76 mm and under)
Control	9.10	7.9	4.70	4.8	2.40	2.4
1.5% PW & 2% SCG	7.7	7.9	3.9	4.8	1.6	2.4
3% PW & 4% SCG	6.9	7.9	3.5	4.8	2.3	2.4
4.5% PW & 6% SCG	6.6	7.9	2.2	4.8	1.6	2.4
6% PW & 8% SCG	6.7	7.9	2.2	4.8	1.5	2.4

Dimensional tolerance of all replacement including control bricks fired at 800 ^{0}C was shown in Table 4.9. In this case, the dimensional tolerance were fulfill the ASTM standard except control bricks along width and height, 1.5% PW and 2% SCG and 3% PW and 4% SCG along width only. So the 800^{0}C was more adequate than other firing temperature. Under 800^{0}C firing temperature only control bricks not satisfied permissible maximum variation of ASTM standard, this was due to the amount of organic matter and water were high in clay soil. During firing the water and organic content in control bricks, 1.5% PW and 2% SCG and 3% PW and 4% SCG were evaporated and the sizes of bricks were decreased.

Table 4.9: Results of Dimension Tolerance Tests Fired @ 800 C

Types of Bricks or Replacements	Average variation Result of ten bricks along Length (mm)		Average variation Result of ten bricks along Width (mm)		Average variation Result of ten bricks along Height (mm)	
	Length (mm)	ASTM C216 permissible maximum variation in (mm)for size (203 mm - 305 mm)	Width(mm)	ASTM C216 permissible maximum variation in (mm) for size (102 mm - 152 mm)	Height (mm)	ASTM C216 permissible maximum variation in (mm) for size (76 mm and under)
Control	7.60	7.9	5.90	4.8	2.80	2.4
1.5% PW & 2% SCG	7.4	7.9	5.4	4.8	2.3	2.4
3% PW & 4% SCG	7.3	7.9	5.5	4.8	1.7	2.4
4.5% PW & 6% SCG	7.1	7.9	4.8	4.8	1.7	2.4
6% PW & 8% SCG	6.9	7.9	2.8	4.8	2.1	2.4

Dimensional tolerance of bricks fired at 900 ^{0}C was shown in Table 4.10. Under this, the fired bricks dimensional tolerances were all most out of the ASTM permissible variation standard except 6% PW & 8% SCG along width and height. This increment of shrinkage was due to increment of firing temperature. The water and organic matter present in the materials were removed from the bricks and the dimension of bricks produced during the wet were different from the harden bricks due to the drying and firing temperature of water and organic matters.

In generally, when the firing temperature increased, the shrinkage increased. When SCG and PW increased, but for all bricks the decrements were no straight forward due to lack of some measurement accuracy.

Table 4.10: Results of Dimension Tolerance Tests Fired @ 900 C

Types of Bricks or Replacements	Average variation Result of ten bricks along Length (mm)		Average variation Result of ten bricks along Width (mm)		Average variation Result of ten bricks along Height (mm)	
	Length (mm)	ASTM C216 permissible maximum variation in (mm) for size (203 mm - 305 mm)	Width (mm)	ASTM C216 permissible maximum variation in (mm) for size (102 mm - 152 mm)	Height (mm)	ASTM C216 permissible maximum variation in (mm) for size (76 mm and under)
Control	11.70	7.9	5.80	4.8	2.90	2.4
1.5% PW & 2% SCG	11.8	7.9	5.5	4.8	2.6	2.4
3% PW & 4% SCG	10.6	7.9	5.0	4.8	2.8	2.4
4.5% PW & 6% SCG	11.8	7.9	5.1	4.8	2.7	2.4
6% PW & 8% SCG	10.5	7.9	4.4	4.8	2.1	2.4

Dimensional tolerance of bricks fired at 1000 ^{0}C was shown in Table 4.11. Under this, the fired bricks dimensional tolerances were all in all out of the ASTM permissible variation standard. These show that the bricks were damaged at 1000^{0}C firing temperature. High firing temperature for bricks was not only changing the dimensions/ shrinkages of bricks, it was affecting the other properties of bricks such as less compressive strength, high porosity. From this, firing temperature could be concluded as greater than 1000^0C lead to the bricks damages rather than increased the good properties of bricks.

Table 4.11: Results of Dimension Tolerance Tests Fired @ 1000 C

Types of Bricks or Replacements	Average variation Result of ten bricks along Length(mm)		Average variation Result of ten bricks along Width(mm)		Average variation Result of ten bricks along Height(mm)	
	Length (mm)	ASTM C216 permissible maximum variation in (mm) for size (203 mm - 305 mm)	Width (mm)	ASTM C216 permissible maximum variation in (mm) for size (102 mm - 152 mm)	Height (mm)	ASTM C216 permissible maximum variation in (mm) for size (76 mm and under)
Control	23.40	7.9	7.80	4.8	4.40	2.4
1.5% PW & 2% SCG	19.1	7.9	7.6	4.8	3.7	2.4
3% PW & 4% SCG	13.7	7.9	6.7	4.8	3.7	2.4
4.5% PW & 6% SCG	14.7	7.9	6.9	4.8	3.4	2.4
6% PW & 8% SCG	13.4	7.9	6.5	4.8	3.0	2.4

4.2.4 Efflorescence Test

As indicated on the Figure 4.6 the bricks were not effloresced. This result shows that, the color of bricks before and after immersed in the water didn't change due to the absence of soluble salt come out on the surface of bricks. According to ASTM C 67- 94 (1995), the bricks were effloresce or not effloresced. Thus all of the results seen on the bricks were not effloresced.

Figure 4.6: Efflorescence test of bricks

4.3 Adequate Firing Temperature of Produced Bricks

In this study, the firing temperatures of bricks were at 600, 7000, 800, 900 and 1000 ^{0}C for 5hr. The compressive strength of produced bricks was less at the beginning (600 ^{0}C) and ending (1000 ^{0}C) temperature. The maximum compressive strength was got at 800^{0}C for all replacement percentage including control bricks. The water Absorption of a produced bricks was decreased with increased temperature from 600 to 1000 ^{0}C and in other case when SCG and PW increased, water absorption increased in the same firing temperature.

The dimensional tolerance of produced bricks was all most fits at 600 to 800^{0}C the standard except those bricks fired at 900 to 1000 ^{0}C.

According to Council of Scientific and industrial Research (2011) report, the dried clay is fired for obtaining high strength, stability and brick red colour. Many changes take place during firing such as evolution of water vapour present in clays, burning of organic matter, chemical constitutional changes and formation of new compounds which are stable at high temperatures and they were fire at 1000 ^{0}C. As Eliche *et al* (2011) founding, the material which has organic residue such as spent coffee ground used in bricks were fired at 950 ^{0}C was effective.

According to Safeer *et al* (2017) studied, the adequate firing temperature for clay brick was 800 ^{0}C. So, the maximum firing temperature gotten for this study was acceptable.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The SCG and PW were suitable for brick production at 2, 4, 6 and 8% and 1.5, 3, 4.5 and 6% replacement by weight respectively. Therefore, this is used to reduce the environmental impact due to SCG and PW.

When the firing temperature increased from 600 up to 800^{0}C, compressive strength increased for all replacement including control bricks, and from 900 up to 1000^{0}C compressive strength is decreased except 6% PW and 8% SCG at 1000^{0}C This might due to the shape of bricks, less accuracy of compression machine and mistake dimensional measurement. In the case of replacement; compressive strength of the bricks decreased with increment of SCG and PW. Maximum compressive strength was got at 800^{0}C for all types of bricks, 23.43MPa for control bricks, 16.51MPa for 1.5%PW and 2% SCG, 20.62MPa for 3% PW and 4% SCG, 14.42MPa for 4.5% PW and 6% SCG and 13.52MPa for 6%PW and 8% SCG. In case of replacement, the maximum compressive strength was at 3% PW and 4% SCG replacement fired at 600, 700, 800, 900 and 1000^{0}C which were 13.72, 16.31, 20.62, 16.72 and 16.37MPa respectively.

Water absorption of the bricks, when the firing temperature increased, water absorption decreased, in the opposite side, when the amount of SCG and PW increased for the same temperature water absorption increased.

The determined Dimension tolerance shows that, when temperature increased, shrinkage increased. In another side, when the SCG and PW increased, shrinkage decreased from 600 up to 800^{0}C and from 900 0C up to 1000^{0}C, shrinkage increased. All of the produced bricks including control bricks were not effloresced.

Generally in addition to protecting natural resource depletion and environmental impact, SCG and PW with clay soil are used for production of bricks for construction purpose.

5.2 Recommendation

The following recommendations are suggested to address the concerned bodies:

1. For Governmental bodies

According to this finding, it is recommended that the governmental construction bodies of Jimma Town and around Jimma should give care to the natural resource depletion and environmental impact by giving consciousness to the small and micro enterprises as they are incorporating spent coffee ground and plastic waste in to clay for brick production.

2. For society

Since the society Jimma zone concerned on plantation of coffee and in addition to this the plastic waste in Jimma Town now this time is high in amount. So this study recommended that, the society of Jimma Zone and Jimma Town should give attention to the spent coffee ground and plastic waste have commercial value for production of Bricks in addition to protecting natural resource depletion and environmental impact.

3. For Further studies

The types and amounts of the mineralogical composition of materials can affect the properties (physically, chemically and mechanically) of the bricks. The reaction occurred during firing between mineralogical composition of CS and SCG shall be checked using advanced technologies like X-ray diffractometry (XRD) and Scanning electron microscopy (SEM).

REFERENCE

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

Aeslina Abdul Kadir, Hermawati Hinta, Noor Amira Sarani (2015). The Utilization Of Coffee Waste Into Fired Clay Brick,. *Asian Research Publishing Network ,Journal of Engineering and Applied Sciences, Vol. 10*.

Akaninyene O. Akankpo, Jonathan O. Stephen. (2016). Investigatoin of the Physical Properties of Uruan Clay Soil Used for Manufacturing of Burnt Bricks. *Advances in Physics theories and Application, Vol. 53*.

Akinshipe O, Kornelius G. (2017). Chemical and Thermodynamic Processes in Clay Brick Firing Technologies and Associated Atmospheric Emissions Metrics-A Review. *Journal of Pollution Effects & Control, Vol. 5*(Issue 2).

Alaa, A Shakir; Sivakumar Naganathan; Kamal Nasharuddin, Bin Mustapha. (2013). Development of Bricks from Waste Material: A review Paper. *Australian Journa of Basic and Aplied Science*.

Altayework Tadesse. (2013). Effects of firing temperature on the physical properties of burnt clay bricks produced around Addis Ababa. *unpublished M. Sc Thesis. Adddis Ababa University*.

Amit Gawande, G Zamare, V.C Renge, Saurabh Tayde, G. Bharsakale (2012). An overview on Waste Plastic Utilization Asphalting of Roads. *Journal of Engineering Research and Studie(JERS), Vol. 3*(Issue 2).

Angle Daniel Munoz Guman, Maria Giovanna, Trotta Munno. (2015). Design of a Brick With Sound Absorption Properties Based on Plastic Waste & Sawdust. *Open Access Journal of Institute for Electrical and Electronics Engineering, Vol. 3*.

Arul Arulraja, Farshid Maghoolpilehrood, Mahdi Miri Disfani, Suksun Horpibulsuk. (2014). Spent coffee grounds as a non-structural embankmentfill material: engineering and environmental considerations. *Farshid Maghoolpilehrood*.

Asrat Gebremariam Woldesenbet, Belay Woldeyes, Bhagwan Singh Chandravanshi (2015). Characteristics of Wet Coffee Processing Waste and Its Environmental Impact in Ethiopia. *International Journal of Research in Engineering and Science, Vol. 2 (Issue 4).*

ASTM C 67- 94. (1995). Standard Test Methods of Sampling and Testing Brick and Structural Clay Tile.

ASTM C216-10. (2010). *Standerd Specification for facing Brick (solid Masonry units from clay or shale).*

ASTM C62-97a. (1999). Standard specification for building bricks (solid Masonry units made from clay or shale). In *Annual book of ASTM standard* Vol. 04.05.

ASTM D422. (1998). Standard Test Method for Particle-Size Analysis of Soils.

ASTM D4318. (2000). Standard test method for Liquid Limit, Plastic Limit and plastic Index of Soils.

ASTM D4943-08. (2017). Standard Test Method for Shrinkage factors of soils by the Wax method. In A. T. committee.

ASTM D698-91 . (2015). Test method for laboratory Compaction characteristics of soil using standard effort. In A. Committee.

ASTM D792 - 08. (2008) Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement.

ASTM D854. (2002). Standard Test Methods for Specific Gravity of Solids by Water Pycnometer. In A. Committee.

ASTM C216-10. (2010). Standard Specification for facing brick(solid masonry units made from clay or shale.

ASTMC43-98a. (1999). Standard Terminology of structural clay products. *Annual book of ASTM standards, Vol. 04.05*.

Braja M. Das (2002). *Soil Mechanics Laboratory Manual.* New York, Oxford University.

Bricks Industry Association. (2004). Technical Notes 9-Manufacturing , Classification, and Selection of Bricks Manufturing : part 1, Retrieved November, 2014 from http://www.bia.org. *Vol. 14*.

British Standard (BS 3921). (1985). Specification for Clay bricks. In B. s. institute.

British Standard 1377. (1990). Methods of test for Soil for Civil Engineering Purposes. In *part two.*

C. Leiva, C. Arenasa, B. Alonso-fariñasa, L.F. Vilchea, B. Peceñob, M. Rodriguez-galána, F. Baena (2015). Characteristics of fired bricks bricks with co-combustion fly ashes. *http://www.researchgate.net/publication*.

Council of Scientific and industrial Research. (2011). *Evaluation of clay samples for suitability for extrusion and production of REBs.* Materials Division National Institute for Interdisciplinary Science and Technology.

D. Eliche-Quesada, L.Perez-Villarejo, F. J. Iglesias-Godino,. C. Martı´nez-Garcı´a.- F.A. Corpas-Iglesias. (2011). Incorporation of coffee grounds into clay bricks producion. *https://www.researchgate.net/publiction, Vol. 110*.

Davies Oladayo Folorunso, Fatai Olufemi Aramide, Peter Olubambi, Joseph Olatunde Borode. (2015). The Effects of Firing Temperatures on the Performance of Insulating Fire Bricks Containing Different Proportions of Alumina and Sawdust. *Journal of Minerals and Materials Characterization and Engineering*.

Dinesh S, Dinesh.A, Kirubakaran.K. A. (2016). Utilization of Waste Plastic in Manufacturing of Bricks and Paver Blocks. *International Journal of Applied Engineering Research, Vol. 11*.

Edward Allen, Robert Hallon. (2011). *Fundamental of residential construction (3rd edition).*

Eshetu Tsega, Alemu Mosisa, Fekadu Fufa (2017). Effects of Firing Time and Temperature on Physical Properties of Fired Clay Bricks. *American Journal of Civil Engineering, Vol. 5*.

Ethiopian standard ES 86 . (2001). Solid clay bricks. In E. S. (ESA), *Ethiopian Standard second edition.*

Expedito Milyaso, Baraka Kichonge, Arthur M. Omari. (2015). Analysis of Soil Samples for Development of Geopolymer Materials for Brick Manufacturing. *International Journal of Advanced Engineering Research and Technology (IJAERT), Vol. 3*(Issue 1).

Head K. (1992). *Manual of soil laboratory testing,* (2 ed.).

Heinrich Mueller, Soumen Maithy, Suyesh Prajapati, Anil Datta Bhatta, Bijay Lal Shrestha. (2008). Green Brick Making Manual, *Nepal*.

I. Johari, S. Said, B. Hisham, A. Bakar, Z. A. Ahmad (2010). Effect of the Change of Firing Temperature on Microstructutere and physical Properties of Clay Bricks from Beruas(Malaysia), . *Science of Sintering*.

Izwan Johari, Syamsuhaili Said, Ramadhansyah Putra Jaha, Badorul Hisham Abu Baka, Zainal Arifin Ahmad (2011). Chemical and Physical Properties of Fired Clay Brick at Didderent Types of Rice Husk Ash., *vol.8.*

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

Kadir A, Mohajerani A. (2015). Effect of Heating Rate on Gas Emission and Properties of Fired Clay Bricks and Fired Clay Bricks Incorporated with Cigarette Butts. *Applied Clay Science, Vol. 104*.

Maneeth P D, Pramod K, Kishor Kumar, Shanmukha Shetty. (2014). Utilization of Waste Plastic in Manufacturing of of plastic- Soil Bricks. *Journal of Engineering Research and Technology, Vol. 3*(Issue 8).

Obam, Ogah, Odaleje, Otor Noel. (2015). Structural and Dimensional Properties of Burnt-Bricks Produced at Oju, Nigeria. *International Journal of Scientific Engineering and Applied Science (IJSEAS), Vol. 1*(Issue 8).

Puttaraj Mallikarjun Hiremath, Shanmukha shetty, Navaneeth Rai.P.G, Prathima.T.B.(2014). utilization of Waste Plastic in Manufacturing of Plastic Soil Bricks. *International Journal of Technology Enhancement and Emerging Engineering Research, Vol. 2*(Issue 4).

Safeer Abbas, Muhammad A. Saleem, Syed M. S. Kazmi, Muhammad J. Munir (2017). Production of Sustainable Clay Bricks using Waste Fly Ash : Mechanical and Durability Properties. *Journal of Building Engineering*.

Sharmistha Chakraborty, Joyanta Pal, Richi Prasad Sharma. C. (2013). Comparative Study of Properties of Manual and Mechanized Bricks and their Strength Behaviour as Masonry. *nternational Journal of Emerging Technology and Advanced Engineering, Vol.3*(Issue 4).

Siti Aishah Wahid, Sullyfaizura Mohd Radi, Norlia Md Desa. (2015). Utilization of Plastic Bottle Waste in Sand Bricks. *Journal of Basic and Applied Scientific Research*.

Tanveer Mehedi Adyel, Syed Hafizur Rahman, S. M. Nazrul Islam, Hossain Md. Sayem, Mala Khan, Md. Abdul Gafur. (2012). Characterization of Brick Making Soil: Geo-engineering, Elemental and Thermal Aspects. *Jahangirnagar University Journal of Science, Vol. 35*.

Tara. (2014) Green brick making manual, Qutub institutional Area, New delhi

V.N.S.Murthy. (2002). *Geotechnical Engineering: Principles and Practices of Soil Mechanics and Foundation Engineering* (2 ed.).

Viruthagiri G., Sathiyapriya S., Shanmugam N. (2014). Reuse of Sugarcane Bagasse Ash (SCBA) for Clay Brick Production. *Indian Journal of Applied Research, Vol. 4*.

APPENDIX ONE

PHYSICAL PROPERTIES OF RAW MATERIALS OF BRICKS DATA SHEETS

Survey Data for availability of coffee ground from different cafeterias

According to Gain report of Global Agricultural information network Ethiopia's coffee production annual (2015/16) consumed inside the country was 6.515 million bags (390,900 metric tons) and 3.52 million bags (212,000 metric tons) was exported.

Data given below show that, data surveyed here in jimma Town to know the amount of coffee waste (coffee ground). From the total amount of used, 37.54% was SCG (coffee waste) as the data collected.

No	Name of Cafeterias by their owner name prepare coffee for drink	Coffee roasted and milled for drink per day in (Kg)	SCG (waste) per Kg	Total SCG (wastes) per day
1	Fatuma Siraj	4	0.28	1.12
2	Tesfanesh Mulalem	7	0.43	3.01
3	Yordanos Fante	5	0.36	1.8
4	Yohanis Kidane	3	0.28	0.84
5	Marema Hassen	6	0.4	2.4
6	Fatiya Mohamed	9	0.45	4.05
7	Kasim Hibrahim	4	0.35	1.4
8	Mamush Taddesse	10	0.31	3.1
9	Lemlem Kasa	5	0.38	1.9
10	Tigist Mosisa	8	0.41	3.28
Total		61	3.65	22.9
percentage of waste coffee ground(waste)				37.54%

Grain Size Analysis: Wet Sieve Analysis

Mass of Soil Taken For Test=500g

Mass of Soil Retain On 0.075 Sieve Size After Washed=41.26g

%of soil pass 0.075 sieve size = ((500-41.26)/500)*100 = 91. 48% ≥35% , this value shows the soil is either clay soil or silt soil it needs hydrometer analysis to determine grain size of this soil.

Hydrometer Analysis

Time(Min.)	R	T(°C)	Ct	Cor. R.		Corr. Temp	L(cm)	K	D(mm)	% fine (P)	Combined % of finer
				R'	R"						
1	47	22	0.65	48	40.35	21.35	8.40	0.0131	0.0383	80.32	73.48
2	41	22	0.65	42	34.35	21.35	9.40	0.0131	0.0286	68.47	62.63
5	37	22	0.65	38	30.35	21.35	10.10	0.0131	0.0186	60.56	55.40
15	30	22	0.65	31	23.35	21.35	11.20	0.0131	0.0114	46.73	42.75
30	27	22	0.65	28	20.35	21.35	11.70	0.0131	0.0082	40.80	37.33
60	24	22	0.65	25	17.35	21.35	12.20	0.0131	0.0059	34.88	31.90
120	21	22	0.65	22	14.35	21.35	12.70	0.0131	0.0043	28.95	26.48
240	18	22	0.65	19	11.35	21.35	13.20	0.0131	0.0031	23.02	21.06
480	16	23	0.90	17	9.10	22.10	13.50	0.0129	0.0022	19.56	17.90
960	14	22	0.65	15	7.35	21.35	13.80	0.0131	0.0016	15.12	13.83
1440	13	22	0.65	14	6.35	21.35	14.00	0.0131	0.0013	13.14	12.02

Computation For percentage of finer

R"= R + Cm ± Ct - Cd

R' = R + Cm

$$L = L1 + \frac{1}{2}\left(\frac{L2-VB}{AC}\right)$$

$$P = a\frac{R''}{M_o}x100$$

Factors a and b for Different Specific Gravity (*for hydrometer analysis*)

G_s	**2.95**	**2.9**	**2.85**	**2.8**	**2.75**	**2.7**	**2.65**	**2.6**	**2.55**	**2.5**	**2.45**
A	0.94	0.95	0.96	0.97	0.98	0.99	1	1.01	1.02	1.03	1.05
B	1509.8	1525.86	1542	1558	1574.04	1590	1606	1622	1638..29	1654.4	1686

The relationship of Specific Gravity and Temperature

TEMP	GS		
	2.7	2.71	2.75
22	0.01312	0.013054	0.013
23	0.01297	0.012904	0.013

Dry sieve analysis of clay sample of Kilole retained on 0.075mm sieve size

sieve size in (mm)	mass retained in g	% of retained	% of cumulative	% of finer passing
9.5	0	0.00	0.00	100.00
4.75	0	0.00	0.00	100.00
2	9.56	2.11	2.11	97.89
0.85	8.6	1.90	4.01	95.99
0.425	4.8	1.06	5.07	94.93
0.3	4.6	1.02	6.08	93.92
0.15	8.41	1.86	7.94	92.06
0.075	2.6	0.57	8.51	91.48

Analysis Name: Grain size Analysis for Spent Coffee Ground

Sample Mass Mo: 500g

Sieve size (mm)	Mass of Retained	% Retained	Cumulative % Retained	% of finer pass
4.75	0	0	0	100
2	0.334	0.0668	0.0668	99.9332
0.85	4.66	0.932	0.9988	99.0012
0.425	97	19.4	20.3988	79.6012
0.3	81.006	16.2012	36.6	63.4
0.15	50	10	46.6	53.4
0.075	43	8.6	55.2	44.8
Pan	224.00	44.8	100	0

Analysis Name: Grain size Analysis for Plastic Waste

Sample Mass Mo: 500g

Sieve size (mm)	Mass of Retained	% Retained	Cumulative % Retained	% of finer pass
4.75	0	0	0	100
2	0	0	0	100
0.85	92	18.4	18.4	81.6
0.425	90	18	36.4	63.6
0.3	61	12.2	48.6	51.4
0.15	37	7.4	56	44
0.075	20.19	4.038	60.038	40
Pan	199.81	39.962	100	0

Specific Gravity

Specific gravity of clay soil of kilole site

Trial	1	2	3
Mass of bottle	28.35	27.58	28.78
Mass of bottle and soil	38.35	37.50	38.82
Mass of bottle, soil and water	85.90	84.41	85.96
Mass of bottle and water	79.69	78.00	79.70
Mass of soil	10.00	9.92	10.04
k@22.5^{0}C	0.9995	0.9995	0.9995
GS @ 20^{0}C	2.64	2.82	2.66
GS Average			2.71

Specific Gravity of Spent Coffee Ground

Trial	1	2	3
Bottle	A	B	C
Mass of bottle	27.72	28.15	28.82
Mass of bottle and coffee ground	37.74	38.22	38.86
Mass of bottle, coffee ground and water	79.83	80.82	80.76
Mass of bottle and water	77.11	79.56	78.65
Mass of Soil	10.03	10.07	10.04
`K@24.5 ^{0}C	0.999	0.999	0.999
GS@20 ^{0}C	1.37	1.14	1.26
GS Average			1.26

Specific Gravity of Plastic Ash

TRIAL	1	2	3
Bottle	A	B	C
Mass of Bottle	27.92	28.29	29.10
Mass of Bottle Plastic Ash	38.012	38.16	38.92
Mass of Bottle, Water Plastic Ash	77.92	80.43	78.99
Mass of Bottle and Water	76.08	79.59	78.01
Mass of Plastic	10.00	9.87	9.82
K@24^0C	0.9991	0.9991	0.9991
GS@20^0C	1.22	1.10	1.11
GS AVERAGE			1.14

Compaction Test

Mass of the mold with base plate: - 3kg and Volume of the mold: - 943.9cm^3

Trial No	M can. soil + mold kg	M. can. soil, kg	can code	mass of can, g	Mass of wet soil + can, g	Mass of dry soil	Mass of water, g	Mass of dry soil,	Moisture content, %	moisture cont. Aver%	□ bulk	□□□dry
1	4.51	1.51	J	17.94	68.90	58.94	10.00	40.96	24.31	24.38	1.59	1.28
			K	17.36	72.76	61.91	10.85	44.55	24.35			
			L	18.07	65.05	55.80	9.24	37.73	24.49			
2	4.60	1.6	A	16.68	44.08	38.16	5.92	21.48	27.57	27.18	1.70	1.33
			B	17.63	51.74	44.39	7.35	26.76	27.47			
			C	18.47	57.24	48.94	8.08	30.48	26.52			
3	4.62	1.62	D	17.33	58.02	48.04	9.98	30.71	32.51	32.73	1.72	1.29
			E	18.79	59.94	49.85	10.09	31.06	32.50			
			F	18.04	51.69	43.31	8.38	25.27	33.18			
4	4.45	1.45	G	19.12	53.15	44.15	9.00	25.03	35.97	35.56	1.54	1.14
			H	17.7	67.4	54.41	12.95	36.64	35.34			
			I	18.02	61.93	50.46	11.47	32.44	35.37			

Atterberg Limit

Liquid Limit for Clay Soil sample

Trial	1	2	3
Can code	F1	F2	F3
Mass of Can	17.65	17.83	17.47
Mass of can with wet soil	33.82	36.00	34.03
Mass of Can with Dry Soil	28.52	30.01	28.50
No of Blows	31	27	20
Mass of Dry soil	10.87	12.17	11.03
Mass of water	5.30	6.00	5.53
Moisture Content (%)	48.80	49.28	50.12
Liquid Limits (%)			49.39

Linear shrinkage

Trials	1	2	3
Initial Length Lo in(mm)	140	140	140
Oven Dried Length LD in mm	134	135	134
Linear shrinkage(%) =(1-LD/Lo)*100	4.29	3.57	4.29
Average result (%)			4.05

APPENDIX TWO

PHYSICAL AND MECHANICAL PROPERTIES OF BRICKS DATA SHEETS

1. Compressive Strength

Compressive strength test results with 0 %(control test) replacement fired @ 600 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	225	110	58	24750	375.02	15.15
2	225	113	54	25425	361.28	14.21
3	226	112	57	25312	363	14.34
4	227	114	56	25878	369.67	14.29
5	225	115	55	25875	365.5	14.13
Mean						14.42

Compressive strength test results with 1.5%PW and 2%SCG replacement fired @ 600 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	226	114	55	25764	355	13.78
2	227	112	57	25424	349.35	13.74
3	226	114	54	25764	357.32	13.87
4	227	114	56	25878	347.78	13.44
5	225	116	57	26100	353.97	13.56
Mean						13.68

Compressive strength test results with 3%PW and 4%SCG replacement fired @ 600 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	226	115	57	25990	367.96	14.16
2	225	114	56	25650	341.44	13.31
3	228	116	57	26448	369	13.95
4	226	114	56	25764	351	13.62
5	225	115	55	25875	348.98	13.49
Mean						13.71

Compressive strength test results with 4.5%PW and 6%SCG replacement fired @ 600 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	226	114	57	25764	330	12.81
2	227	114	56	25878	335.54	12.97
3	226	115	55	25990	315.34	12.13
4	225	115	56	25875	336.67	13.01
5	225	114	54	25650	326.22	12.72
Mean						12.73

Compressive strength test results with 6%PW and 8%SCG replacement fired @ 600 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	227	115	57	26105	309.45	11.85
2	228	116	58	26448	328.66	12.43
3	226	114	56	25764	330	12.81
4	227	115	57	26105	336.67	12.90
5	226	115	56	25990	320.43	12.33
Mean						12.46

Compressive strength test results with 0 %(control test) replacement fired @ 700 ^{0}C

No	`Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	224	111	58	24864	481.12	19.35
2	225	112	55	25200	496.89	19.72
3	224	113	58	25312	449.41	17.75
4	227	114	56	25878	462.31	17.86
5	226	111	55	25086	444.08	17.70
Mean						18.48

Compressive strength test results with 1.5%PW and 2%SCG replacement fired @ 700 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	225	111	57	24975	409.32	16.39
2	224	112	55	25088	381.13	15.19
3	224	111	56	24864	417.07	16.77
4	226	113	54	25538	399.98	15.66
5	224	112	56	25088	426.64	17.01
Mean						16.20

Compressive strength test results with 3%PW and 4%SCG replacement fired @ 700 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	227	114	56	25878	419.70	16.22
2	226	113	55	25538	415	16.25
3	225	112	57	25200	405.67	16.10
4	226	113	54	25538	411	16.09
5	224	112	56	25088	423.78	16.89
Mean						16.31

Compressive strength test results with 4.5%PW and 6%SCG replacement fired @ 700 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	227	115	57	26105	357.93	13.71
2	225	114	56	25650	346.43	13.51
3	226	115	57	25990	374.04	14.39
4	224	116	55	25984	339.21	13.05
5	226	112	56	25312	377.74	14.92
Mean						13.92

Compressive strength test results with 6%PW and 8%SCG replacement fired @ 700 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	225	116	55	26100	328	12.57
2	227	113	56	25651	363	14.15
3	226	114	54	25764	334.06	12.97
4	225	115	56	25875	360	13.91
5	226	113	57	25538	331.53	12.98
Mean						13.32

Compressive strength test results with 0 %(control test) replacement fired @ 800 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	224	114	57	25536	546.05	21.38
2	225	113	55	25425	646.24	25.42
3	224	114	57	25536	533.63	20.90
4	223	112	55	24976	610.71	24.45
5	224	111	55	24864	621.13	24.98
Mean						23.43

Compressive strength test results with 1.5%PW and 2%SCG replacement fired @ 800 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	226	114	57	25764	413.20	16.04
2	225	113	56	25425	411.50	16.18
3	224	114	57	25536	407	15.94
4	227	113	55	25651	417.5	16.28
5	224	112	55	25088	454	18.10
Mean						16.51

Compressive strength test results with 3%PW and 4%SCG replacement fired @ 800 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	224	112	56	25088	476.02	18.97
2	225	111	57	24975	521.78	20.89
3	224	113	55	25312	504	19.91
4	223	112	55	24976	528.13	21.15
5	224	111	55	24864	551	22.16
Mean						20.62

Compressive strength test results with 4.5%PW and 6%SCG replacement fired @ 800 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	225	112	58	25200	367.5	14.58
2	224	111	56	24864	373.6	15.03
3	225	110	57	24750	357.3	14.44
4	224	112	55	25088	347.5	13.85
5	224	111	55	24864	353.6	14.22
Mean						14.42

Compressive strength test results with 6%PW and 8%SCG replacement fired @ 800 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	225	113	57	25425	347.51	13.67
2	224	112	55	25088	337.5	13.45
3	225	114	56	25650	333	12.98
4	226	113	55	25538	331.6	12.98
5	224	112	54	25088	363.65	14.49
Mean						13.52

Compressive strength test results with 0 %(control test) replacement fired **@** 900 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	222	111	58	24642	562	22.81
2	223	112	56	24976	497.23	19.91
3	224	113	57	25312	491	19.40
4	222	114	55	25308	519	20.51
5	224	112	56	25088	539	21.48
Mean						20.82

Compressive strength test results with 1.5%PW and 2%SCG replacement fired @ 900 ^{0}C

No	Dimension in (mm)			Area(mm$^{2)}$	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	223	110	57	24530	392	15.98
2	222	111	54	24642	348	14.12
3	224	110	55	24640	443	17.98
4	221	111	54	24531	407	16.59
5	224	113	55	25312	430	16.99
Mean						16.33

Compressive strength test results with 3%PW and 4%SCG replacement fired @ 900 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	221	111	56	24531	414.61	16.90
2	222	112	55	24864	409.34	16.46
3	223	110	54	24530	413	16.84
4	221	112	55	24752	412.82	16.68
5	223	112	54	24976	417.64	16.72
Mean						16.72

Compressive strength test results with 4.5%PW and 6%SCG replacement fired @ 900 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	222	110	54	24420	327.4	13.41
2	219	111	55	24309	345	14.19
3	210	112	54	23520	301.4	12.81
4	221	110	54	24310	299	12.30
5	222	112	53	24864	339	13.63
Mean						13.27

Compressive strength test results with 6%PW and 8%SCG replacement fired @ 900 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	222	112	54	24864	297	11.94
2	223	113	56	25199	285	11.31
3	224	112	55	25088	283	11.28
4	221	113	54	24973	307	12.29
5	224	112	56	25088	343	13.67
Mean						12.10

Compressive strength test results with 0 %(control test) replacement fired **@** 1000 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	221	105	53	23205	505.5	21.78
2	224	105	54	23520	477.78	20.31
3	224	113	57	25312	489	19.32
4	222	114	55	25308	464	18.33
5	224	112	56	25088	528	21.05
Mean						20.16

Compressive strength test results with 1.5%PW and 2%SCG replacement fired @ 1000 ^{0}C

No	Dimension in (mm)			Area(mm^2)		Compressive strength(Mpa)
	Length	Width	Height			
1	224	105	56	23520	442	18.79
2	223	112	55	24976	383	15.33
3	220	113	54	24860	406	16.33
4	224	112	54	25088	362	14.43
5	223	113	56	25199	388.5	15.42
Mean						16.06

Compressive strength test results with 3%PW and 4%SCG replacement fired @ 1000 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	221	109	56	24089	397.59	16.51
2	222	110	54	24420	396	16.22
3	220	111	55	24420	389.79	15.96
4	221	112	56	24752	403.56	16.30
5	223	109	54	24307	410	16.87
Mean						16.37

Compressive strength test results with 4.5%PW and 6%SCG replacement fired @ 1000 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	221	110	56	24310	339	13.94
2	223	109	55	24307	317	13.04
3	221	111	56	24531	321.5	13.11
4	220	112	57	24640	311	12.62
5	223	110	55	24530	313.4	12.78
Mean						13.10

Compressive strength test results with 6%PW and 8%SCG replacement fired @ 1000 ^{0}C

No	Dimension in (mm)			Area(mm^2)	failure load(KN)	Compressive strength(Mpa)
	Length	Width	Height			
1	210	111	55	23310	282.5	12.12
2	224	112	54	25088	324.4	12.93
3	223	113	57	25199	297.5	11.81
4	221	111	56	24531	297.2	12.12
5	222	112	54	24864	290	11.66
Mean						12.13

2. Dimension Tolerance of Bricks

Dimension tolerance along length (240mm) fired @ 600 ^{0}C

SAMPLES	Control	1.5%PW & 2%SCG	3%PW & 4%SCG	4.5%PW & 6% SCG	6%PW & 8%SCG
Sample 1	226	228	227	229	230
Sample 2	225	226	227	229	230
Sample 3	229	227	229	230	228
Sample 4	223	225	227	228	228
Sample 5	226	225	229	228	229
Sample 6	229	228	227	227	227
Sample 7	225	226	228	228	228
Sample 8	229	227	227	229	228
Sample 9	226	226	226	228	229
Sample 10	231	227	228	227	228
Average Result in (mm)	226.9	227	227.5	228.3	228.5
Average Reduced in dimension in (mm)	**8.1**	**8**	**7.5**	**6.7**	**6.5**
ASTM dimension tolerance(mm)	**7.9**	**7.9**	**7.9**	**7.9**	**7.9**

Dimension tolerance along length (240mm) fired @ 700 ^{0}C

SAMPLES	control	1.5%PW & 2%SCG	3%PW & 4%SCG	4.5%PW & 6% SCG	6%PW & 8%SCG
Sample 1	226	227	229	229	229
Sample 2	225	228	228	228	228
Sample 3	227	227	228	227	228
Sample 4	226	228	227	228	229
Sample 5	225	227	229	229	229
Sample 6	227	226	228	229	228
Sample 7	226	228	228	229	228
Sample 8	226	227	229	229	227
Sample 9	226	228	228	227	228
Sample 10	225	227	227	229	229
Average Result in (mm)	225.9	227.3	228.1	228.4	228.3
Average Reduced in dimension in (mm)	**9.1**	**7.7**	**6.9**	**6.6**	**6.7**
ASTM dimension tolerance(mm)	**7.9**	**7.9**	**7.9**	**7.9**	**7.9**

Dimension tolerance along length (240mm) fired @ 800 ^{0}C

SAMPLES	control	1.5%PW & 2%SCG	3%PW & 4%SCG	4.5%PW & 6% SCG	6%PW & 8%SCG
Sample 1	226	227	228	228	228
Sample 2	227	229	229	228	227
Sample 3	228	`227	227	228	229
Sample 4	227	228	227	227	228
Sample 5	228	226	229	229	227
Sample 6	227	228	227	227	228
Sample 7	228	227	228	228	229
Sample 8	226	229	227	228	228
Sample 9	229	226	227	229	229
Sample 10	228	229	228	227	228
Average Result in (mm)	227.4	227.6	227.7	227.9	228.1
Average Reduced in dimension in (mm)	7.6	7.4	7.3	7.1	6.9
ASTM dimension tolerance(mm)	**7.9**	**7.9**	**7.9**	**7.9**	**7.9**

Dimension tolerance along length (240mm) fired @ 900 ^{0}C

SAMPLES	Control	1.5%PW & 2% SCG	3%PW & 4% SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	220	224	227	224	224
Sample 2	223	223	224	223	225
Sample 3	224	223	223	224	224
Sample 4	223	224	225	223	224
Sample 5	224	223	224	222	224
Sample 6	225	222	226	224	225
Sample 7	223	224	223	223	226
Sample 8	224	223	224	222	224
Sample 9	223	223	225	224	224
Sample 10	224	223	223	223	225
Average Result in (mm)	223.3	223.2	224.4	223.2	224.5
Average Reduced in dimension in (mm)	**11.7**	**11.8**	**10.6**	**11.8**	**10.5**
ASTM dimension tolerance(mm)	**7.9**	**7.9**	**7.9**	**7.9**	**7.9**

Dimension tolerance along length (240mm) fired @ 1000 ^{0}C

SAMPLES	Control	1.5%PW & 2%SCG	3%PW & 4%SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	210	215	219	218	220
Sample 2	211	216	220	219	223
Sample 3	211	218	220	220	224
Sample 4	212	214	219	220	223
Sample 5	213	215	223	221	220
Sample 6	212	216	222	223	220
Sample 7	213	217	221	220	223
Sample 8	211	215	222	219	222
Sample 9	210	216	224	222	221
Sample 10	213	217	223	221	220
Average Result in (mm)	211.6	215.9	221.3	220.3	221.6
Average Reduced in dimension in (mm)	**23.4**	**19.1**	**13.7**	**14.7**	**13.4**
ASTM dimension tolerance(mm)	**7.9**	**7.9**	**7.9**	**7.9**	**7.9**

Dimension tolerance along width (120mm) fired @ 600 ^{0}C

SAMPLES	Control	1.5%PW & 2% SCG	3%PW & 4% SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	113	114	116	116	116
Sample 2	114	113	115	115	117
Sample 3	112	113	115	115	116
Sample 4	113	114	116	114	116
Sample 5	112	112	114	116	115
Sample 6	114	113	116	115	115
Sample 7	113	114	115	116	115
Sample 8	112	112	114	114	117
Sample 9	114	114	115	116	116
Sample 10	113	113	116	115	116
Average Result in (mm)	**113**	**113.2**	**115.2**	**115.2**	**115.9**
Average Reduced in dimension in (mm)	**5**	**4.8**	**2.8**	**2.8**	**2.1**
ASTM dimension tolerance(mm)	**4.8**	**4.8**	**4.8**	**4.8**	**4.8**

Dimension tolerance along width (120mm) fired @ 700 ^{0}C

SAMPLES	Control	1.5%PW & 2%SCG	3%PW & 4% SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	113	115	115	116	116
Sample 2	114	113	114	115	117
Sample 3	113	114	114	116	116
Sample 4	114	115	115	117	117
Sample 5	113	115	115	116	115
Sample 6	114	113	114	115	115
Sample 7	112	114	114	116	116
Sample 8	114	114	114	117	116
Sample 9	113	115	115	115	115
Sample 10	113	113	115	115	115
Average Result in (mm)	**113.3**	**114.1**	**114.5**	**115.8**	**115.8**
Average Reduced in dimension in (mm)	**4.7**	**3.9**	**3.5**	**2.2**	**2.2**
ASTM dimension tolerance(mm)	**4.8**	**4.8**	**4.8**	**4.8**	**4.8**

Dimension tolerance along width (120mm) fired @ 800 ^{0}C

SAMPLES	Control	1.5%PW & 2%CG	3%PW & 4%CG	4.5%PW & 6% CG	6%PW & 8%CG
Sample 1	111	112	113	113	116
Sample 2	112	113	113	114	115
Sample 3	112	112	112	113	115
Sample 4	113	114	112	113	114
Sample 5	112	112	112	113	116
Sample 6	112	112	112	114	115
Sample 7	113	113	113	114	114
Sample 8	112	114	112	113	116
Sample 9	111	112	113	112	115
Sample 10	113	112	113	113	116
Average Result in (mm)	**112.1**	**112.6**	**112.5**	**113.2**	**115.2**
Average Reduced in dimension in (mm)	**5.9**	**5.4**	**5.5**	**4.8**	**2.8**
ASTM dimension tolerance(mm)	**4.8**	**4.8**	**4.8**	**4.8**	**4.8**

Dimension tolerance along width (120mm) fired @ 900 ^{0}C

SAMPLES	Control	1.5%PW & 2%SCG	3%PW & 4% SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	112	113	113	114	115
Sample 2	111	112	112	113	114
Sample 3	112	112	113	115	111
Sample 4	112	112	114	112	113
Sample 5	113	113	112	114	114
Sample 6	112	112	113	112	115
Sample 7	111	112	114	112	113
Sample 8	114	114	112	111	114
Sample 9	113	113	114	113	114
Sample 10	112	112	113	113	113
Average Result in (mm)	**112.2**	**112.5**	**113**	**112.9**	**113.6**
Average Reduced in dimension in (mm)	**5.8**	**5.5**	**5**	**5.1**	**4.4**
ASTM dimension tolerance(mm)	**4.8**	**4.8**	**4.8**	**4.8**	**4.8**

Dimension tolerance along width (120mm) fired @ 1000 ^{0}C

SAMPLES	Control	1.5%PW & 2% SCG	3%PW & 4% SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	110	110	111	110	110
Sample 2	109	109	111	111	112
Sample 3	109	110	111	111	111
Sample 4	109	112	112	112	112
Sample 5	111	111	112	112	112
Sample 6	110	110	111	112	110
Sample 7	112	109	110	110	112
Sample 8	109	112	111	112	112
Sample 9	112	111	112	111	112
Sample 10	111	110	112	110	112
Average Result in (mm)	**110.2**	**110.4**	**111.3**	**111.1**	**111.5**
Average Reduced in dimension in (mm)	**7.8**	**7.6**	**6.7**	**6.9**	**6.5**
ASTM dimension tolerance(mm)	**4.8**	**4.8**	**4.8**	**4.8**	**4.8**

Dimension tolerance along height (60mm) fired @ 600 ^{0}C

SAMPLES	Control	1.5%PW & 2% SCG	3%PW & 4% SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	59	58	58	59	59
Sample 2	58	59	59	59	59
Sample 3	59	57	58	58	59
Sample 4	58	59	59	59	59
Sample 5	59	58	58	59	58
Sample 6	59	59	59	58	58
Sample 7	59	58	58	58	58
Sample 8	59	59	59	59	59
Sample 9	58	58	58	59	59
Sample 10	58	59	59	59	59
Average Result in (mm)	**58.6**	**58.4**	**58.5**	**58.7**	**58.7**
Average Reduced in dimension in (mm)	**1.4**	**1.6**	**1.5**	**1.3**	**1.3**
ASTM dimension tolerance(mm)	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**

Dimension tolerance along height (60mm) fired @ 700 ^{0}C

SAMPLES	Control	1.5%PW & 2% SCG	3%PW & 4% SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	57	58	57	59	59
Sample 2	58	59	57	59	59
Sample 3	57	59	59	59	59
Sample 4	59	58	58	58	58
Sample 5	57	59	58	58	57
Sample 6	58	59	57	58	58
Sample 7	58	58	59	59	58
Sample 8	57	58	58	59	59
Sample 9	58	57	57	57	59
Sample 10	57	59	57	58	59
Average Result in (mm)	**57.6**	**58.4**	**57.7**	**58.4**	**58.5**
Average Reduced in dimension in (mm)	**2.4**	**1.6**	**2.3**	**1.6**	**1.5**
ASTM dimension tolerance(mm)	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**

Dimension tolerance along height (60mm) fired @ 800 ^{0}C

SAMPLES	Control	1.5%PW & 2% SCG	3%PW & 4% SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	57	57	59	59	59
Sample 2	58	57	59	59	59
Sample 3	57	58	59	58	59
Sample 4	58	58	59	58	59
Sample 5	57	58	58	58	59
Sample 6	57	58	58	57	57
Sample 7	59	57	58	59	57
Sample 8	57	58	58	59	57
Sample 9	56	57	58	58	57
Sample 10	56	59	57	58	56
Average Result in (mm)	**57.2**	**57.7**	**58.3**	**58.3**	**57.9**
Average Reduced in dimension in (mm)	**2.8**	**2.3**	**1.7**	**1.7**	**2.1**
ASTM dimension tolerance(mm)	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**

Dimension tolerance along height (60mm) fired @ 900 ^{0}C

SAMPLES	Control	1.5%PW & 2% SCG	3%PW & 4% SCG	4.5%PW & 6%SCG	6%PW & 8% SCG
Sample 1	58	57	57	57	57
Sample 2	57	58	58	58	58
Sample 3	58	57	58	58	59
Sample 4	59	56	57	56	59
Sample 5	57	59	57	56	57
Sample 6	57	59	57	57	58
Sample 7	56	56	56	57	58
Sample 8	56	57	58	57	58
Sample 9	56	57	57	58	57
Sample 10	57	58	57	59	58
Average Result in (mm)	**57.1**	**57.4**	**57.2**	**57.3**	**57.9**
Average Reduced in dimension in (mm)	**2.9**	**2.6**	**2.8**	**2.7**	**2.1**
ASTM dimension tolerance(mm)	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**

Dimension tolerance along height (60mm) fired @ 1000 ^{0}C

SAMPLES	Control	1.5%PW & 2% SCG	3%PW & 4% SCG	4.5%PW & 6%SCG	6%PW & 8% SCG
Sample 1	55	56	56	55	56
Sample 2	56	57	56	56	57
Sample 3	56	55	57	57	57
Sample 4	55	57	56	57	58
Sample 5	56	56	56	57	58
Sample 6	56	56	57	58	58
Sample 7	55	57	57	56	57
Sample 8	56	57	55	57	56
Sample 9	55	56	57	57	56
Sample 10	56	56	56	56	57
Average Result in (mm)	**55.6**	**56.3**	**56.3**	**56.6**	**57**
Average Reduced in dimension in (mm)	**4.4**	**3.7**	**3.7**	**3.4**	**3**
ASTM dimension tolerance(mm)	**2.4**	**2.4**	**2.4**	**2.4**	**2.4**

3. Water Absorption For 24 Hrs Immersed In Cold Water And 5Hrs Boiling Saturation Coefficient

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling for control test fired @ 600 ^{0} C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.87	2.38	21.43	2.39	27.81	0.98
Sample2	1.88	2.40	21.67	2.42	28.72	0.96
Sample3	1.87	2.57	27.24	2.59	38.50	0.97
Sample4	1.88	2.42	22.52	2.44	30.13	0.96
Sample5	1.88	2.46	23.58	2.47	31.38	0.98
Mean Result			23.29		31.31	0.97

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling for control test fired @ 700 ^{0} C

Control Bricks	Oven Dried Weight (W1) in KG	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.87	2.28	17.98	2.29	22.46	0.98
Sample2	1.90	2.35	19.36	2.37	25.07	0.96
Sample3	1.88	2.46	23.74	2.47	31.66	0.98
Sample4	1.78	2.33	23.61	2.35	32.02	0.96
Sample5	1.68	2.21	23.98	2.22	32.14	0.98
Mean Result			21.73		28.67	0.97

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling for control test fired @ 800 ^{0} C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.89	2.35	19.40	2.39	26.46	0.91
Sample2	1.88	2.38	21.01	2.41	28.19	0.94
Sample3	1.91	2.41	20.75	2.42	26.70	0.98
Sample4	1.92	2.32	17.24	2.38	23.96	0.87
Sample5	1.84	2.34	21.58	2.40	30.79	0.89
Mean Result			20.00		27.22	0.92

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling for control test fired @ 900 ^{0} C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.82	2.30	21.09	2.31	27.27	0.98
Sample2	1.83	2.28	19.74	2.30	25.68	0.96
Sample3	1.86	2.27	18.28	2.28	22.91	0.98
Sample4	1.80	2.25	20.00	2.27	26.11	0.96
Sample5	1.79	2.26	20.80	2.27	26.82	0.98
Mean Result			19.98		25.76	0.97

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling for control test fired @ 1000 ^{0} C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.87	2.23	16.37	2.25	20.64	0.95
Sample2	1.86	2.26	17.92	2.28	22.91	0.95
Sample3	1.83	2.25	18.67	2.27	24.04	0.95
Sample4	1.87	2.22	15.77	2.25	20.32	0.92
Sample5	1.80	2.34	23.08	2.36	31.11	0.96
Mean Result			18.36		23.81	0.95

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 1.5%PW & 2% SCG test fired @ 600 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.63	2.25	27.56	2.3	41.10	0.93
Sample2	1.76	2.30	23.53	2.33	32.76	0.94
Sample3	1.80	2.28	21.27	2.30	28.13	0.96
Sample4	1.77	2.31	23.59	2.34	32.58	0.95
Sample5	1.80	2.39	24.90	2.40	33.70	0.98
Mean Result			24.17		33.66	0.95

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 1.5%PW & 2% SCG test fired @ 700 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.77	2.30	23.26	2.35	33.14	0.91
Sample2	1.75	2.22	21.40	2.24	28.37	0.96
Sample3	1.67	2.19	23.74	2.20	31.74	0.98
Sample4	1.65	2.22	25.68	2.23	35.15	0.98
Sample5	1.81	2.15	15.81	2.17	19.89	0.94
Mean Result			21.98		29.66	0.96

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 1.5%PW & 2% SCG test fired @ 800 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.74	2.25	22.89	2.26	30.26	0.98
Sample2	1.74	2.23	22.20	2.24	29.11	0.98
Sample3	1.74	2.16	19.68	2.18	25.65	0.96
Sample4	1.75	2.24	21.92	2.25	28.94	0.97
Sample5	1.73	2.17	20.51	2.18	26.38	0.98
Mean Result			21.44		28.07	0.97

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 1.5%PW & 2% SCG test fired @ 900 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.72	2.20	22.05	2.22	29.45	0.96
Sample2	1.71	2.19	21.92	2.20	28.65	0.98
Sample3	1.69	2.15	21.40	2.16	27.81	0.98
Sample4	1.75	2.13	18.08	2.15	23.21	0.95
Sample5	1.73	2.12	18.63	2.13	23.48	0.98
Mean Result			20.41		26.52	0.97

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 1.5%PW & 2% SCG test fired @ 1000 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.67	2.07	19.32	2.08	24.55	0.98
Sample2	1.68	2.10	20.24	2.11	25.97	0.98
Sample3	1.68	2.05	18.29	2.10	25.37	0.88
Sample4	1.65	2.04	19.12	2.05	24.24	0.98
Sample5	1.60	1.98	19.19	2.00	25.00	0.95
Mean Result			19.23		25.03	0.95

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 3%PW & 4% SCG test fired @ 600 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.70	2.19	22.37	2.20	29.41	0.98
Sample2	1.65	2.18	24.31	2.20	33.33	0.96
Sample3	1.68	2.16	22.22	2.19	30.36	0.94
Sample4	1.58	2.15	26.51	2.16	36.71	0.98
Sample5	1.59	2.16	26.39	2.17	36.48	0.98
Mean Result			24.36		33.26	0.97

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 3%PW & 4% SCG test fired @ 700 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.64	2.07	21.01	2.09	27.83	0.96
Sample2	1.65	2.13	22.54	2.14	29.70	0.98
Sample3	1.70	2.16	21.30	2.18	28.24	0.96
Sample4	1.63	2.12	23.11	2.16	32.52	0.92
Sample5	1.60	2.09	23.44	2.12	32.50	0.94
Mean Result			22.28		30.16	0.95

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 3%PW & 4% SCG test fired @ 800 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.68	2.18	22.94	2.21	31.55	0.94
Sample2	1.69	2.20	23.18	2.32	37.28	0.81
Sample3	1.69	2.16	21.76	2.17	28.40	0.98
Sample4	1.65	2.10	21.43	2.11	27.88	0.98
Sample5	1.71	2.1	18.81	2.13	24.93	0.93
Mean Result			21.62		30.01	0.93

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 3%PW & 4% SCG test fired @ 900 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.75	2.22	21.17	2.23	27.43	0.98
Sample2	1.71	2.19	22.15	2.21	29.62	0.96
Sample3	1.76	2.21	20.36	2.23	26.70	0.96
Sample4	1.73	2.17	20.28	2.18	26.01	0.98
Sample5	1.72	2.19	21.46	2.20	27.91	0.98
Mean Result			21.08		27.53	0.97

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 3%PW & 4% SCG test fired @ 1000 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.61	2.08	22.60	2.10	30.43	0.96
Sample2	1.60	1.99	19.60	2.01	25.63	0.95
Sample3	1.64	2.12	22.64	2.14	30.49	0.96
Sample4	1.69	2.09	19.14	2.11	24.85	0.95
Sample5	1.70	2.11	19.43	2.14	25.88	0.93
Mean Result			20.68		27.46	0.95

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 4.5%PW & 6% SCG test fired @ 600 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.60	2.23	28.25	2.24	40.00	0.98
Sample2	1.69	2.15	21.63	2.16	28.19	0.98
Sample3	1.76	2.24	21.43	2.28	29.55	0.92
Sample4	1.65	2.29	27.95	2.39	44.85	0.86
Sample5	1.61	2.14	24.77	2.15	33.54	0.98
Mean Result			24.80		35.22	0.95

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 4.5%PW & 6% SCG test fired @ 700 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.56	2.14	27.10	2.21	41.67	0.89
Sample2	1.65	2.09	21.29	2.10	27.66	0.98
Sample3	1.67	2.10	20.48	2.11	26.35	0.98
Sample4	1.70	2.20	22.73	2.21	30.00	0.98
Sample5	1.72	2.21	22.17	2.22	29.07	0.98
Mean Result			22.75		30.95	0.96

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 4.5%PW & 6% SCG test fired @ 800 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.57	2.12	25.94	2.17	38.22	0.92
Sample2	1.63	2.19	25.57	2.20	34.97	0.98
Sample3	1.64	2.17	24.42	2.18	32.93	0.98
Sample4	1.69	2.20	23.18	2.21	30.77	0.98
Sample5	1.67	1.89	11.64	1.94	16.17	0.81
Mean Result			22.15		30.61	0.94

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 4.5%PW & 6% SCG test fired @ 900 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.55	2.06	24.76	2.08	34.19	0.96
Sample2	1.69	2.09	19.14	2.10	24.26	0.98
Sample3	1.62	2.05	20.98	2.06	27.16	0.98
Sample4	1.65	2.08	20.67	2.1	27.27	0.96
Sample5	1.60	2.11	24.17	2.13	33.13	0.96
Mean Result			21.94		29.20	0.97

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 4.5%PW & 6% SCG test fired @ 1000 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.64	2.09	21.53	2.13	29.88	0.92
Sample2	1.62	2.11	23.22	2.16	33.33	0.91
Sample3	1.64	2.10	21.90	2.14	30.49	0.92
Sample4	1.63	2.09	22.01	2.11	29.45	0.96
Sample5	1.61	2.03	20.69	2.04	26.71	0.98
Mean Result			21.87		29.97	0.94

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 6%PW & 8% SCG test fired @ 600 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.76	2.35	25.11	2.37	34.66	0.97
Sample2	1.68	2.23	24.66	2.25	33.93	0.96
Sample3	1.81	2.40	24.58	2.42	33.70	0.97
Sample4	1.67	2.21	24.43	2.22	32.93	0.98
Sample5	1.69	2.30	26.52	2.33	37.87	0.95
Mean Result			25.06		34.62	0.97

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 6%PW & 8% SCG test fired @ 700 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.67	2.17	23.04	2.18	30.54	0.98
Sample2	1.64	2.13	23.00	2.15	31.10	0.96
Sample3	1.71	2.19	21.92	2.21	29.24	0.96
Sample4	1.66	2.18	23.85	2.19	31.93	0.98
Sample5	1.65	2.14	22.90	2.17	31.52	0.94
Mean Result			22.94		30.86	0.96

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 6%PW & 8% SCG test fired @ 800 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.68	2.20	23.64	2.24	33.33	0.93
Sample2	1.67	2.16	22.69	2.19	31.14	0.94
Sample3	1.67	2.17	23.04	2.19	31.14	0.96
Sample4	1.62	2.01	19.40	2.04	25.93	0.93
Sample5	1.61	2.09	22.97	2.10	30.43	0.98
Mean Result			22.35		30.39	0.95

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 6%PW & 8% SCG test fired @ 900 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample 1	1.76	2.20	20.00	2.22	26.14	0.96
Sample 2	1.69	2.19	22.83	2.20	30.18	0.98
Sample 3	1.63	2.16	24.54	2.20	34.97	0.93
Sample 4	1.58	2.03	22.17	2.05	29.75	0.96
Sample 5	1.67	2.11	20.85	2.13	27.54	0.96
Mean Result			22.08		29.71	0.96

Water Absorption of 24 hrs immersed in cold water and 5hrs boiling Bricks for 6%PW & 8% SCG test fired @ 1000 ^{0}C

Control Bricks	Oven Dried Weight (W1) in Kg	Water immersed Weight(W2) in Kg	Water Absorption for 24hrs in (%)	5hrs boiling weight (W3) in Kg	Water Absorption for 5hrs boiling (%)	saturation coefficient
Sample1	1.65	2.12	22.17	2.13	29.09	0.98
Sample2	1.63	2.08	21.63	2.10	28.83	0.96
Sample3	1.60	2.07	22.71	2.11	31.88	0.92
Sample4	1.62	2.07	21.74	2.10	29.63	0.94
Sample5	1.61	2.05	21.46	2.12	31.68	0.86
Mean Result			21.94		30.22	0.93

4. **Efflorescence**

Efflorescence Test of Bricks fired at 600 ^{0}C

Samples	control Bricks	1.5%PW & 2% SCG	3%PW & 4% SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 2	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 3	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 4	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 5	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 6	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 7	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 8	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 9	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 10	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced

Efflorescence Test of Bricks fired at 700 ^{0}C

Samples	control Bricks	1.5%PW & 2% SCG	3%PW & 4% SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 2	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 3	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 4	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 5	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 6	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 7	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 8	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 9	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 10	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced

Efflorescence Test of Bricks fired at 800 ^{0}C

Samples	control Bricks	1.5%PW & 2% SCG	3%PW & 4% SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 2	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 3	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 4	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 5	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 6	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 7	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 8	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 9	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample	Not	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced

10	Effloresced				

Efflorescence Test of Bricks fired at 900 ^{0}C

Samples	control Bricks	1.5%PW & 2% SCG	3%PW & 4% SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 2	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 3	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 4	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 5	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 6	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 7	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 8	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 9	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 10	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced

Efflorescence Test of Bricks fired at 1000 ^{0}C

Samples	control Bricks	1.5%PW & 2% SCG	3%PW & 4% SCG	4.5%PW & 6% SCG	6%PW & 8% SCG
Sample 1	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 2	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 3	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 4	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 5	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 6	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 7	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 8	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 9	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced
Sample 10	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced	Not Effloresced

APPENDIX THREE

Sample Photo Gallery Taken During the Research

Photo taken during collection of raw materials of Bricks

Photo taken during raw material preparation for production of bricks

Picture taken during liquid and plastic limit tests

Mould and green bricks manufactured