JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIROMENTAL ENGINEERING

STRUCTURAL ENGINEERING CHAIR

EXPERIMENTAL INVESTIGATION OF THE EFFECT OF HIGH TEMPERATURE ON CONCRETE PROPERTY AS PARTIALLY REPLACEMENT OF COARSE AGGREGATE BY WASTE BRICK

A Research Submitted To School of Graduate Studies, Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering in Partial Fulfillment of the Requirement for the Degree Master of Science In Structural Engineering

By:
RIBKA ALEMU DABA

JUNE, 2024
JIMMA, ETHIOPIA

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By:

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DECLARATION

I declare that this research entitled "*Experimental Investigation Of The Effect Of High Temperature On Concrete Property As Partially Replacement Of Coarse Aggregate By Waste Brick*" Is my original work and has not be submitted as a requirement for the award of any degree in Jimma University or elsewhere.

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As research Advisor, I hereby certify that I have read and evaluated this research paper prepared under any guidance, by Ribka Alemu Daba entitled "EXPERIMENTAL INVESTIGATION OF THE EFFECT OF HIGH TEMPERATURE ON CONCRETE PROPERTY AS PARTIALLY REPLACEMENT OF COARSE AGGREGATE BY WASTE BRICK'' recommend and would be accepted as a fulfilling requirement for the degree Master of Science in Structural Engineering.Advisor:

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ABSTRACT

Concrete is the most widely used man-made construction material. It is obtained by mixing cement, water and aggregates (and sometimes admixture) in required proportions. Aggregates contain approximately 75% of the concrete's body and give greater volume stability and durability than hydrated cement paste. Despite being a relatively simple idea, concreting can be difficult to understand at times, and even seemingly insignificant variables like temperature can have a significant impact on how well concrete performs.

A comprehensive investigation of the compressive and split tensile strengths by percentage of waste brick aggregate used in concrete that was mixed, poured, and allowed to cure at varied temperatures was conducted. The effect on workability using slump test and water absorption test were investigated. The waste brick used as replacements was collected from brick production area that is found in a Jimma.

This objective provides an overview of the effects of high temperature on the property of concrete materials and structure temperature on waste brick aggregate as partial replacement for natural coarse aggregate by 10%, 20%, 30%, and 40% by volume in C-25 concrete production with investigation of optimum ratio of replacement and engineering properties of C-25 concrete.

A total of ninety three concrete mixes were made that include the control and the replacement mixes. A water/cement ratio of 0.5 was used for all the mixes. From the research, it was observed that the addition waste brick aggregate reduces workability of wet concrete. The results harden concrete work have shown that, up to 30% replacement of the waste brick aggregate with temperature effect achieved a higher compressive strength, split tensile strength and water absorption at all test ages i.e. 7and 28 days of curing test.

It can therefore, be concluded that 30% replacement of natural coarse aggregate by waste brick aggregate with temperature effect results in a similar concrete properties with control test and it is the optimum replacement. This paper also deals with the procedure and precautions to be observed while concreting in high temperature conditions so as to minimize the detrimental effects of temperature on concreting in general types of construction, such as buildings, and other similar structures.

***Keyword**: compressive strength, temperature effect, waste brick coarse aggregate,*

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ACCRONOMY

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BA	Brick Aggregate
CBA	Crushed Brick Aggregate
CM	Control Mix
CSA	Central Statistical Agency
ECC	Engineered Cementitious Composite
JiT	Jimma institute of Technology
NCA	Natural course aggregate
ST	Slump Test
STST	Split Tensile Strength Test
WBA	Wasted Brick Aggregate

LIST OF SYMBOLES

Roman Upper Case Letters

A	Area
A	Average distance between line of fracture and the nearest support measured on the tension surface of the beam
D	Diameter of the cylinder
E_{cm}	Secant modulus of elasticity of concrete
L	Length of the cylinder
L	Span length
P	Compressive load on the cylinder
P	Maximum applied load
T	Spilt tensile strength of the concrete

Roman Lower Case Letters

b	Average width of specimen
d	Average depth of specimen
f_c	Compressive strength of concrete
f_{ck}	Characteristic compressive cylinder strength of concrete at 28 days
$f_{ck}(t)$	Characteristic compressive cylinder strength of concrete at t
f_{cm}	Mean value of concrete cylinder compressive strength
$f_{cm}(t)$	Mean concrete compressive strength at an age of t days
f_{ct}	Tensile strength of concrete
$f_{ct,sp}$	Splitting tensile strength of concrete
f_{ctk}	Characteristic axial tensile strength of concrete
f_{ctm}	Mean value of axial tensile strength of concrete
$f_{ctm}(t)$	Mean value of axial tensile strength of concrete an age of t days
k	Coefficient
s	Coefficient which depends on the type of cement
t	Age of the concrete in days

CHAPTER ONE

1. INTRODUCTION

1.1 Back Ground

In our country concrete is one of the most widely used construction material. It is the proper mixture of water, cement and aggregates and sometimes adds admixtures. Properties of the material used for concrete and their ratios affect the quality and performance of concrete [1]. There is an effect on the concrete from each material utilized.

Aggregates impart higher volume stability and better durability than hydrated cement paste in concrete and provide around75 per cent of the body of concrete [2]. The aggregates are sensually derived from natural and wastes materials sources. Strength of concrete prepared using different aggregates are not the same under high temperatures[3].

Governments over the world are encouraging research efforts to use these waste materials in a greater quantity in secondary building materials[4]. One way of using waste materials in sustainable way is utilizing the materials in construction materials such as concrete. Knowing engineering properties of locally available materials and improving them may be alternative option rather only depending on standard materials like concrete[4].Different research studies have focused on replacing natural materials in concrete with waste products.

Because of its strength, beauty, and simplicity of handling, clay brick is among the most traditional and widely used building materials. Clay bricks are used for both exterior and interior walls, piers, footings, and other load-bearing structures [5]. Clay bricks are now created utilizing a variety of production systems all around the world.

A waste brick aggregate is on type of aggregate made of waste material from construction, production area those are broken during transportation. Besides the unit weight of brick aggregate concrete has been reported to be much less than that of stone aggregate concrete [2]. And the use of waste brick aggregate instead of stone aggregate in various components of a building structure can result in a significant reduction of dead load , fire resistance and its make the construction economical.

Despite being a relatively simple idea, concreting can be difficult to understand at times, and even seemingly insignificant variables like temperature can have a significant impact on how well concrete performs. Thus, the kind and characteristics of the aggregate also have a significant impact on the characteristics of concrete that is exposed to high temperatures. Under high temperatures, the ways in which concretes with varying particles lose strength change.

Furthermore, high temperatures are a concern, particularly in mass concrete pours where the mass effect can cause the core temperature to rise significantly while the surface temperature falls. This result in a temperature gradient between the surface and the core, and a temperature differential of too great an extent can lead to thermal cracking.

Therefore, the primary objective of this study is to evaluate the performance of waste brick aggregate with temperature effect on the mechanical, physical properties of concrete and the workability of concrete because we have enormous amount of waste brick aggregate but we don’t utilized it efficiently even, and the requirements of this research is to find out the optimum percentage of waste brick aggregate is enough to improve the mechanical, physical properties of concrete well.

1.2 Statement of the Problem

Most of concrete structures are typically exposed to a temperature range that is no greater than that which is imposed by the surrounding environment. When concrete is exposed to high temperatures during fire or when used in furnaces, this greatly reduces the mechanical properties of concrete strength, size deformation and coefficient Flexibility, therefore we must select the appropriate materials, to minimize the harmful effects on the concrete structure and prevent unwanted structural failure [6]. It is known that aggregates are one of the main elements influencing the properties of concrete as constituent materials.

Many studies have been carried out to investigating the effect of high temperature on different concrete specimens. Chan et al, 2000, they studied the response of high-strength concrete to elevated temperature, Anson, 2006 studied effect of high temperature on high performance steel fiber reinforced concrete. In Ethiopia, using of waste brick aggregate as consistency of concrete in construction industry is not used commonly, even though less availability of natural course aggregate in some part of country. Brick is a highly available construction material around Jimma Zone.

Using the waste clay brick as an aggregate in concrete it is possible to design concrete mixtures in the same way as the design mixtures for commonly used aggregates. The use of above mentioned aggregate for concrete high porosity and water absorption of the material. Consequently, that can affect workability of fresh concrete made with that aggregate is the ability of a fresh concrete mix to fill the form mold properly with the desired work and without reducing the concrete's quality.

This research was done the Effect of temperature on the concrete property as partially replacement of coarse aggregate by Waste Brick. Utilization waste brick aggregate as natural course aggregate replacement material with is, To understand the behavior of concrete under high temperature, it is necessary that several factors be taken into account for each experiment such as Strength of concrete, type of cement, aggregate, water cement ratio are some of the important factors that affect the performance of concrete at high temperature.

1.3 Research Questions

- Does addition of waste brick aggregate on the concrete will affect the workability of concrete?
- Does temperature affect the addition of waste brick aggregate in the concrete mix will improve the mechanical properties of concrete such as, compressive strength and split tensile strength?
- What is the effect of replacing of natural course aggregate by waste brick aggregate in water absorption property of concrete?
- What is the relationship of concrete stress and strain in the partial replacement of natural coarse aggregate with waste brick aggregate in concrete mix under the effect of temperature?

1.4 Objective

1.4.1 General Objective

The general objective of this research was to investigate an experimental investigation of the effect of temperature on the waste brick as a partial replacement of coarse aggregate on concrete properties.

1.4.2 Specific Objective

- To determine the effects of replacing natural coarse aggregate by waste brick aggregate on the workability of concrete.
- To assess the effect of temperature on replacing natural coarse aggregate by waste brick aggregate on the strength capacity of concrete such as, compressive strength and split tensile strength.
- To determine the effects of replacing natural coarse aggregate by waste brick aggregate on water absorption of concrete property.
- To find out the basic relationship of concrete stress and strain.

1.5 Significance of the Study

During its lifespan, concrete structures are subjected to a variety of temperature variations. Concrete in case of unexpected fire, the concrete properties are changes after fire. The effect of Aggregate on the behavior of concrete subjected to high temperatures has been widely researched. Yet, there aren't many studies in the technical literature discussing how waste brick aggregate affects the behavior of concrete at high temperature. The significance of this study is to measures the concrete's heat degradation in terms of different specimens' compressive and split tensile strengths by partial replacement of natural coarse aggregate by waste brick aggregate. The other importance of this study is, the replacement of stone aggregate by brick aggregate may reduce building dead weights and it makes buildings economical.

In addition to this study is significant to use local material in appropriate way for buildings, to give awareness for user the extent of quality problem and indicate ways of improving qualities since waste brick is widely used in Jimma; So that it reduces the scarcity of construction material especially in load bearing wall materials for low cost buildings. Also, to know up to degree of temperature does waste brick aggregate concrete attain targeted compressive strength and split tensile strength.

Therefore ,this study is will be believed to contribute a new knowledge area on the effect of high temperature by using waste bricks from brick factories in and around Jimma in concrete as coarse aggregate.

1.6 Scope and Limitation of the Study

The scope of this research is to investigate the effects of temperature on addition of different percentage value of WBA on the mechanical and physical properties of concrete, to get the optimum percentage value of combination of WBA and also investigate stress strain of concrete.

The research was done by adding different percentage value of WBA, as 0%, 10%, 20%, 30%, and 40% by volume of WBA, on the concrete mix of C-25 grade of concrete. Three specimens were casted for each test at the age of 7 and 28 days. Then different samples for different tests was taken, for compressive strength test 60 samples of cube 150x150x150 mm, for split tensile strength test 30 samples of cylinder 150x300 mm and for water absorption test 3 sample of cube 150x150x150 mm. This experimental investigation on the effect of temperature on waste brick as partially replacement of coarse aggregate on concrete property.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 General Overview

Concrete is a composite material that most commonly used in building construction. It is made up of different constituents such as, aggregate, sand, cement, water and sometimes adding admixture. Concrete is a versatile material that can easily be mixed to meet a variety of special needs and formed to virtually any shape. It is currently one of the most common and extensively used materials in construction and it is one of most durable, fire resistance, economical and energy efficient.

The principal components of concrete are coarse and fine aggregates, water, Portland cement and other bindings, and chemical additives, with a proper mix design and construction procedure, produce the concrete with the required engineering properties.

Clay bricks have always been one of the widely used construction materials in the construction industry. In earlier times of construction, these waste clay bricks were used as concrete aggregate in crushed form[6]. Crushed clay brick is the form of this material that has an aggregate size between 0.075 mm up to 50 mm and ground brick is another form powdered to cement fineness[4] .

The densities of these aggregates were in the range of 1500-2000 kg/m3, which is a difficult range to explicitly categorize these kinds of aggregates. For instance, De Pauw et al., [6] classified them between the lightweight aggregate and normal weight aggregate. However, looking at some other characteristics such as porosity and water absorption, the aggregates would be classified as lightweight aggregate [6].

Previously carried out researches show that crushed aggregate from clay brick may be used to produce normal strength concrete with reduced weight in comparison to natural crushed basaltic rock aggregate concrete [7].

Fire represents one of most severe risks to buildings and structures. Considering the characteristics of the waste brick aggregates is very important to know the performance of waste brick aggregates concrete when it is exposed to different temperatures. The main cause of temperature effects on structures in improper design of the structure or non-engineered structure. studying temperature effect on concrete have different advantage such as, knowing the amount strength, bearing capacity of concrete, failure plan in concrete and safety level during heat exposure.

The performance of these concretes will be study when they will be exposing to the following temperatures: 200°, 400°, 600°, 800° and 1000°C that means at high temperature. Because Jimma bricks need more burning to get better strength as it dominant construction material[8].

The compressive strength, concrete mass loss, apparent volume, apparent density and water porosity are evaluated on recycled brick concrete before and after heating, some of these properties were compared with the values obtained on similar conventional concrete (equal w/c ratio and mixture proportions) made with the same type of NCA[9].

The temperature effects on concrete during exposure of heat, fire, climatically changes occurs seasonal variation has been investigated by reviewing some international journals[10].

2.2 Replacement of Natural Course Aggregate by Construction Material Wastage

Globally, during the last decades, it has been recognized with growing concern that waste materials from construction and demolition are of large volume and that is increasing year by year[9].The large quantities waste material from construction, commercial, industry, domestic and agricultural waste becomes one of the main factors that cause environmental damage and pollution to the earth and depletion of natural resources such as coarse aggregates and sands. There are many type wasted aggregates used as natural aggregate such as, concrete, brick, glass, rubber and etc. The uses of recycled materials have different profits, such as, ecologically sustainable environment, minimizing cost, time and space consumptions.

Governments over the world are encouraging research efforts to use these waste materials in a greater quantity in secondary building materials [11].This is seen as being essential to reduce the total amount of waste materials going into landfill, especially in the urban areas where land is very scarce Green concrete has nothing to do with color [12].It is a concept of thinking environment into concrete considering every aspect from raw materials manufactures over mixture design to structural design, construction and service life.

The raw materials of concrete consist of cement, sand and crushed aggregates. Partial or 100% replacement of these raw materials by waste products may decrease the cost, reduce the energy consumption and also reduce the environment pollution[13]. Due to the use of recycled materials whereby avoiding the charges for the disposal of waste, less energy consumption and greater durability[14].so, nowadays, using wastes are necessary to produce a new product for sustainable environment friendly construction

2.3 Components of Concrete with Replacement of Natural Course Aggregate by Waste Brick Aggregate

Components of concrete with replacement of natural course aggregate by waste brick aggregate are cement, course aggregate, and fine aggregate (sand), water, admixture and waste brick aggregate.

2.3.1 Cement

Cement is actually an ingredient of concrete. It is the fine powder that, when mixed with water, sand, and gravel or crushed stone (fine and course aggregate) they harden and bind the aggregates forms concrete. These types of cements are generally known as hydraulic cements which are of a great interest in making concrete. Hydraulic cements are mainly made up of silicates and aluminates of lime, and can be classified broadly as natural cements, Portland cements, and high-alumina cements[15].

It is recommended to conduct material testing of the mixture in order to verify compatibility of the mixture and that setting time, workability, strength and porosity can provide the necessary characteristics for the intended use of concrete [16].The rise in construction activities is promoting the cement demand considerably, demand for cement from civil engineering is rising strongly, due to the increasing investment by government on residential as well as public work sectors, and these factors enable the cement manufacturers to produce cement on a large scale and thereby raise consumption volume[17].

2.3.2 Aggregate

Aggregates are inert granular materials such as sand, gravel, or crushed stone and are divided into two distinct categories fine and coarse. The total amount of course and fine aggregate occupied in concrete 70% to 85% by mass and because of that the strength of aggregate is very important for the final strength of the concrete. Fine aggregates generally consist of natural sand or crushed stone with most particles smaller than 5 mm .Course aggregates are combination of crushed stone and gravels which have greater than 5 mm particle size and generally between 9.5 mm and 37.5 mm .We can get natural gravel and sand from different source such as pit, lake, river and seabed. Crushed stone is produced by crushing quarry rock, boulders, cobbles, or large-size gravel [18]. The aggregates are usually washed and graded at the pit or plant. Properties should have expected from aggregate are quality, cleanliness, grading, moisture content and etc. Aggregates must conform to certain standards for optimum engineering use: they must be clean, hard, strong, durable particles free of absorbed chemicals, coatings of clay, and other fine materials in amounts that could affect hydration and bond of the cement paste. The aggregates are handled and stored to minimize segregation and degradation and prevent contamination. Aggregates strongly influence concrete's freshly mixed and hardened properties, mixture proportions, and economy. Therefore, selecting aggregates is an important task.

2.3.2.1 Classification of aggregate

Aggregates can be classified based on shape, grain size, density and geographical origin. In terms of geological origin they are classified in to two groups namely natural and processed (artificial aggregate).

Shape is one of the most effective ways of differentiating aggregates. The shape of your chosen aggregates will have a significant effect on the workability of your concrete. Based on their shape they are rounded, angular, irregular, elongated and etc.

Regarding density, aggregates are classified as Lightweight, Standard and High density. Different density aggregates will have much different applications. Lightweight and ultra-lightweight aggregates are more porous than their heavier counterparts, so they can be put to great use in green roof construction. They are also used in mixes for concrete blocks and pavements, as well as insulation and fireproofing. High density aggregates are used to form heavyweight concrete. They are used for when high strength, durable concrete structures are required – building foundations or pipework ballasting.

Physical properties of Aggregates

Aggregate attributes including mineral composition, hardness, and pore structure are greatly influenced by the origin of the aggregate. The properties of these aggregates used in concrete production have effect on the quality and property of the fresh and hardened concrete produced [15].

a. Particle shape and surface texture

Aggregate particles can be categorized according to their shape as angular, sub angular, sub rounded, or rounded; each shape has benefits and drawbacks based on the desired qualities of the finished product. Particle shape and texture Aggregate affects the strength of aggregate particles, their bond with cementitous materials, and their resistance to sliding one particle over another. Rounded aggregates are preferable to produce workable concrete mixes however the strength of concrete produced is lower than that of produced with angular aggregates. This is due to the higher bond strength between angular aggregates and cement paste[5] .

b. Grading of Aggregates

The size of the aggregates used in construction projects is determined by their grading. There are several reasons for specifying grading limits and nominal maximum aggregate size; they affect relative aggregate proportions as well as cement and water requirements, workability, pump ability, economy, porosity, shrinkage, and durability of concrete.

c. Moisture Content of Aggregates

ASTM C 566, the Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying, determines the moisture content of an aggregate sample by drying the aggregate and determining the mass of water present in the aggregate sample. There are four main moisture conditions that aggregates often reach. Those are , oven dry condition, an air dry condition, saturated surface dry condition (SSD) and wet condition. The saturated surface dry condition, out of the four moisture states, is the most desirable. The moisture condition of the aggregates will have an effect on the density of aggregate hence density should be measured at some specified moisture state. Because at this state, the aggregate will neither give off extra water to the mix and reduce the strength nor take up from the mixing water and affect workability[19] .

d. Water Absorption capacity of Aggregates

Absorption is the property of material to absorb the water. Permeability is the property of material to pass the water or fluid. Porosity is the property of material which contains the voids. And also ,Porosity of aggregates refers to the proportion of the volume of internal pores to the total volume of the solid matter[19] . Some aggregate pores are entirely within the solid, while others open onto the particle's surface, allowing water to pass through, with the amount and rate of penetration varying on the pores' size, continuity, and total volume [20].

The water absorption rate of concrete is equal to the change in mass of concrete specimen divided by area of the sample exposed to water times the density of water. Then the absorption of the aggregate is expressed in percentage as the ratio of the increase in mass of the oven dried aggregate as a result of water immersion and being saturated, to the mass of the oven-dried sample [19].

The water absorption of lightweight concrete might be considerably higher than the conventional concrete due to higher rate of pores in concrete and lightweight aggregate. The maximum water absorption (WAmax) of lightweight aggregate may vary from a few percent up to 45 %. To prevent such absorption during the process of concrete production is reasonable to soak aggregates with high absorption capacity before mixing.

e. Bulk Density

The Bulk density (“Unit weight”) of aggregate is defined as the weight of an aggregate sample filling up a container of known volume. It is thus a density measurement and also known as bulk density. And also calculating bulk density used to determine unit weight of coarse, fine and mixed aggregates.

2.3.3 Water

Water is the key ingredient, which when mixed with cement, forms a paste that binds the aggregate together. To prepare concrete which have a good quality must add little water as possible, but with enough water to hydrate the cement and to properly handle it. A lower ratio water to cement leads to higher strength and durability, but may make the mix more difficult to work with and form.

2.3.4 Waste brick aggregate

Brick aggregates are made by crushing clay burnt bricks mechanically or by hand. Though now a day experimental work briefly describe that the suitability of the locally available brick aggregate (WBA) is environmentally friendly and present important attributes, such as light weight, low cost and WBA is used without prior knowledge of its engineering properties.

Debieb and Kenai [21] examined the potential of using crushed brick as coarse and fine aggregates for new concrete. Their findings show that the concrete shares similar characteristics with natural-aggregate concrete prepared with recycled aggregate, with a percentage limited to 25 and 50% for coarse and fine aggregates, respectively.

Cachim[22]evaluated the properties of concrete made with two types of crushed bricks replacing natural aggregates considering w/c ratios of 0.45 and 0.5. The tested results indicate that the type and manufacturing process of bricks seem to influence the properties of the resulting concrete. Also, the properties of concrete with bricks indicate the possibility of using this type of concrete in precast applications.

In Jimma, it is easy get locally produced bricks in every home at least as decorating front side of houses and In addition many bricks are stronger than Hollow concrete block may be used also as masonry column in low cost houses in place of wood and stone[8].

2.4 Properties of Concrete with Replacement of Natural Course Aggregate by Waste Brick Aggregate

They are two most important properties of Concrete with Replacement of Natural Course Aggregate by Brick Aggregate analyzed within this study, those are:

- Fresh property and
- Harden property

2.4.1 Fresh concrete

Fresh concrete or plastic concrete is a freshly mixed material that can be molded into any shape. The relative quantities of cement, aggregates, and water combined, control the properties of concrete[23]**.**they have different properties such as, workability, segregation, water absorption, consistency, bleeding, setting time, unit weight and uniformity.

Workability

The American Concrete Institute (ACI 116R-00) describes workability as “that property of freshly mixed concrete or mortar that determines the ease with which it can be mixed, placed, consolidated, and finished to a homogenous condition” (ACI 116R, 2000).A concrete mix satisfying these conditions is said to be workable and it is determined to a large extent by measuring the “consistency” of the mix. There is no single test method that can simultaneously measure all the properties involved in workability. Test methods for measuring workability are, flow test, Kelly ball test, slump test and compaction factor test. Slump test is the most commonly used method.

Slump test

The slump test measures the consistency of a concrete batch to see how easily the concrete will flow the inexpensive test. The test not only observes consistency between batches, but it also identifies detects in a mix, the operator a chance to amend the mix before it poured on site. The test method is widely standardized throughout the world, including in ASTM C143 in the United States and EN 12350-2 in Europe. The apparatus consists of a mold in the shape of a frustum of a cone with a base diameter of 20cm, a top diameter of 10cm, and a height of 30cm.

Depending on the water ratio of the mix, the concrete slump will fall under one of four categories:

1. True slump –the mix is cohesive and its workability isn't too high.
2. Shear slump- concrete mix has workability but low cohesion.
3. Collapse slump - where the concrete collapses completely.
4. Zero slump- concrete retains its shape, this show that the mix is very dry

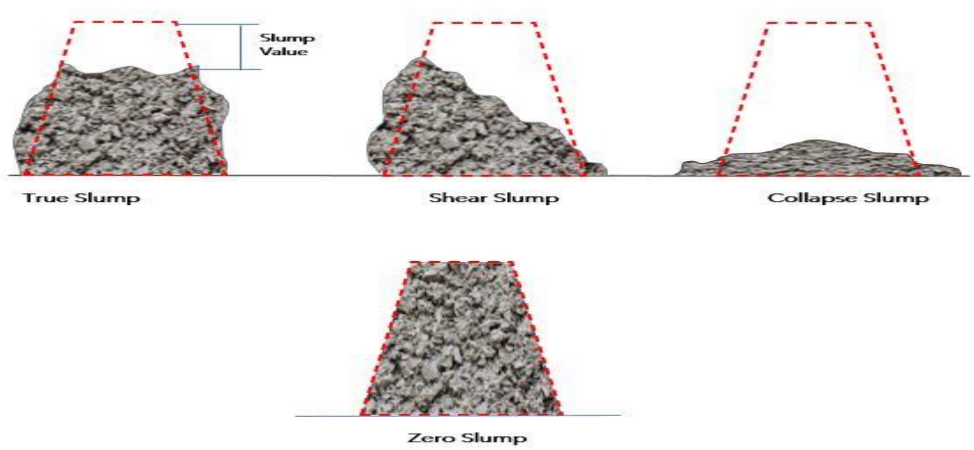

Figure 2 -1: Types of slump

Tests perform on the fresh concrete give an idea about the workability of concrete mix. In order to determine the workability slump cone test is perform. To determine consistency of concrete, Slump test is conduct, before concrete is placed, the slump will be check in terms of the specifications using the slump cone test[17].

Ekwulo and Eme, studied four concrete specimens made from aggregate size of 9.5mm, 12.7mm, 19.1mm and graded aggregate specimen and concluded that workability (slump) of fresh concrete decreases with increase in aggregate size and that compressive strength increases with increase in aggregate size[24].

2.4.2 Hardened Concrete properties

Concrete is a highly complex heterogeneous material whose response to stress depends not only on the response of the individual components but also upon the interaction between those components. Fully cured, hardened concrete must be strong enough to withstand the structural and service loads which will be applied to it and must be durable enough to withstand the environmental exposure for which it is designed. If concrete is made with high-quality materials and is properly proportioned, mixed, handled, placed and finished, it will be the strongest and durable building material. There are different properties which determine the quality of the hardened concrete such as, strength, durability, dimensional stability, thermal insulation and etc.

Strength

Strength of concrete is its resistance to rupture. It may be measured in a number of ways, such as, strength in compression, in tension, in shear or in flexure. All these indicate strength with reference to a particular method of testing. When concrete fails under a compressive load the failure is essentially a mixture of crushing and shear failure. There are several factors affecting the strength of concrete such as, Concrete constituents and mix proportions, concrete curing, Concrete production and Concrete age and testing conditions.

2.4.2.1 Compressive strength

The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concrete is employed primarily to resist compressive stresses. Therefore, the concrete making properties of various ingredients of mix are usually measured in terms of the compressive strength. Compressive strength is also used as a qualitative measure for other properties of hardened concrete. No exact quantitative relationship between compressive strength and flexural strength, tensile strength, modulus of elasticity, wear resistance, fire resistance, or permeability have been established. However, approximate or statistical relationships, in some cases, have been established and these give much useful information to engineers.

The compressive strength of concrete is taken as the maximum compressive load it can carry per unit area. The specimen will place in machine in such a manner that the load will applied to opposite sides of the cubes i.e., not top and bottom[17].The applied load will increase continuously at a constant rate until the resistance of the specimen to the increasing load breaks down and no longer can be sustained. The maximum load applied on specimen will recorded. Lastly, the load at the failure divided by area of specimen gives the compressive strength of concrete[25].

Some researchers investigated that generally, 33% reduction in compressive strength of concrete is found due to the use of brick aggregate instead of stone aggregate for the strength range of concrete studied and also, there is reduction in compressive strength at 50% and 100% replacement of stone aggregate with brick aggregate result the reductions in concrete compressive strength of 9.6% and 32.9% respectively[26].

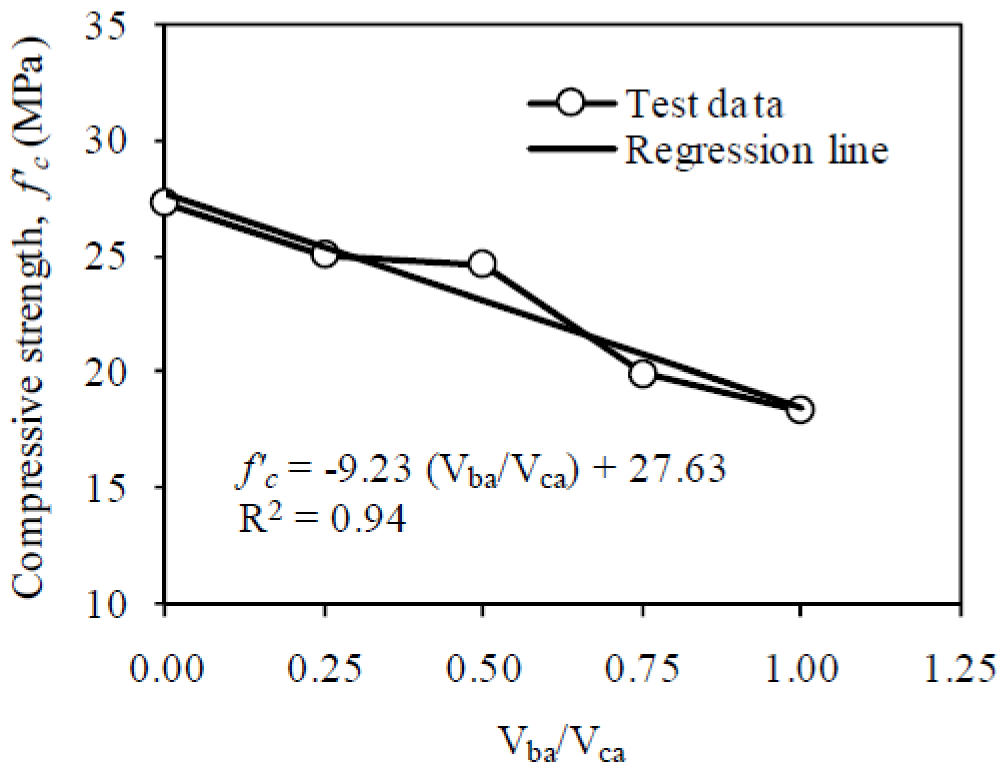

Figure 2-2: Effect of brick to total coarse aggregate ratio on compressive strength

Also another researcher investigated that a 28 days, the compressive strength of micro-concrete with recycled crushed brick aggregate was about 23,8 % lower than the one of river aggregate micro-concrete[27].

The compressive strength was decreasing when the percentage of Brick waste was increased and the optimum level is 25% replacement. However, less workability of the aggregate may limit the percentage even below the specified amount on reinforced structure[28].

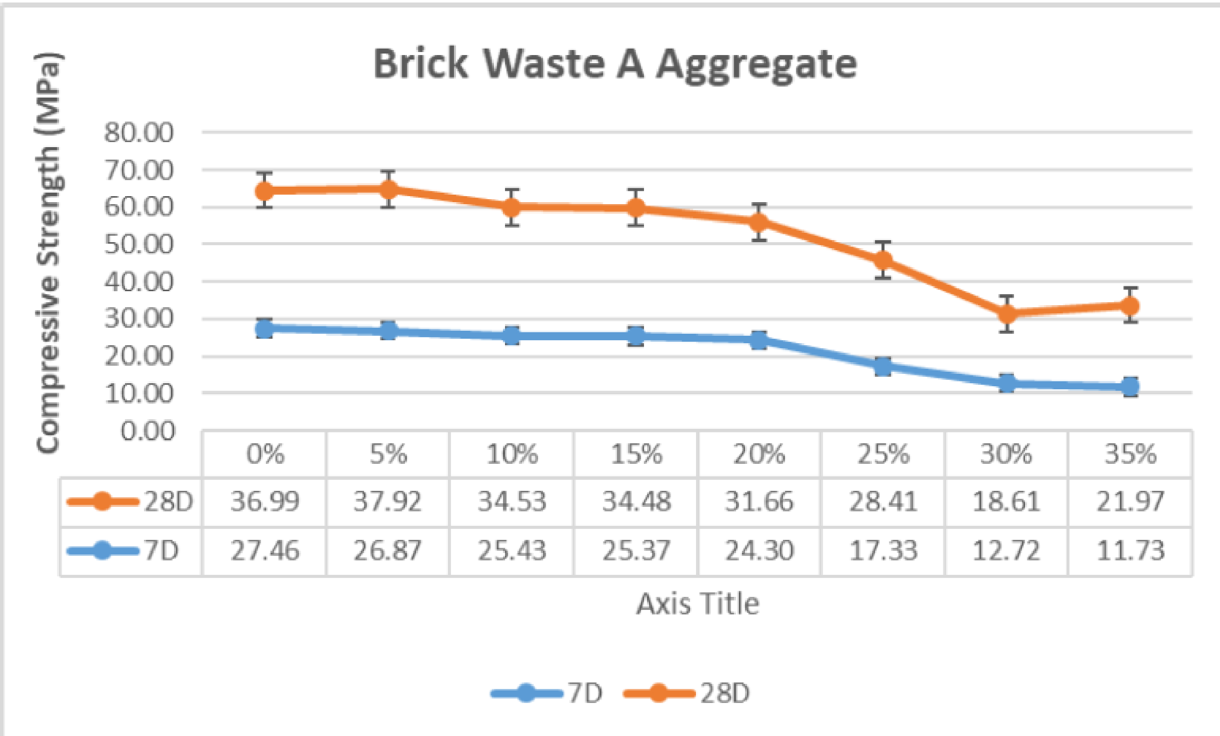

Figure 2-3: Effect of waste brick to total coarse aggregate ratio on compressive strength

As the result concrete produce by this aggregate does not used for structure need high strength. However, the concrete still has a strength that would make it suitable for some applications, with the added benefit that density values are much lower; making it suitable in where self-weight is a problem.

Generally, it is possible to estimate the strength of the concrete with the brick as the coarse aggregate from the strength of the original brick [7]. This estimation of the compressive strength could be important when waste bricks from a construction waste are used as an aggregate for a new concrete[27].

2.4.2.2 Split tensile strength

The tensile strength of concrete is very important to concrete because concrete structures are very vulnerable to tensile cracking due to various effects and applied loading. The tensile strength of concrete is very low however compared to its compressive strength. Split tensile strength a method of determining the tensile strength of concrete using a cylinder which splits across the vertical diameter. It is an indirect method of testing tensile strength of concrete.

For the split tensile test, the vertical diameter will be split, and force will be applied at a consistent rate until failure Load at which the specimen failed is recorded and the splitting tensile stress is obtained using the following formula.

$$T = \frac{2P}{\pi LD} \ldots\ldots\ldots eq\ 2.2$$

Where, T= the spilt tensile strength of the concrete

P= compressive load on the cylinder

L= length of the cylinder

D= diameter of the cylinder [29].

The 150×300 mm cylindrical molds were filled with fresh concrete in three equal layers, and each layer was rodded 25 times with a standard tamping rod. The cylinder molds were filled with fresh concrete mix in three layers, with each layer rodded one stroke. for approximately each 2.0 in2. The top surface of fresh concrete for both the cylinder specimens was finished off with a trowel.. The specimens were demolded after 24 hours of casting. They were cured by immersing them in a curing tank in the lab for 28 days.

2.4.2.3 Concrete stress and Strain

The stress strain of concrete is obtained by testing concrete cylinder specimen at age of 28-days, using compressive machine. Stress-strain behavior of the concrete is different in tension and in compression under uniaxial and biaxial loading. Stress- strain curve has three portion those are elastic, peak point (maximum compress stress point) and descending portion. Finally, the performance of concrete structure is controlled by the stress- strain curve relationship and type of stress to which the concrete is subjected in the structure.

The elastic range is exceeded and concrete begin to show nonlinearity or plastic behavior when a load is further increased and after elastic range, the curve reaching maximum compressive stress. For normal weight concrete, the EBCS code specified that, a strain of 0.0035 is maximum strain that concrete can reach and this value used for design of concrete structural element. Compression and tension exhibit identical stress-strain characteristics. .

The post peak behavior is actually a function of the stiffness of the testing machine in relation to the stiffness of the test specimen, and the rate of strain. Concrete becomes more brittle as its strength increases, as seen by a decrease in the strain at failure. The strain at failure is typically around 0.005 for normal strength concrete, as shown in Figure 2-4.

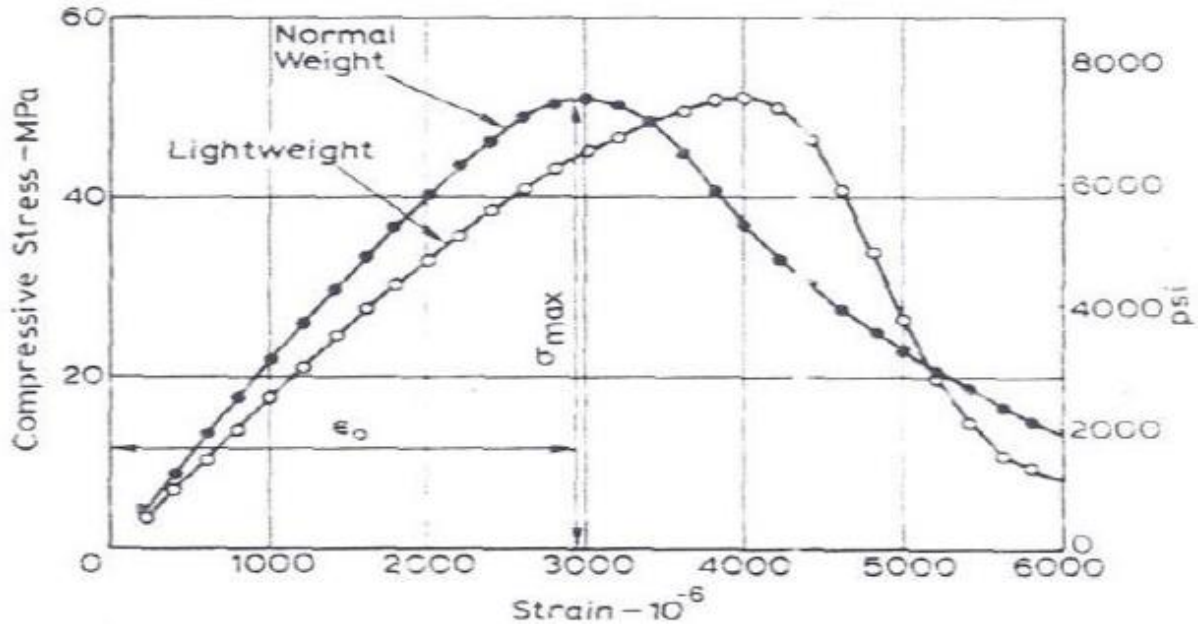

Figure 2-4: Complete stress-strain curve including post-peak response

2.4.2.4 Water absorption

Absorption test is a popular method of determining the water tightness of concrete. The water absorption rate of concrete is equal to the change in mass of concrete specimen divided by area of the sample exposed to water times the density of water. The high surface water absorption only decreased compressive strength of concrete depends on both surface and internal structures. So, strength of concrete cannot be evaluated by water absorption. On the other hand, the absorption of aggregate from fresh concrete may enhance adhesion of cement paste to the aggregates and thus the tightness of hardened concrete, which was revealed in some research.

The absorption of recycled crushed brick is estimated to a value between 22 % and 25 % by weight in relation to the material in its dry state. From the studies of absorption recycled bricks aggregates, it was concluded that recycled crushed brick becomes almost totally saturated with water after just 30 min of submersion in water [17].

Natural aggregates present higher value of density than recycled aggregate, on the other hand water absorption is around 2.5times bigger than in recycled aggregate than in natural aggregate [18].

2.5 Advantage of Concrete with Partial Replacement of Natural Coarse Aggregate by Using Waste Brick Aggregate

The greater advantage of using waste brick aggregate is it has greater fire resistance than concrete made with natural aggregates. Also, brick aggregates are light weight aggregates so, using waste brick aggregate instead of natural coarse aggregate reduce dead load on structure and make the construction economical.

CHAPTER THREE
3. RESEARCH METHODOLOGY

3.1 Study area

This research conducted Jimma, Ethiopia, at JiT university. Jimma is the oldest city in Ethiopia. Jima, also spelled Jimma, town, southwestern Ethiopia, 220 miles (353 km) by road southwest of Addis Ababa. It lies at an elevation of 5,740 feet (1,750 meters) in a forested region known for its coffee plantations. Jimma serves as the commercial center for the region, handling coffee and other products. The city of Jimma was established in 1830. It was founded by king Abba Jifaar the 1st Jimma (Oromo: Jimmaa) is the largest city in southwestern Oromia Region, Ethiopia. It is a special zone of the Oromia Region and is surrounded by Jimma Zone. It has a latitude and longitude of 7°40′N 36°50′E.

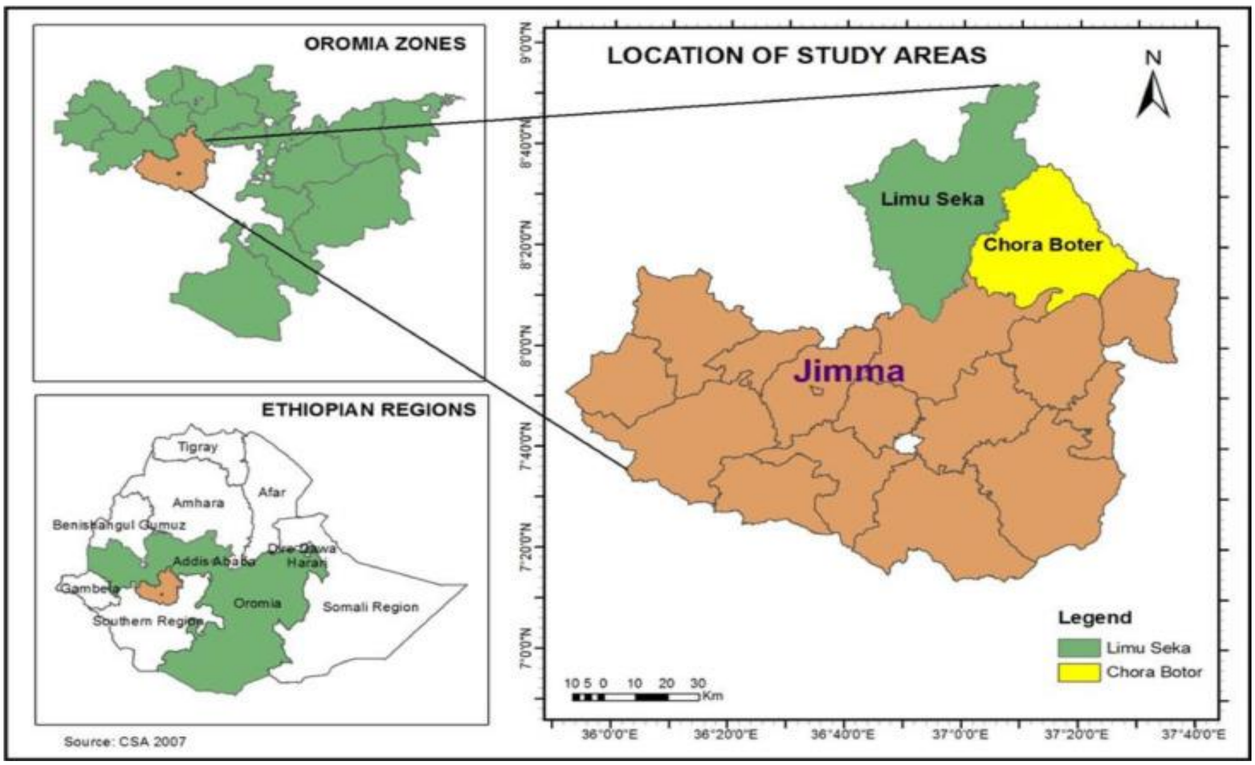

Figure 3-1 Map Oromia Regional State (JIMMA)

3.2. Data requirement

For the experimental analysis of the waste brick aggregate concrete with the available workability testing apparatus and universal testing machine the following properties was conducted.

1. for fresh concrete

    A. Slump test

2. Harden Concrete

    A. Compressive strength
    B. Split tensile strength
    C. Water absorption

3.3. Research design

The aim of this research is to study the effect of temperature on using waste bricks obtained from a brick factory in Jimma as a partial replacement for coarse aggregate in normal strength or C-25 concrete production.The research is conducted through laboratory experimental works by replacing the natural coarse aggregate of a reference concrete mix with waste brick aggregate in an amount of 10%, 20%, 30%, and 40% by volume at different temperatures, such as 200°C, 400°C, 600°C, 800°C, and 1000°C.

The experimental study includes material characterization, mix design proportioning, concrete specimen preparation, and conducting laboratory tests on the fresh and hardened concrete. A slump test was performed on fresh concrete to determine its workability. On the hardened concrete, compressive strength, split tensile strength, stress strain, and water absorption tests were conducted at different temperatures.All the laboratory work for the experimental study was conducted at the Jimma Institute of Technology Construction Materials Laboratory.

3.4. Study variables

3.4.1. Dependent variables

- Performance of concrete
  - ✓ Workability
  - ✓ Compressive strength
  - ✓ Split tensile strength
  - ✓ Water absorption

3.4.2. Independent variables

- Percentage of WBA

Properties of concrete such as workability of fresh concrete hardened concrete strength; compressive strength, split tensile strength and water absorption were depend on the percentage of waste brick aggregate.

3.5. Population and sampling method

The grade of concrete that used for this research is C-25.By adding different percentage values of WBA in this concrete, samples were taken for the different tests. The study used purposive sampling technique and the procedure taken according to ASTM and ACI standards which means minimum of cube samples per each test day was three samples. The samples for compressive strength , split tensile strength and water absorption for all five groups such as 0%, 10%, 20%, 30%, and 40%, replaced by of WBA concrete will cured by ponding method and test taken on 7 and 28 days. For compressive strength, split tensile strength and water absorption cube size was $150mm \times 150mm \times 150\ mm$ and cylinder of size 150 mm diameters and 300mm length was casted respectively. Total numbers of specimens casted for the study were 93 specimens. The samples casted to determine mix control (0% replacement) and partially replaced concrete are summarized on the table 3.1.

Table 3.1: Summary of total population

Types of specimen	Types and number of tests on 7 and 28 days			Total
	Compressive	Split Tensile	Water Absorption	
Control	6	3	-	9
10% WBA	6	3	-	9
20% WBA	6	3	-	9
30% WBA	6	3	3	12
40% WBA	6	3	-	9
Checking the optimum percentage with effect of temperature				
200°C	6	3	-	9
400°C	6	3	-	9
600°C	6	3	-	9
800°C	6	3	-	9
1000°C	6	3	-	9
Total summation of specimens				93

3.6. Source of data

There are primary and secondary data were used for this study.

3.6.1. Primary data

The primary data sources are from field study for material source determination and sample size, test results obtained on physical properties of material, Mix design results for both control and experimental groups and laboratory order test results of specimens after 7and 28 days curing.

3.6.2. Secondary data

The secondary data come from various published and unpublished sources such as, Books, journals and research reports.

3.7. Data collection procedure

Both descriptive and analytical data collection techniques were used in this investigation. Secondary sources of data from various published journals, books, conferences, and standard manuals were evaluated as part of the descriptive data collection method. On the other hand, primary data collecting techniques such as laboratory examination for physical properties of materials and field study to determine the material source are used. Also, specimens that are placed in laboratory for different curing and testing time with different percentage ratio of WBA , such as 0%, 10%, 20%, 30% and 40%, tested in their order of curing and casting time, then the data registered with their code tagged on it for 7and 28 days.

3.8. Data presentation and analysis

After collecting the necessary materials for the production of concrete those are cement, aggregates, clean water, waste brick aggregate, the laboratory experiment was continued. By using the results obtained from the laboratory the researcher analyzed the data by comparing and contrasting the effects of temperature by partially replacement waste brick by coarse aggregate concrete with the control group using Microsoft word and excels 2010. The analyzed data then presented using charts, figures, and tables. Furthermore, this research paper was present the facts of laboratory result and recommend the optimum percentage of waste brick aggregate that must be used as a partial replacement of coarse aggregate in concrete.

3.9. Experimental procedure

In this study waste brick sample was collected from Jimma town brick production area and Enough amount of waste clay bricks to produce all the concrete mixes for the study were collected from brick production area then the waste bricks were then slightly reduced in to smaller sizes as manually using a steel hammer. The material such as cement, fine aggregate and course aggregate was buy from Jimma town and collected to the place where the experiment was conducted.

3. 10 Materials Used

3. 10.1 Cement

The cement used for the research is Ordinary Portland cement (OPC) class-42.5 N and brand type of Dangote cement.

3. 10.2 Fine aggregate

For the experimental study, river sand was used as fine aggregate. The fine aggregate was bought from the local market which was sourced from the Gambela area and called Gambela sand.

3. 10.2.1 Silt content of fine aggregate

According to the Ethiopian Standard it is recommended to wash the sand or reject if the silt content exceeds a value of 6% [30]. The river sand used for the research was thoroughly washed in order to remove dust, loam and clay particles as the presence of these materials in concrete decrease the strength of concrete by affecting the bond between the constituents of concrete [30]. The silt content of the sand was tested and it was found to be 1.42%, which is within the acceptable limit.

3. 10.2.2 Gradation of fine aggregate

Gradation or Sieve analysis test is a practice or procedure used to assess the particle size distribution for sand. Gradation affects many properties of fine aggregates. The degree of gradation also called fineness modulus of sand. The sieve analysis for the fine aggregate was conducted and the result obtained is shown in Table A-10 under Appendix A along with the grading requirement of the ASTM C33.

3. 10.3 Coarse aggregate

The coarse aggregate that used for this study was bought from the local market.

3. 10.3.1 Gradation of coarse aggregate

The sieve analysis for the coarse aggregate and waste brick aggregate was conducted and the result obtained is shown below in Table A-8 coarse aggregate and Table A-9 waste brick aggregate under Appendix- A along with the grading requirement of the ASTM C33.

3. 10.4 Water

A potable water used for drinking supplied from Jimma town water supply and sewerage authority was used for washing aggregate, mixing and curing of concrete.

3. 10.5 Waste Crushed Clay Brick

The waste crushed clay bricks used in this experimental study were collected from brick manufacturing factories around jimma. The production area selected depends on production capacity and location. So that, “Qofe” Brick Production factory was selected.

Figure 3-2 selected brick factories location

3. 10.5.1 Preparation of waste brick

The same procedure was used to prepare all types of WBA as coarse aggregates used for this experimental study. Enough amount of waste bricks to produce all the concrete mixes for the study were collected from brick production area. The waste bricks were in size as shown in Figure 3-2 when obtained from the production area.

Figure 3-3 received size of waste bricks from production area

The waste bricks were then slightly reduced in to smaller sizes as shown in Figure 3.4 manually using a steel hammer.

Figure 3-4 Size of manually crushed clay brick

The waste brick aggregate was then taken to the Geological Survey center of Ethiopia for the complete silicate analysis to determine major oxide and minor oxide element. The mineralogical compositions of a good brick raw material or clay are summarized in Table 3.2 [5]:

Table 3.2 Ingredients of a good clay brick[5]

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

3. 10.6 Admixtures

A super plasticizing admixture(high range water reducer) Sikament NN was added to the mixing water used, in order to improve a very high plasticity ,good workability and to study the effect of admixtures on the properties of fresh and hardened concrete.

Figure 3-5 Admixture used for mix

3.11 Methods and Mix Design

3. 11.1 Mix Design

The investigation was carried out by conducting laboratory tests on fresh and hardened concrete with the sets of two concrete mixes. The first was the control mix and the second set included the replacement with WBA mixes. In all the mixes produced, the water/cement ratio used in all mix used were kept constant while the crushed natural coarse aggregate was replaced by 10%, 20%, 30% and 40% by volume. The waste brick was crushed and sieved in to the same particle size as that of the natural coarse aggregate. Moreover, the waste brick aggregate was used in a surface saturated dry condition in the concrete mix.

To test the 7th and 28th day compressive strength of the concrete produced with 10%, 20%, 30% and 40% of WBA aggregate, waste brick was used from production area selected. Whereas, the split tensile strength and stress strain of concrete test was done only for 28th day and water absorption tests was conducted for 28th day on concrete specimens that were prepared with the same replacement percentages of WBA aggregates sourced from the production area that gave the maximum compressive strength at different temperatures. The steps for the mix design done based on ACI code are listed as follow.

Step 1: The desired strength is 25MPa

Collected data for mix design:-

Mix design of concrete C-25

Collected data for mix design:-

- Fineness modulus of selected fine aggregate = 2.80

- Rodded Unit weight of coarse aggregates =1638 kg/m3
- Specific gravity of coarse and fine aggregate in saturated surface dry condition is 2.68 and 2.60 respectively
- Absorption characteristic of both coarse and fine aggregate is 0.74%and 1.34% respectively
- Specific gravity of Portland pozzolana cement = 2.90
- Free surface moisture in sand and Corse aggregate is 1.53 % & 0.30% respectively

Step 1: Determination of water to cement ratio

Effective water cement ratio from strength point of view is 0.62 and from exposure point of view is 0.5. So, by adopt water to cement ratio is 0.50 for the exposure condition.

Step 2: Maximum size of aggregate and workability

Maximum size of coarse aggregate is 20mm.Slump value is assumed 30-50mm and air content 2%.

Step 3: Cement content

For the slump of 30-50mm and 20mm maximum size of aggregate, the maximum water content is 185kg/m3

Cement content =185/0.50=370 kg/m3

Step 4: weight of coarse aggregate

From ACI table, for maximum size of 20mm coarse aggregate and fineness modulus of sand 2.80, the dry rodded bulk volume of coarse aggregate is 0.67 per unit volume of concrete. The weight of coarse aggregate = 0.67*1630 kg/m3= 1092 kg/m3

Step 5: weight of fine Aggregate

Table 3.3: weight of fine Aggregate

Item No	Ingredient	Weight(kg/m3)	volume (cm3)	volume (m3)
1	Cement	356	$113.02*10^3$	0.12063
2	Water	185	$185*10^3$	0.185
3	Gravel	1092	$398.54*10^3$	0.406
4	Air	_	$20*10^3$	0.02

Therefore, absolute volume of fine aggregate = (1000-725.234)*103= $271.592*10^3$

Weight of fine aggregate = 271.592*2.60= 706.138 kg/m3

Step 6: Proportions

Table 3.4: Content of concrete constituent before adjustment

Ingredients	**Cement**	**Sand**	**Gravel**	**water**
quantity (kg/m3)	370	737	1092	185
Ratio	1	1.99	2.95	0.500
Quantity in kg,	50	99.59	147.57	25.00

Step 7: Adjustment for field condition

Fine aggregate has surface moisture of 1.78 % and absorbs 1.34%

Weight of fine aggregates = (706.138+0.0153*706.138)kg/m3 = 715.6 kg/m3

Coarse aggregate absorbs 0.28% of water.

Weight of coarse aggregate= (1092+0.0074*1092) kg/m3= 1100 kg/m3

Adjust the amount of water based on moisture content

The required mixing water=185 -728*(0.0132-0.0153) - 1095*(0.0026-00036) = 192

Step 8: Final design proportion

Table 3.5: Adjusted content of concrete constituent

Ingredients	Cement	Sand	Gravel	Water
quantity (kg/m3)	370	715.6	1100	192
Ratio	1	1.93	2.97	0.52
One bag cement	50	97	149	25.9

3.11.2 Laboratory specimen preparation

All concrete mixes were prepared using a pan mixer. During each batch of mix the cement, coarse and fine aggregates were added and the mixer ran for duration of 30 seconds. Then half of the same amount mixing water was added and the mixer ran for 2 minutes, after that measuring amount of superplastizer were added then mixed again. Then the concrete was turned over in the pan a few times using a trowel to ensure uniformity of the mix. Then the remaining water was added and the mixer ran for additional 2 minutes. Finally the mix was once again turned over using a trowel.

After the mixing process was completed, placing started immediately in molds coated with oil to prevent concrete bonding to the surface of the molds. 150mm*150mm*150mm cubic molds were used to cast concrete for compressive and water absorption tests. Whereas cylinder of size

150 mm diameters and 300mm length molds were used to cast concrete for split tensile strength test. The molds were compacting by using tamping rod until the concrete surface had smooth and glazed appearance. The concrete specimens were covered with a plastic sheet and left in sealed condition for 24 hours. Then, they were removed from the mold and were kept in a curing tank until the 7^{th} and 28^{th} day of the test.

Figure 3-6 Casted concrete molds

➢ Heating procedure

An electrical furnace was used to heat three specimens from each mixture at a constant rate of 3 °C/min, starting from room temperature (20 ± 2)°C and increasing to 200°C, 400°C, 600°C, 800°C, and 1000°C. To reduce the thermal gradient between the surface and center of the concrete samples and to ensure consistent heating throughout, the electrical furnace was set to a target temperature, which was then maintained for an hour. After this heating treatment, the specimens were allowed to cool naturally to room temperature inside the electrical furnace in order to prevent thermal shock. The average cooling rate was about 1 °C/min. To compare the original and residual qualities, unheated (20 ± 2) °C and heated samples conducted physical and mechanical tests.

3. 11.2.1 Slump test

The slump test measures the consistency of a concrete batch to see how easily the concrete will flow the inexpensive test. The test method is widely standardized throughout the world, including in ASTM C143 in the United States and EN 12350-2 in Europe as the waste brick aggregates have significant absorption capacities, the waste bricks aggregate were used in a saturated surface dry condition to prevent water absorption from the mix.

Additionally, in order to eliminate the slump difference between the control and replacement mixes, the waste bricks were added with the same gradation as the natural coarse aggregate.

Figure 3-7 Slump cone test for the control mix

3. 11.2.2 Compressive strength

The compressive strength of concrete is one of the most important and useful harden properties of concrete. The 7th and 28th day compressive strength test was conducted on all the concrete mixes. The test was carried out on 150 mm cubic concrete specimens heated by electrical furnace at different temperature values on with a loading rate of 0.28 MPa/s. For each concrete mix three specimens were tested after burned at electrical furnace and the average value is reported.

Figure 3-8 Cube specimens in compression test machine

3. 11.2.3 Split tensile strength

The concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. The split tensile test is an indirect way of evaluating the tensile test of concrete. In this test, a standard cylindrical specimen is laid horizontally, and the force is applied on the cylinder radially on the surface which causes the formation of a vertical crack in the specimen along its diameter. The cracking is a form of tension failure. The 7th and 28th day split tensile strength test was conducted on all the concrete mixes. The test was carried out on a cylinder of 100mm by 200mm length was placed horizontally on a compression testing machine after heated by electrical furnace at different temperature values and the cylinders were tested using compression testing machine having 2000 KN capacity.

The splitting tensile stress is obtained using the following formula.

$$T = \frac{2P}{\pi LD} \ldots\ldots\ldots\ldots\ldots eq\ 3.3$$

Where, T= the spilt tensile strength of the concrete P= compressive load on the cylinder L= length of the cylinder D= diameter of the cylinder

Figure 3-9 Split tensile strength test setup

3. 11.2.4 Water absorption test

The water absorption test of concrete measures the amount of water that a concrete sample can absorb. This test is important for determining the durability and resistance to water of the concrete, and helps to ensure that the concrete will perform as expected in its intended environment.

The water absorption of concrete is expressed as a percentage of the initial weight of the sample. The lower the water absorption, the more water-resistant and durable the concrete is considered to be.

Water absorption of brick is the mass of water that is absorbed by the brick under a given condition, and it is usually expressed in percentage of the dry mass of the brick [31]. Water absorption is an essential factor for the durability of clay bricks, because when more water penetrates brick its durability decreases[32]. Clay bricks with more porosity tend to absorb more water and vice versa. Water absorption is also dependent on the firing temperature of the clay bricks. Clay bricks produced with higher firing temperature have relatively lower water absorption[33].

In conclusion, the water absorption test is an important tool for engineers and contractors to evaluate the durability and resistance to water of concrete. The test provides valuable information about the quality and consistency of the concrete mix, and helps to ensure that the concrete meets the required standards and specifications for a particular application. The results of the water absorption test can also be used to determine the most appropriate type of concrete for a particular project, and to ensure that the concrete will perform as expected over its expected service life.

Figure 3-10 Water absorption test

3.12 The structural framework of the study

Generally, the methodology which was carried out during the study is presented in the form of sequential steps as illustrated in the following figure 3-11.

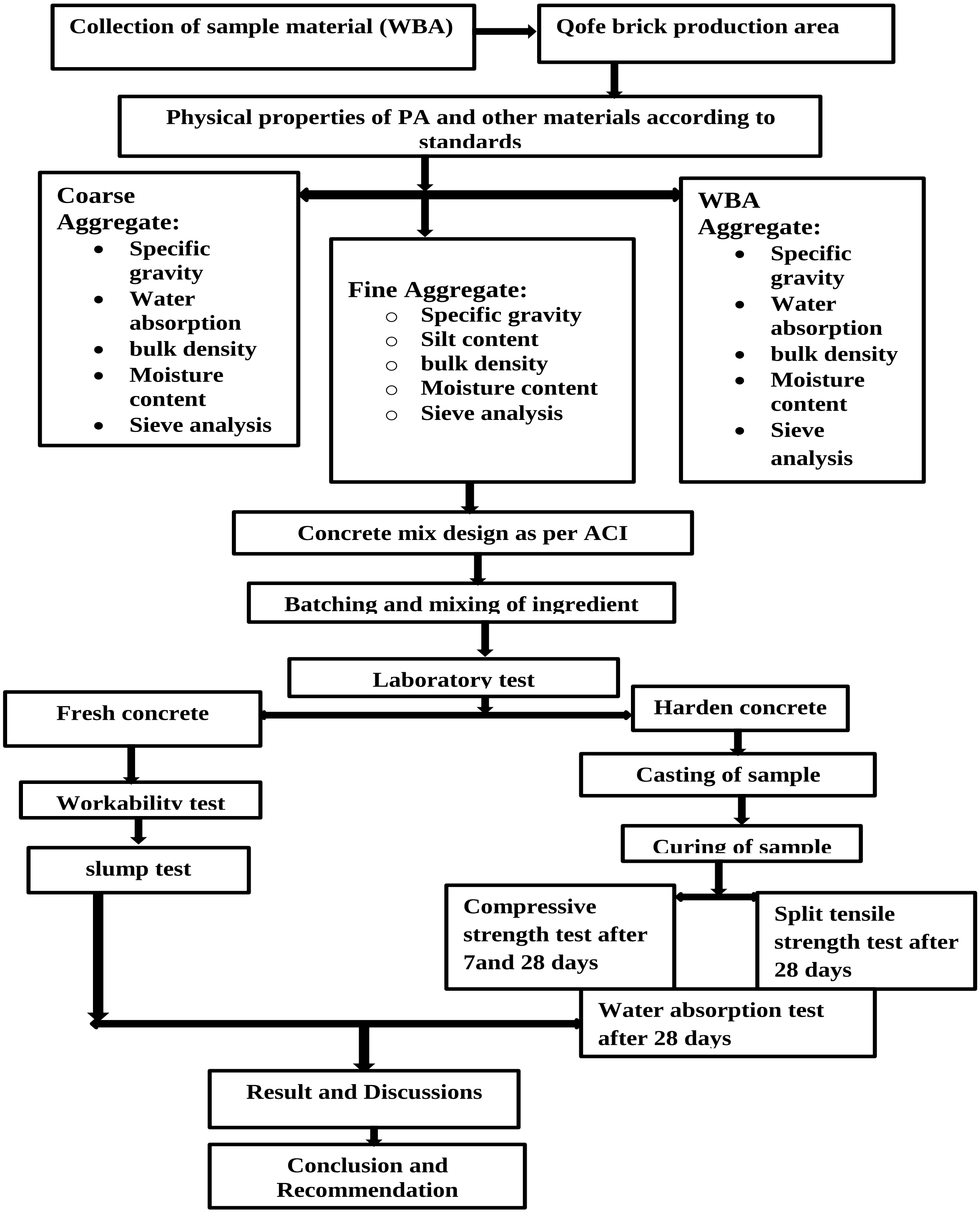

Figure 3-11 The structural framework of the study

CHAPTER FOUR

4. RESULTS AND DISCUSSION

In this section, the results of the laboratory tests are discussed. The results presented include the properties of both the fresh and hardened concrete produced by partial replacement of natural coarse aggregate with waste clay brick with different temperature effect. Slump test for the fresh property was tested. For the hardened property; compressive strength, split tensile strength, stress strain and water absorption tests were conducted.

4.1 Sieve Analysis

The purpose Sieving analysis was used to determine the grading or particle size distribution of fine and coarse aggregate. Sieve analysis is done in order to determine the fineness modulus of aggregate and the relative number of various sizes of particles present in the aggregate using sieving series of square or round openings starting with the largest. Gradation affects many properties of fine and coarse aggregates.

The coarse aggregate with a maximum aggregate size of 20 mm was used. According to ASTM, the term coarse aggregate is used to describe particles larger than 4.75 mm (retained on No. 4 sieve) and passing the sieve sizes 25mm. The coarse aggregate grading, upper and lower limits bounds are shown in figure 4.1.

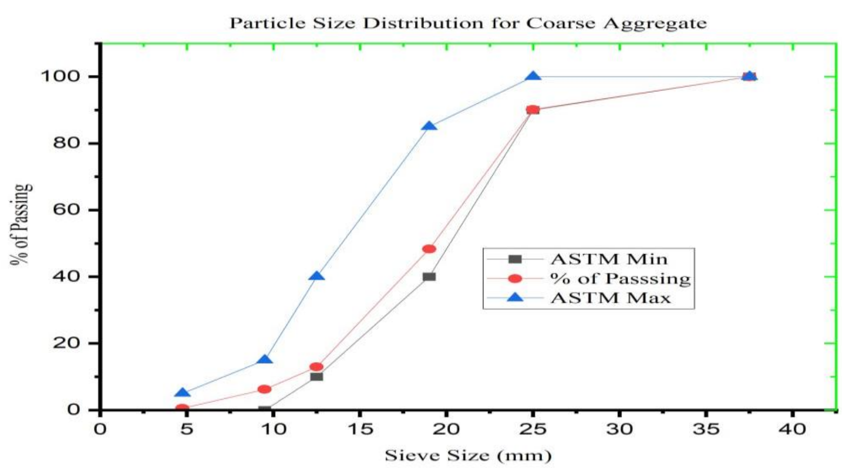

Figure 4.1: Coarse aggregate particle size distribution

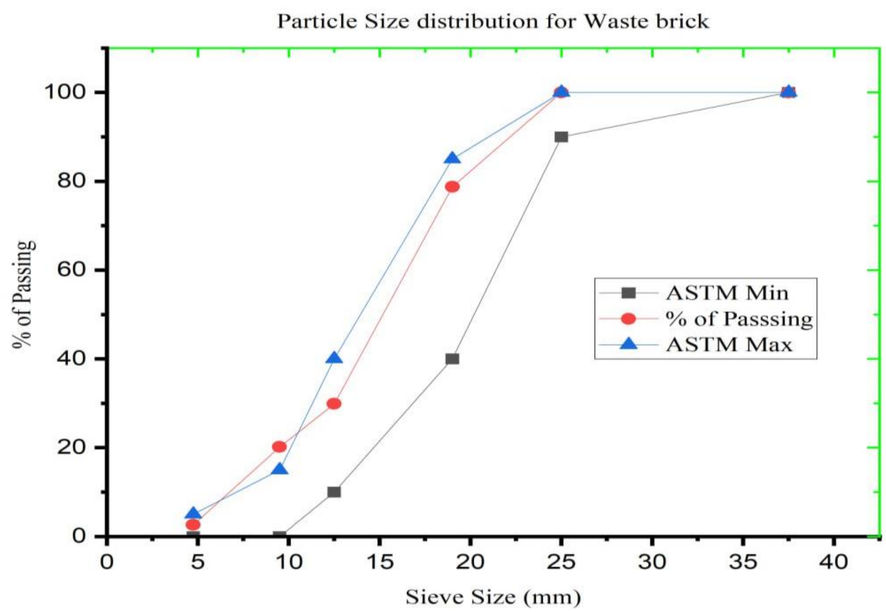

Figure 4.2: waste brick aggregate particle size distribution

Fine aggregate shall mean aggregate passing 9.5mm sieve & almost entirely passing the 4.75mm sieve. For mix design, the average fineness modulus was calculated by using the particle size distribution data.

4.2 Chemical properties of waste brick aggregate

The waste brick was then taken to the Geological Survey center of Ethiopia for the complete silicate analysis and major oxide elements are given in Table 4.1.

The mineralogical compositions of a good brick raw material or clay are summarized in Table 3.2 [5]:

Table 4.1: Major and minor oxides of waste brick

component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
Waste brick	83.40	8.86	4.19	0.20	0.41	<0.01	0.50	0.09	0.15	1.39	0.33	0.54

The silica (SiO_2) content of the waste brick is 83.40% however; the acceptable range for silica

(SiO_2) content is between the 50-60% ranges. The alumina (Al_2O_3) content of waste brick is below the given range (20-30% range). The ferric oxide (Fe2O3) for waste brick is slightly below 7% .For a good clay brick, the ferric oxide (Fe2O3) content is usually recommended less than 7%. The CaO (lime) for waste brick is 0.20% and as given in table 4.1 the lime content for a good clay brick is up to 10%. The lime content for waste brick is very small and insignificant. This shows the waste brick lack lime (CaO) and as a result the brick could be susceptible to shrinkage upon drying. As for the loss on ignition (LoI) which refers to the mass loss of a combustion residue whenever it is heated in an air or oxygen atmosphere to high temperatures , all brick types have an LoI value less than 5% as specified in ASTM C330-99 .

4.3 Results and discussion on fresh and harden waste brick concrete properties

In this part of the thesis, the fresh and hardened waste brick aggregate concrete properties such as workability, compressive strength tests, stress strain relationship for compressive strength test, split tensile strength test and water absorption test are presented and analyzed respected to control specimens and pertinent standards.

4.3.1 Fresh concrete properties

4.3.1.1. Workability Test

Slump cone test was done on fresh concrete for knowing the workability of concrete by replacing natural coarse aggregate by waste brick aggregate discussed as follows. The detail result of slump is illustrated under Appendix–B.

A. Slump Test

Slum test is the simplest and most commonly used test for workability both in laboratory and on construction site. The freshly mixed concrete was compressed by rodding after being molded into the shape of a frustum. The test was conducted for each mix of concrete to determine the workability of the fresh concrete as per ASTM Designation C 143[34], the cone was filled with freshly prepared concrete in three stages; each layer was tamped 25 times using a rod of standard dimensions 16mm.As per ASTM C 143 concrete having slump value less than 15mm may not be adequately plastic as well as concrete with slump value greater than 230mm may not be adequately cohesive.

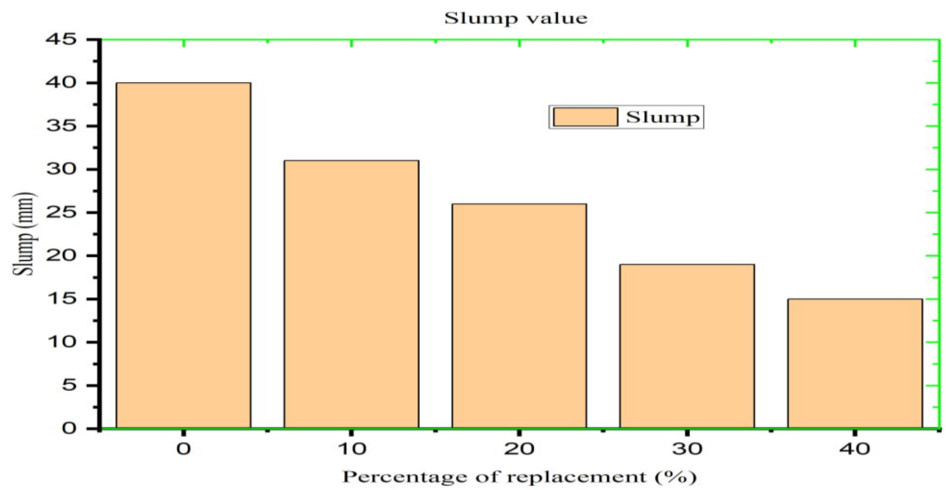

Figure 4.4: Slump taste

Every type of concrete mix, including the control mix, has been tested. Slump value of concrete with waste brick aggregate was below the minimum (25mm) which is 15mm for 40 % replacement. The lesser slump value than the control mix is due to the high water absorption capacity of WBA. In order to prevent the water absorption capacity from the mix, the waste crushed bricks were used in a saturated surface dry condition as the waste aggregates have high absorption capacities and also used water reducer superplastesizer. In addition, the waste bricks were used with the same gradation as the natural coarse aggregate and with the same water cement ratio in order to avoid the slump difference between the control and replacement mixes.

4.3.2 Hardened Concrete properties

4.3.3.1 Compressive strength Test

Compressive strength test, mechanical test measuring the maximum amount of compressive load a material can bear before fracturing. To specify the concrete compressive strength, fck(t), at time t for a number of stage (e.g. demoulding, transfer of prestress) [27**].**

Where

$$f_{ck}(t) = f_{cm}(t) - 8(MPa) \ldots\ldots eq\ 4.1 \qquad for\ 3 < t < 28\ days$$

$$(t) = f_{ck} \qquad for\ \geq 28\ days$$

The compressive strength of concrete at an age t depends on the type of cement, temperature and curing conditions. For a mean temperature of 20°C and curing in accordance with EN 12390 the compressive strength of concrete at various ages f_{cm}(t) may be estimated from Expressions (3.1) and (3.2) [35].

$$f_{cm}(t) = \beta_{cc}(t) fcm \ldots\ldots eq\ 4.2$$

$$\beta_{cc}\ (t) = \exp\{s\ [1-(28/t)^{1/2}\ ]\} \ldots\ldots eq\ 4.3$$

Where:

$f_{cm}\ (t)$: *is the mean concrete compressive strength at an age of t days*

f_{cm}: *is the mean compressive strength at* 28 *days*

$\beta_{cc}(t)$: *is a coefficient which depends on the age of the concrete t*

t: *is the age of the concrete in days*

s: *is a coefficient which depends on the type of cement*:

= 0.20 for cement of strength Classes CEM 42.5 R, CEM 52.5 N & CEM 52.5R (Class R)

= 0.25 for cement of strength Classes CEM 32.5 R, CEM 42.5 N (Class N)

= 0.38 for cement of strength Classes CEM 32.5 N (Class S)

For this study Dangote OPC grade 42.5R was used and the value of s =0.25

Where the concrete does not conform to the specification for compressive strength at 28 days the use of Expressions (eq.4.2) and (eq.4.3) is not appropriate.

7th day Concrete Conform the Specification

$$\beta_{cc}\ (t) = \exp\{s\ [1-(28/t)^{1/2}\ ]\}$$

$$s = 0.25\ and$$

$$for\ 7^{th}\ day\ t = 7$$

$$(7) = \exp\{s\ [1-(28/7)^{1/2}\ ]\}$$

$$\beta_{cc}\ (7) = 0.7788$$

$$f_{cm}(t) = \beta_{cc}(t) fcm$$

$$fcm\ for\ concrete\ C20/25 = 28MPa$$

$$fcm\,(7) = 0.7788 * 28$$

$$fcm\,(7) = 21.806MPa$$

$$f_{ck}(t) = f_{cm}(t) - 8(MPa)$$

$$for\ 3 < t < 28\ days$$

$$f_{ck}\,(7) = 21.806MPa - 8MPa$$

$$f_{ck}\,(7) = 13.806MPa$$

To convert the 7th day compressive strength of concrete using cylinder to its value by cube 1.25factor used based on ESEN-2:2015 for C20/25.

$$\boldsymbol{f_{ck,cube} = 1.25 * f_{ck}}$$

$$\boldsymbol{f_{ck,cube}(7) = 1.25 * 13.806 \quad f_{ck,cube}(7) = 17.258MPa}$$

Table 4-2: Compressive strength test result on 7th day before burning electrical furnace

Compressive strength test result on 7th day before burning electrical furnace							
Mix no	percentage of Waste brick added	Avg Peak load (kN)	Avg stress (MPa)	Variation from control (%)	$f_{ck},cube$ (7)(MPa)	Minimum required $f_{ck},cube$ (7)(MPa)	Remark
1	Control	731.59	32.52	0	32.52	17.258	Concrete Confirm the Specification
2	10 %	700.02	31.11	4.33	31.11	17.258	Concrete Confirm the Specification
3	20 %	601.08	26.72	17.84	26.72	17.258	Concrete Confirm the Specification
4	30 %	400.45	17.80	45.26	17.80	17.258	Concrete Confirm the Specification
5	40 %	350.61	16.03	50.7	16.03	17.258	Concrete does not Conform the Specification

Table 4-3: Compressive strength test result on 7th day after burning electrical furnace

Compressive strength test result on 7th day after burning electrical furnace							
Mix no	percentage of Waste brick added	Avg Peak load (kN)	Avg stress (MPa)	Variation from control (%)	$f_{ck},cube$ (7)(MPa)	Minimum required $f_{ck},cube$ (7)(MPa)	Remark
1	control	731.59	31.83	0	31.83	17.258	Concrete Confirm the Specification
2	10 %	700.02	31.84	-0.03	31.84	17.258	Concrete Confirm the Specification
3	20 %	601.08	28.39	10.81	28.39	17.258	Concrete Confirm the Specification
4	30 %	400.45	25.33	20.42	25.33	17.258	Concrete Confirm the Specification
5	40 %	350.61	19.00	40.31	19.00	17.258	Concrete Confirm the Specification

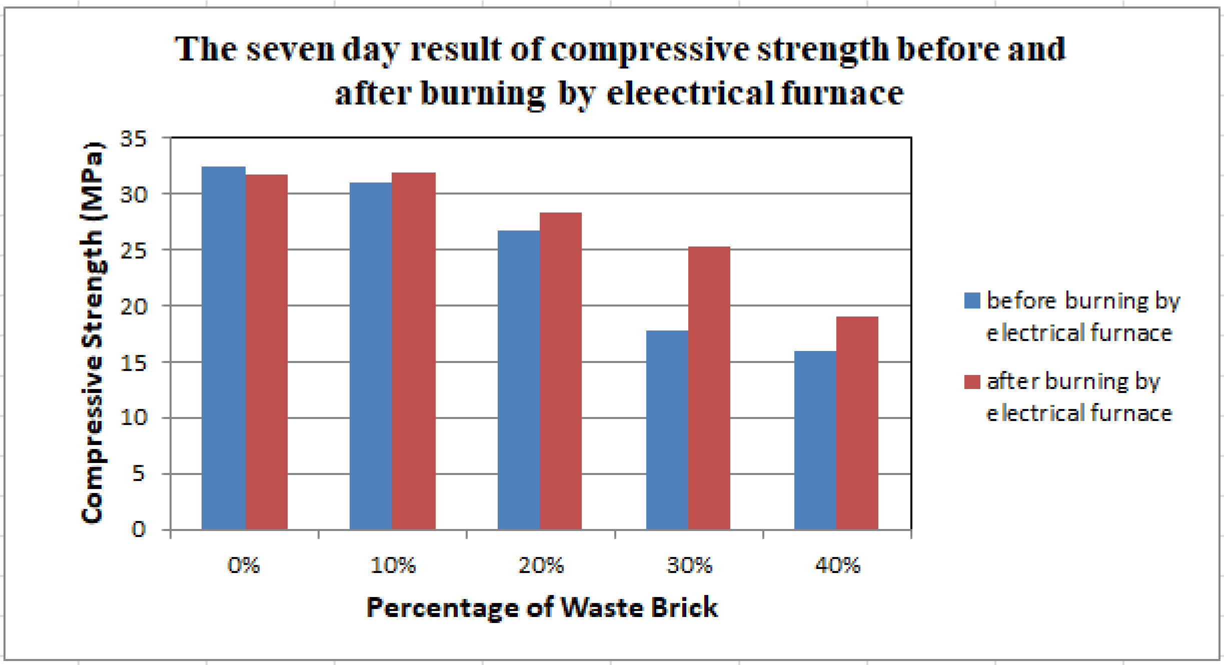

Figure 4-5: compressive strength Result for 7th day before and after burning electrical furnace

The determination of compressive strength has received a large amount of attention because the concrete is primarily meant to withstand compressive stresses. Compressive strength of concrete at the age of 7th day curing period before and after oven dry is given in figure 4.5. The concrete gain of its compressive strength on the 7th day before and after oven dry up to 30% but there is a difference in strength with increment. During the concrete is burning with the oven dry, the compressive strength of each replacement WBA i.e. up to 40% attained the mean target strength. But the waste brick aggregate up to 30 % attained the mean target strength in both case.

28th day Concrete Conform the Specification

$$\beta_{cc}(t) = \exp\{s\,[1-(28/t)^{1/2}]\}$$

$$s = 0.25 \ and$$

$$for 28^{th} \ day \ t = 28$$

$$\beta_{cc}(28) = \exp\{s\,[1-(28/28)^{1/2}]\}$$

$$\beta_{cc}(28) = 1$$

$$f_{cm}(t) = \beta_{cc}(t) fcm$$

$$f_{cm} \ for \ concrete \ C20/25 = 28MPa$$

$$(28) = 1.0 * 28$$

$$(28) = 28MPa$$

$$(t) = (t) - 8(MPa)$$

$$for \ 3 < t < 28 \ days$$

$$(28) = 28MPa - 8MPa = 20MPa$$

OR

$$(28) = f_{ck} \qquad for \ \geq 28 \ days$$

$$f_{ck} \ for \ concrete \ C20/25 = 20MPa$$

To convert the 28th day compressive strength of concrete using cylinder to its value by cube 1.25factor used based on ESEN-2:2015 for C20/25.

$$\boldsymbol{f_{ck,cube} = 1.25 * f_{ck}}$$

$$\boldsymbol{f_{ck,cube}(28) = 1.25 * 20}$$

$$f_{ck,}(28) = 25MPa$$

Table 4-4: Compressive strength test result on 28th day before burning electrical furnace

Compressive strength test result on 28th day before burning electrical furnace							
Mix no	Percentage of waste brick	Avrg. Peak load(KN)	Avg stress (MPa)	Variation from control (%)	$f_{ck},cube(28)$ MPa	Minimum required $f_{ck},cube$	Remark
1	Control	807.47	35.89	0	35.89	25.00	Concrete Confirm the Specification
2	10 %	784.73	34.88	2.81	34.88	25.00	Concrete Confirm the Specification
3	20 %	619.80	27.55	23.24	27.55	25.00	Concrete Confirm the Specification
4	30 %	589.12	26.20	27.0	26.20	25.00	Concrete Confirm the Specification
5	40 %	380.81	16.73	53.38	16.73	25.00	Concrete doesn't confirm the specification

Table 4-5: Compressive strength test result on 28th day after burning electrical furnace

Compressive strength test result on 28th day after burning electrical furnace							
Mix no	percentage of Waste brick added	Avg Peak load (kN)	Avg stress (MPa)	Variation from control (%)	$f_{ck},cube$ (28)	Minimum required $f_{ck},cube$ (28)	Remark
1	Control	833.3	38.20	0	38.20	25.00	Concrete Confirm the Specification
2	10 %	750.33	35.24	7.75	35.24	25.00	Concrete Confirm the Specification
3	20 %	746	34.00	11.0	34.00	25.00	Concrete Confirm the Specification
4	30 %	658	29.24	23.46	29.24	25.00	Concrete Confirm the Specification
5	40 %	391.67	17.407	54.43	17.40	25.00	Concrete doesn't confirm the specification

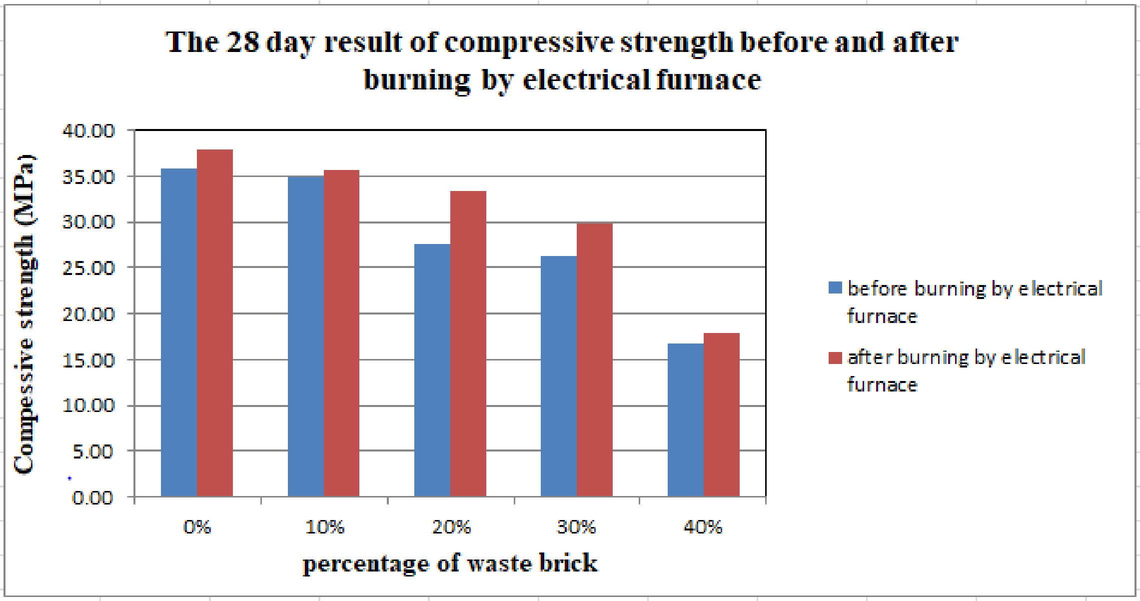

Figure 4-6: compressive strength Result for 28th day before and after burning electrical furnace

The 28th average compressive strength of the control specimen before and after oven dry is 35.89 N/mm2 and 38.20N/mm2 respectively.

Compressive strength test result on 28th day before burning electrical furnace

The compressive strength of before oven dry or without any temperature effect concrete specimen with waste brick aggregate with percentage replacement of 10 %, 20 %, 30 %, 40 % is 35.24N/mm2, 34.00N/mm2, 29.24N/mm2, and 17.407N/mm2 respectively. According to a study by S.Assefa[36], the hardened property waste brick around jimma shows, this brick waste can be used as an aggregate 20% -25% for C-25 normal concrete.

According to M.A Rashed[26], 33% reduction in compressive strength of concrete is found due to the use of brick aggregate instead of stone aggregate for the strength range of concrete studied.

Moreover, a study by Wengelawi [28] , It was possible to produce concrete with 28th day compressive strength of 25 MPa with 40% of replacement with all four types of CCB aggregates, but 30% was taken as an appropriate percentage of replacement.

The compressive strength before oven dry result obtained for WBA replacement percentage of 10 % was above 99 % of the targeted mean strength on 28th days of curing periods and the replacement above 30 % WBA has a lower result than mean targeted strength for both cases.

Table 4-6: Compressive strength test result of optimum percentage on 28th day after burning at different temperature.

Compressive strength test result of optimum percentage on 28th day after burning at different temperature						
Mix no	Different Temperature	Avg Peak load (kN)	Avg stress (MPa)	f_{ck},$cube$ (28)	Minimum required fck,$cube$ (28)	Remark
1	200^{0}C	552.67	24.563	24.563	25.00	Concrete Confirm the Specification
2	400^{0}C	606.67	26.963	26.963	25.00	Concrete Confirm the Specification
3	600^{0}C	658	29.24	29.24	25.00	Concrete Confirm the Specification
4	800^{0}C	643.67	28.607	28.607	25.00	Concrete Confirm the Specification
5	1000^{0}C	667.33	29.659	29.659	25.00	Concrete Confirm the Specification

Compressive strength test result on 28th day after burning electrical furnace at average temperature and other temperature values

Concrete structure is subjected to various temperature changes during its lifespan. The engineer building should design for structure can withstand high temperatures and also mainly for fire exposures.

The compressive strength of concrete after oven dry specimen with WBA of 10 %, the replacement had 7.75% reduction from the control mix, and the 40 % WBA replacement had 54.43% reduction from the control mix. As shown in Table 4.6 cube compressive strength of optimum percentage (30%) on 28th day result the compressive strength of waste brick aggregate concrete is increased amount of temperature increased as from 200^{0}C-1000^{0}C.The probable reason for increasing of waste brick aggregate concrete compressive strength is due to increasing temperature, thus reducing water absorption of the mixture, which in turn causes a reduction in the strength reaction.

Apart from strength parameter in ambient temperature Khalaf and DeVenny [7] studied the thermal properties of brick aggregate concrete and it was found that brick aggregate concrete perform similar and even better than granite aggregate concrete in elevated temperature.

According to S. Hachem and A.Ounis [11], For temperatures higher than 400 °C, the loss of strength becomes more significant and When the specimens are exposed to 600 °C, the residual compressive strength decreases by 17, 9 and 19% for conventional concrete NAC-1, NAC-2 and NAC-3, respectively. However, in study the compressive strength was increases when temperature increases.

The results of the compressive strength of concrete cubes show that the compressive strengths reduced as the percentage waste brick aggregate increased, addition of waste brick aggregate resulted in reduction in concrete compressive strength compared with the control mix. However, the compressive strengths increased as the number of days of curing increased for each percentage waste brick aggregate replacement.

4.3.3.2 Spilt Tensile Strength

The tensile strength refers to the highest stress reached under concentric tensile loading. Where the tensile strength is determined as the splitting tensile strength, fct,sp, an approximate value of the axial tensile strength, fct, may be taken as:

$$fct = 0.9\ fct,sp \ldots \ldots \ldots .. eq\ 4.4$$

The development of tensile strength with time is strongly influenced by curing and drying conditions as well as by the dimensions of the structural members[35]. As a first approximation it may be assumed that the tensile strength fctm (t) is equal to:

$$fctm\ (t) = (\beta cc(t))^{\alpha}\ .fctm \quad \ldots \ldots \ldots .. eq\ 4.5$$

Where βcc(t) follows from Expression (3.2) and

$\alpha = 1$ for $t < 28$

$\alpha = 2/3$ for $t \geq 28$. The values for fctm are given in Table 3.1.

28th day Concrete Conform the Specification

$$s = 0.25\ and\ for\ 28^{th}\ day\ t = 14\ \alpha = 2/3$$

$$\beta_{cc}\ (28) = \exp\{0.25[1-(28/28)^{1/2}]\}=1.0$$

$$f_{ctk,0.95} = 1.3 * f_{ctm}$$

$$f_{ctk,0.95} = 1.3 * 2.20$$

$$f_{ctk,0.95} = 2.86\ for\ 28^{th}\ day$$

Table 4-7: Split tensile strength test result on 28th day after burning electrical furnace

Split tensile strength test result on 28th day after burning electrical furnace								
Mix no	percentage of Waste brick added	Avg Peak load (kN)	Avg stress (MPa)	Variation from control (%)	$f_{ct,sp}$ (MPa)	$f_{ct,sp}$ (28)(MPa)	Minimm required $f_{ctk}(28)$ (MPa)	Remark
1	control	105.80	3.37	0	3.37	3.03	2.86	Concrete Confirm the Specification
2	10 %	102.07	3.25	3.56	3.25	2.93	2.86	Concrete Confirm the Specification
3	20 %	102.83	3.27	2.98	3.27	2.94	2.86	Concrete Confirm the Specification
4	30 %	99.94	3.18	5.64	3.18	2.86	2.86	Concrete Confirm the Specification
5	40 %	65.43	2.08	11.36	2.08	1.88	2.86	Concrete does not Confirm the Specification

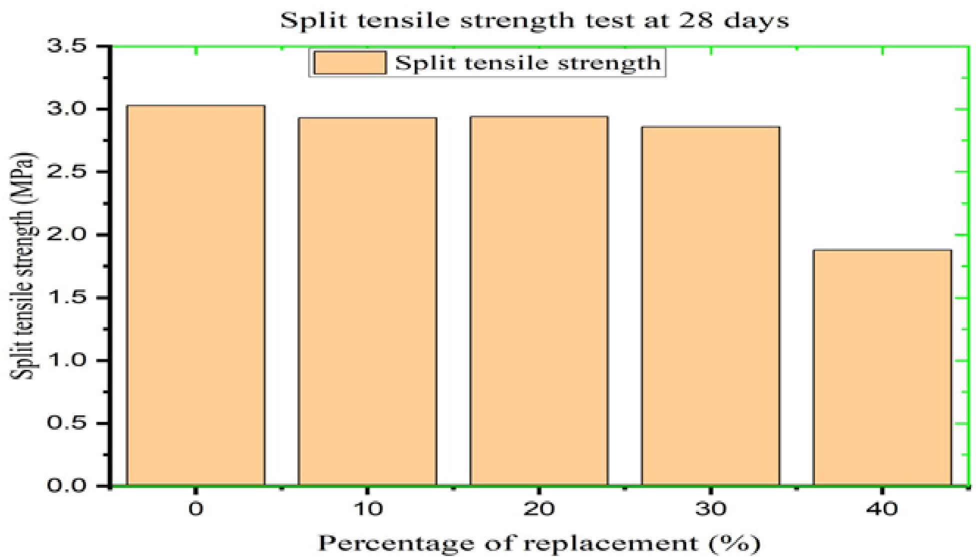

Figure 4.6: Split tensile strength

Table 4-8: Split tensile strength test result on 28th day after burning electrical by furnace at different temperature

Split tensile strength test result on 28th day after burning electrical by furnace at different temperature							
Mix no	percentage of Waste brick added	Avg Peak load (kN)	Avg stress (MPa)	$f_{ct,sp}$(MPa)	$f_{ct,sp}$ (28(MPa))	Minimum required $f_{ctk}(28)$(MPa)	Remark
1	200^0C	110.33	3.51	3.51	3.16	2.86	Concrete Confirm the Specification
2	400^0C	102.47	3.26	3.26	2.94	2.86	Concrete Confirm the Specification
3	600^0C	99.94	3.18	3.18	2.86	2.86	Concrete Confirm the Specification
4	800^0C	81.37	2.59	2.59	2.33	2.86	Concrete does not Confirm the Specification
5	1000^0C	82.13	2.62	2.62	2.35	2.86	Concrete does not Confirm the Specification

From Table 4.7, Table 4.8 and Figure 4.6 a clear relationship was observed between control mix split tensile strength and waste brick aggregate content with temperature effect. As waste brick aggregate content was increased, the 28th-day split tensile strength decreased proportionally. However, their values are still in a reasonable range up to 30 % and for 40 % replacement is slightly out of range for targeted grade of concrete C-25 and WBA Concrete does not confirm the Specification for targeted grade of concrete C-25.

4.3.3.3 Stress strain of concrete

The relation between stress and strain is that they are directly proportional to each other up to an elastic limit. To determine the strain for each stress which were gained using dial gauge ESEN-2:2015 was used [35].The relation between $\boldsymbol{\sigma_c}$ and s$_c$ (compressive stress and shortening strain) for short term uniaxial loading is described by the equation 4.6:

$$\frac{\sigma_c}{f_{cm}} = \frac{k\eta - \eta^2}{1 + (k-2)} \ldots\ldots\ldots\ldots\ldots eq\ 4.6$$

$$where\ \eta = \frac{\varepsilon_c}{\varepsilon_{c1}}$$

$$\varepsilon_{c1}\ is\ the\ strain\ at\ peak\ stress$$

$$k = \frac{E_{cm} * |\varepsilon_{c1}|}{f_{cm}} \ldots\ldots\ldots\ldots\ldots\ldots eq\ 4.7$$

$$\frac{\sigma_c}{f_{cm}} = \frac{k\eta - \eta^2}{1 + (k-2)}\ and\ k = \frac{E_{cm} * |\varepsilon_{c1}|}{f_{cm}}$$

$$\frac{\sigma_c}{f_{cm}} = \frac{\frac{E_{cm} * |\varepsilon_{c1}|}{f_{cm}}\eta - \eta^2}{1 + (\frac{E_{cm} * |\varepsilon_{c1}|}{f_{cm}} - 2)\,\eta}$$

$$and\ \eta = \varepsilon_c$$

$$\frac{\sigma_c}{f_{cm}} = \frac{\frac{E_{cm} * |\varepsilon_{c1}|}{f_{cm}}\frac{\varepsilon_c}{\varepsilon_{c1}} - (\frac{}{\varepsilon_{c1}})^2}{1 + (\frac{E_{cm} * |\varepsilon_{c1}|}{f_{cm}} - 2)\frac{\varepsilon_c}{\varepsilon_{c1}}}$$

$$solving\ for\ the\ above\ equation$$

$$\frac{\sigma_c}{f_{cm}} * (1 + (\frac{E_{cm} * |\varepsilon_{c1}|}{f_{cm}} - 2)\frac{\varepsilon_c}{\varepsilon_{c1}}) = \frac{E_{cm} * |\varepsilon_{c1}|}{f_{cm}}\frac{\varepsilon_c}{\varepsilon_{c1}} - (\frac{\varepsilon_c}{\varepsilon_{c1}})^2$$

$$\frac{\sigma_c}{} \quad \frac{f_{cm}}{} + \sigma_c * \frac{f_{cm}}{} \quad E_{cm} * |\varepsilon_{c1}| \quad \overline{f_{cm}} * \varepsilon_c \quad \varepsilon_{c1}$$

$$-2*\frac{\sigma_c}{f_{cm}}*\frac{\varepsilon_c}{\varepsilon_{c1}}+\frac{{\varepsilon_c}^2}{{\varepsilon_{c1}}^2}-\frac{E_{cm}*\varepsilon_c}{f_{cm}}=0$$

$$\frac{1}{{\varepsilon_{c1}}^2}*{\varepsilon_c}^2+\varepsilon_c*\left(\frac{\sigma_c E_{cm}}{{f_{cm}}^2}-\frac{E_{cm}}{f_{cm}}-2*\frac{\sigma_c}{f_{cm}\varepsilon_{c1}}\right)+\frac{\sigma_c}{f_{cm}}=0$$

$$\frac{1}{{\varepsilon_{c1}}^2}*{\varepsilon_c}^2+\varepsilon_c*\left(\frac{E_{cm}}{f_{cm}}\left(\frac{\sigma_c}{f_{cm}}-1\right)-2*\frac{\sigma_c}{f_{cm}\varepsilon_{c1}}\right)+\frac{\sigma_c}{f_{cm}}=0 \ldots\ldots..eq\ 4.8$$

$$now\ it\ is\ in\ the\ form\ of\ qadratic\ equation\ ax^2+bx+c$$

$$a=\frac{1}{{\varepsilon_{c1}}^2}\quad b=\frac{E_{cm}}{f_{cm}}\left(\frac{\sigma_c}{f_{cm}}-1\right)-2*\frac{\sigma_c}{f_{cm}\varepsilon_{c1}}\quad and\ c=\frac{\sigma_c}{f_{cm}}$$

By using equation 4.6 the value of strain for each corresponding stress determined by scilab-5.5.1. The averaged value of compressive stress and averaged value of strain for the five experimental group samples and the optimum percentage with the 28th day resulted in table 4.9and 4.10 respectively. The detailed cube stress -strain relation for 28^{th} day test are listed under appendix.

Table 4-9: Average compressive stress and strain at peak load

28^{th} Day Average compressive stress and strain at peak load				
Mix No	Percentage of replacement	Average Peak load (KN)	Average compressive strength in Mpa	Avg strain
1	Control	833.3	38.20	0.00221
2	10%	750.33	35.24	0.0021732
3	20%	746	34	0.002157
4	30%	658	29.24	0.002085
5	40%	391.67	17.407	0.0018633

Table 4-10: Average compressive stress and strain of optimum percentage after burning at different temperature of waste brick at peak load

Average compressive stress and strain of optimum percentage after burning at different temperature of waste brick at peak load				
Mix No	Percentage of replacement	Average Peak load (KN)	Average compressive strength in Mpa	Avg strain
1	200° C	552.67	24.563	0.001991
2	400° C	606.67	26.963	0.0020392
3	600° C	658	29.24	0.002085
4	800° C	643.67	28.607	0.0020763
5	1000° C	667.33	26.659	0.00208630

The results show that from 28^{th} day test result the maximum average strain obtained at 38.20MPa compressive strength is 0.00221 for control mix concrete. In addition from 28^{th} day test result the maximum average strain obtained for optimum percentage after burning at different temperature at peak load 29.24 MPa compressive strength is 0.002085 at temperature 600^{o}.

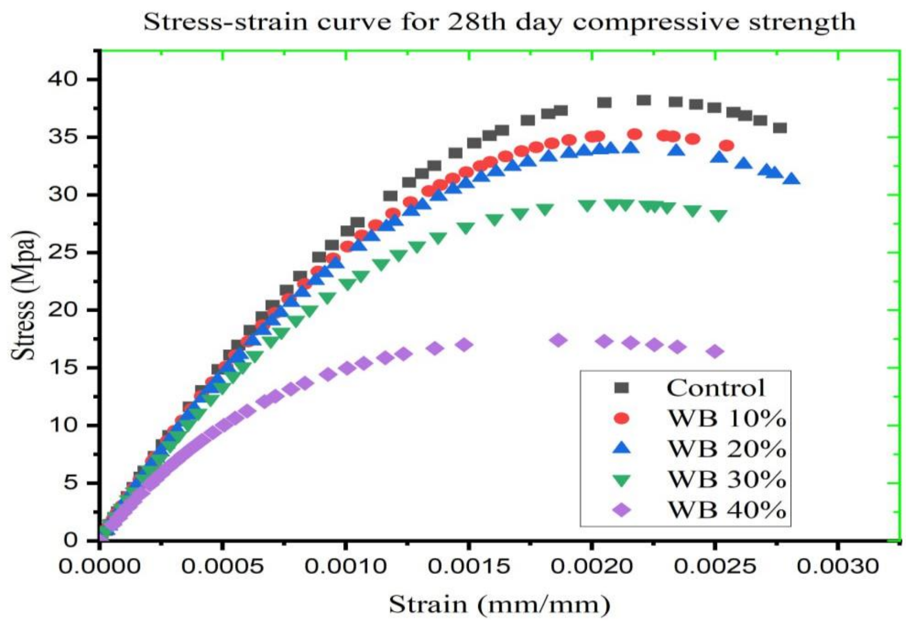

Figure 4.7: Stress-strain curve for 28-day compressive strength test

The Stress-strain curve for 28-day compressive strength test is drawn for 0% waste brick aggregate, 20% waste brick aggregate, 30% waste brick aggregate and 40% waste brick aggregate graph for each mix for comparison with control. Figure 4. **7** illustrate peak compressive stress and the corresponding strain for 28th days test result.

From the above stress-strain curve the following observations are drawn.

As the percentage of waste brick replacement increases, compressive strength and strain of concrete decreases.

At one time all of the graphs overlap and the compressive stress and related strain are almost directly proportionate based on the curves for each blend. This illustrates the concrete's elastic range. The ultimate load is reached; the load carrying capacity (ductile properties of concrete) is changed for each mix based the parentage of WBA replacement and percentage variation. After the point of ultimate load, the duration of strain up to the point of rupture for waste brick aggregate concrete is less than the point of failure of control.

A minimum average stress and average strain was recorded by the time natural coarse aggregate is replaced by waste brick aggregate of 40% was added and when the optimum percentage of waste brick aggregate burned at the temperature of 200°.

4.3.3.4 Water Absorption

Water absorption is the main factor which is directly related to strength and durability property of concrete.

The water absorption test involves the specimens were prepared and initial weights of all cubes taken. In order to build durable oriented and practicable concrete structures, it is needed to be able to accurately predict the water absorption, and sorptivity coefficient within the concrete structures. This research work was aim to determine the concrete water absorption to characterize the concrete mixtures design for in concrete cubes. The water cured concrete cubes (28 days) were then oven dried at 105 ±5ºC for 1 day until the mass became constant and again weighed. This weight was noted as the dry weight (W1) of the concrete cube. Specimens were kept in contact with water from one surface with water level not more than 5 mm above the base of specimen. Flow of water from the peripheral surface is prevented by sealing it properly with non-absorbent coating for a specified time interval as per [ASTM C 1585] with their arrangement. Then this weight is noted as the wet weight (W2) of the concrete cube.

According ASTM C1585[37]

$$\text{Water Absorption} = \frac{w2 - w1}{w1} * 100\%$$

Table 4-11: Water Absorption Result at 28th Day

Water Absorption Result at 28th Day optimum percentage of replacement of WBA				
Sample No.	Weight of before Dry (Kg)	Weight of after Dry (Kg)	Water Absorption (%)	Average Water Absorption (%)
1	7.922	7.376	7.402	6.551
2	7.887	7.402	6.552	
3	8.167	7.717	5.701	

The rate of water absorption test is carried out on 3 concrete cubes with size (150 mm3) in optimum percentage of replacement of WBA (30%) as per ASTM C1585. The results confirm that, the water absorption testing is considerably influenced by sample preparation.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The research aimed to study the strength characteristics of concrete using by different proportioning values of 0%, 10%, 20%, 30% and 40%, waste brick aggregate as partial replacement of natural coarse aggregate with different temperature effect. Furthermore, to achieve the aim of this study the researcher collected related literature and conducted different tests of materials and specimens to determine the effects of temperature using waste brick aggregate on concrete strength. Therefore, based on the findings of the study the following conclusions are drawn:

1. Tests were conducted on slump and compressive strength. Based on the test results:

- The workability of concrete containing waste brick aggregate slightly decrease as the waste brick aggregate content increases which is due to the higher water, the roughness and angularity of the aggregates.
- Compressive strength increased during the curing process and reduced as the volume of waste brick aggregate increased. Also for optimum percentage, when the effect of temperature increases from 200°C- 1000°C compressive strength of waste brick aggregate concrete increases. Even though the waste brick aggregates are weak in strength and decrease the compressive strength of concrete as the replacement percentages increase, it was possible to use the aggregates as replacement of coarse aggregate in normal strength concrete.

2. Split tensile strength on the 28th day was slightly decreasing with an increase in waste brick aggregate; with the range of 3.56% to 11.36% for the content of 10% to 40% waste brick aggregate as compared to the control mix. In contrast, percentage of variation is decreased with increased when natural coarse aggregate is partially replaced by 10% and 20% WBA as compared to the control mix and for 30% natural coarse replacement by waste brick aggregate the result is vice versa; the percentage of variation is increased with replacement is increased.

3. From Compressive Strength stress-strain curve as the percentage of waste brick aggregate increases the average compressive strength and strain of concrete decreases. When the maximum load was applied, waste brick aggregate concrete's load carrying ability (ductile properties)

allowed for shorter strain duration until the point of rupture than the control mix's point of failure.

4. The rate of water absorption test is carried out on 3 concrete cubes with size (150 mm3) in optimum percentage of replacement of WBA (30%) as per ASTM C1585. The results confirm that, the water absorption testing is considerably influenced by sample preparation.

Therefore, the investigation of this study has found out that replacement of natural coarse aggregate by waste brick aggregate with the effect of temperature from up to 30% results were reasonable range in compressive strength, split tensile strength and water absorption for targeted grade of concrete C-25. Therefore, 30 % of waste brick aggregate replacement is the optimum ratio for C-25 concrete.

5.2 Recommendations

Other researchers can use the findings of this study as a reference to validate, improve and dig out other properties of concrete. Hence, some of the focus areas for future study are:

- Further studies on concrete plasticity variables for concrete containing waste brick aggregate to validate the experimental results by numerical method using finite element software. Further studies on validation of this the experimental results by numerical method using finite element software.
- Study on improving the mechanical properties of concrete containing waste brick aggregate at lower temperature effect.
- Study on improving the mechanical properties of concrete containing waste brick aggregate with high strength of concrete grade with lower and high temperature effect.

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APPENDICES

APPENDIX-A Physical properties of materials

A-1 Specific gravity and Water absorption test for aggregates

Specific gravity is the ratio of the mass (or weight in air) of a unit volume of material the Mass of the same volume of water at stated temperature. Knowing the value of specific Gravity helps for design mix and calculating the void contents in aggregate. The water Absorption value is the difference in mass between the saturated surface dry sample and oven Dry sample expressed as percentage of dry mass of sample. Information regarding water Absorption value of aggregate is necessary for calculating total water to be added to the Mixes. The following procedures are the steps in which the physical properties of coarse aggregate and fine aggregates are determined in laboratory as per [21].

A. Coarse aggregates

Step 1- rejecting materials passing 4.75mm sieve and using sample splitter 2 Kgs sample of aggregate measured and washed to remove fine particles

Step 2- using basket with sample immersed in distilled water for 24 hours at constant temperature

Step 3 – the basket placed at 50mm of water above the top of the basket and the entrapped air is removed by lifting the basket 25mm above the base of the tank by allowing to drop25 times at one drop per second

Step 4- after 24hour jolt and weight the basket with sample in water then remove sample from water allowed to drain then the empty basket placed in water jolted 25 times and weight in water

Step 5- the sample aggregate surface dried by cloth and weight then placed in an oven for 24 hours

Step 6 -after 24 hours the sample removed from oven and cooled for one hour and finally the dried sample weighted. Using the following formula, the specific gravity and absorption capacity calculated for coarse aggregate tabulated on table A-1

- $Apparent\ specific\ gravity = \frac{MD}{MD-MW}$
- $Bulk\ specific\ gravity = \frac{MD}{\mathrm{MSSD}-MW}$Oven dry

- $Bulk\ specific\ gravity = \frac{\mathrm{MD}}{-\mathrm{MW}}$
- $Percentage\ of\ water\ Absorption = (MSSD - MD) * 100\ MD$
- $Weight\ of\ aggregate\ in\ water\ WW = (Wa - WB)$

Where

MW Weight in water of the saturated aggregate

M_{SSD} Weight in air of the saturated surface dry aggregate

MD Weight in air of oven dried aggregate

SSD Saturated surface dry

Table A - 1 Specific gravity and water absorption of Natural coarse aggregate

Description	Trial1	Trial2	Trial3
M_W=Weight in water of saturated aggregate (Kg)	1313	1306	1309.5
M_{SSD}=Weight in air of saturated surface dry(Kg)	2006.5	2008	2007.5
MD=Weight in air of oven dried aggregate(Kg)	1993.5	1992.2	1993
Bulk specific gravity=MD/(M_{SSD}-MW)	2.875	2.837	2.855
Bulk specific gravity (sat.sur.dry basis) =M_{SSD}/(M_{SSD}-MW)	2.893	2.859	2.876
Apparent specific gravity=MD/(MD-MW)	2.929	2.903	2.916
Absorption capacity (%)	0.627	0.793	0.728

B. Fine aggregate

Step 1- A sample of 500g fine aggregate which is at free-flowing condition without moisture measured and placed into the pycnometer then filled up with water 90 % capacity of the pycnometer.

Step 2 – Using rod the air bubbles are eliminated with adjusted temperature and the water level of pycnometer filled up to its calibrated capacity.

Step 3- The total weight of the pycnometer, sample and water recorded.

$$C = 0.9976V\ a + 500 + w$$

Where

C –Weight of pycnometer filled with sample plus water

Va– Volume of water added to pycnometer

W - Weight of the pycnometer empty

Step 4 – Oven dried the aggregate removed from pycnometer at 105±5°Cfor an hour then cooled and measured

$$B = 0.9976V + W$$

$Where$

$B – Weight\ of\ flask\ filled\ with\ water$

$V - Volume\ of\ flask$

$W – Weight\ of\ the\ flask$

- $Bulk\ specific\ gravity = \frac{A}{B+500-C}$
- $Bulk\ specific\ gravity$ (saturated surface dry basis) $= \frac{500}{B+500-C}$
- $Apparent\ specific\ gravity = \frac{A}{B+A-C}$
- $Absorption = \frac{(500-A)*100}{A}$

Where

A – Weight of oven dried sample

B – Weight of pycnometer filled with water

Table A- 2 Specific gravity and water absorption of fine aggregate

Description	Trial1	Trial2	Trial3	Avg.
Weight of saturated & surface dry sand (gm)	500	500	500	
Weight of pycnometer + sample + water (C) (gm)	1862.59	1862.4	1862.7	
Weight of pycnometer +water (B) (gm)	1560.5	1561.5	1561.3	
Weight of oven dry sand (A) (gm)	498.4	498.75	498.45	
Bulk specific gravity=A/(B+500-C)	2.51	2.503	2.510	
Bulk specific gravity (sat.sur.dry basis)=500/(B+500-C)	2.53	2.531	2.52	
Apparent specific gravity=A/(B+A-C)	2.54	2.52	2.53	
Absorption capacity(%)=((500-A)/A)*100	0.32	0.3	0.31	

- **Unit weight of aggregate**

Table A-3 Unit weight for natural coarse Aggregate

	Result(coarse Aggregate)	Volume(m3)=0.010		
Sample	mass of cylinder (Kg)	Mass of sample (Kg)	Mass of cylinder and sample(Kg)	Unit weight(Kg/m3)
1	1.670	18.834	20.504	1716.4
2	1.670	18.607	20.277	1693.7
3	1.670	18.715	20.385	1704.5

Table A-4 Unit weight for natural coarse Aggregate

	Result(coarse Aggregate)	Volume(m^3)=0.010		
Sample	mass of cylinder (Kg)	Mass of sample (Kg)	Mass of cylinder and sample(Kg)	Unit weight(Kg/m3)
1	1.670	10.046	11.716	872
2	1.670	10.397	12.067	837
3	1.670	10.168	11.838	850

Table A-5 Table A-4 Unit weight for fine Aggregate

Fine Aggregate (GAMBELA)		V= 0.005 m^3		
Sample	mass of cylinder (Kg)	Mass of sample (Kg)	Mass of cylinder and sample(Kg)	Unit weight(Kg/m3)
1	1.049	8.546	9.595	1499.4
2	1.049	8.596	9.645	1504.4
3	1.049	8.601	9.65	1510.4

Table A-6 Total moisture content for natural coarse aggregate

S.NO	Description	Sample		
		1	2	3
1	Weight of original sample ,A (Kg)	2.0	2.0	2.0
2	Weight of oven dried sample B ,(Kg)	1.991	1.990	1.992
3	Moisture content in %=((A-B)/B)*100	0.45	0.5	0.4

Table A-7 Total moisture content for fine aggregate

S.NO	Description	Sample		
		1	2	3
1	Weight of original sample ,A (Kg)	0.5	0.5	0.5
2	Weight of oven dried sample B ,(Kg)	0.498	0.498	0.498
3	Moisture content in %=((A-B)/B)*100	0.4	0.4	0.4

- **Particle Size distribution test for coarse and fine aggregate**

TableA-8 Particle size distribution for Natural Coarse aggregates

Sieve Size, mm	Mass retained (gm)				%Retained	%Cumulative Retained	%passing	ASTM SpecRange
	Trial1	Trial 2	Trial 3	Avrg.				
37.5	0	0	0	0	0	0	100	
25	458.3	524.7	491.4	491.5	9.83	9.83	90.17	
19	2418.2	1769.5	2093.75	2093.8	41.88	51.71	48.29	
12.5	1552.6	1980.6	1766.5	1766.6	35.33	87.04	12.96	
9.5	324.6	350.5	337.45	337.5	6.75	93.79	6.21	
4.75	240.2	327.8	283.9	284.0	5.68	99.47	0.53	
Pan	6.1	46.4	26.15	26.2	0.52	100	0.00	
TOTAL	5000	4999.5	4999.15	4999.55				

TableA-9 Particle size distribution for waste brick Coarse aggregates

Sieve Size, mm	Mass retained (gm)				%Retained	%Cumulative Retained	%passing	ASTM SpecRange
	Trial1	Trial 2	Trial 3	Avrg.				
37.5	0	0	0	0	0	0	100	
25	0	0	0	0.0	0	0.00	100	
19	434.8	839.6	637.1	637.2	21.24	21.24	78.76	
12.5	1315.6	1617.5	1466.45	1466.5	48.88	70.12	29.88	
9.5	326.3	255.6	290.85	290.9	9.70	79.82	20.18	
4.75	799.4	252.3	525.75	525.8	17.53	97.35	2.65	
Pan	123.9	35	79.35	79.4	2.65	100	0.00	
TOTAL	3000	3000	2999.5	2999.8		0	100	

Table A-10 Particle size distribution for fine aggregates

Sieve Size, mm	Mass retained (gm)				%Retained	%Cumulative Retained	%passing	ASTM SpecRange
	Trial1	Trial 2	Trial 3	Avrg.				
9.5	0	0	0	0	0	0	100	
4.75	19	47.4	33.1	33.2	1.66	1.66	98.34	
2.36	117.4	136.4	126.8	126.9	6.34	8.00	92.00	
1.18	345	337.4	341.1	341.2	17.06	25.06	74.94	
0.6	624.1	588	605.95	606.0	30.30	55.36	44.64	
0.3	640	634	636.9	637.0	31.85	87.21	12.79	
0.15	220.5	221.4	220.85	220.9	11.05	98.26	1.75	
pan	34	35.3	34.55	34.62	1.73	100.0	0.0	
total	2000	1999.9	1999.25	1999.7				

APPENDIX-B Slump Test Results on Fresh concrete

Table B-1 Slump Test

Mix No.	Percentage of waste brick added	Replaced natural coarse aggregate (%)	Observed Slump (mm)
1	Control	0	40
2	10%	10	31
3	20%	20	26
4	30%	30	19
5	40%	40	15

APPENDIX-C Hardened concrete test results

TableC-1 Average Compressive strength for 7th day test results before dry oven

Compressive strength for 7th day test results before dry oven					
Mix. No	Percentage of waste brick	Sample	Peak load(kN)	Compressive Stress (MPa)	Avg. compressive strength
1	control	1	703.21	31.26	32.52
		2	738.09	32.81	
		3	753.47	33.49	
2	10%	1	726.45	32.29	31.11
		2	711.02	31.60	
		3	662.55	29.45	
3	20%	1	609.63	27.11	26.72
		2	623.27	27.71	
		3	570.34	25.35	
4	30%	1	402.62	17.90	17.80
		2	414.48	18.43	
		3	384.24	17.08	
5	40%	1	336.41	16.29	16.03
		2	348.83	15.50	
		3	366.60	16.30	

Table C-2 Average Compressive strength for 7th day test results after dry oven

Compressive strength for 7th day test results before dry oven					
Mix. No	Percentage of waste brick	sample	Peak load(kN)	Compressive Stress (MPa)	Avg. compressive strength
1	Control	1	685.52	30.47	32.52
		2	711.32	31.62	
		3	751.53	33.41	
2	10%	1	691.7	30.75	31.11
		2	785.91	34.94	
		3	671.26	29.84	
3	20%	1	644.22	28.65	26.72
		2	656.34	29.17	
		3	615.27	27.35	
4	30%	1	693.09	30.82	17.80
		2	489.26	21.36	
		3	535.29	23.81	
5	40%	1	438.1	19.48	16.03
		2	436.19	19.39	
		3	407.7	18.12	

Table C-3 Average Compressive stress and strain for 28th day test results

Compressive strength for 7th day test results before dry oven					
Mix. No	Percentage of waste brick	sample	Peak load(kN)	Compressive Stress (MPa)	Avg. compressive strength
1	200	1	469	20.844	24.563
		2	577	25.644	
		3	612	27.200	
2	400	1	528	23.467	26.963
		2	569	25.289	

		3	723	32.133	
3	600	1	675	30.000	29.244
		2	640	28.444	
		3	659	29.289	
4	800	1	553	24.578	28.607
		2	635	28.222	
		3	743	33.022	
5	1000	1	663	29.467	29.659
		2	637	28.311	
		3	702	31.200	

Table C-4 Split tensile strength on 28th day

Split tensile strength test result on 28th day						
Mix. No	Percentage of waste brick	sampl e	Peak load(kN)	Split tensile Stress (MPa)	Avg. Peak load(kN)	Avg. Stress
1	control	1	109.2	3.48	105.80	3.37
		2	102.5	3.26		
		3	105.7	3.37		
2	10%	1	909	2.89	102.07	3.25
		2	111.7	3.56		
		3	103.6	3.30		
3	20%	1	101.9	3.25	102.83	3.27
		2	99.8	3.18		
		3	106.8	3.40		
4	30%	1	101.3	3.23	99.94	3.18
		2	98.9	3.15		
		3	99.63	3.17		
5	40%	1	59.7	1.90	65.43	2.08
		2	68.6	2.18		
		3	67.98	2.16		

Table C-5 Split tensile strength of optimum percentage on 28th day

Split tensile strength of optimum percentage on 28th day at different temperature						
Mix. No	Percentage of waste brick	sample	Peak load(kN)	Split tensile Stress (MPa)	Avg. Peak load(kN)	Avg. Stress
1	200	1	116.1	3.70	110.33	3.51
		2	92.7	2.95		
		3	122.2	3.89		
2	400	1	104.3	3.32	102.47	3.26
		2	83.9	2.67		
		3	119.2	3.80		
3	600	1	39.7	1.26	53.53	1.70
		2	68.6	2.18		
		3	52.3	1.67		
4	800	1	86.8	2.76	81.37	2.59
		2	82.2	2.62		
		3	75.1	2.39		
5	1000	1	81.4	2.59	82.13	2.62
		2	88.5	2.82		
		3	76.5	2.44		

Table C-6 water absorption test result on 28th day

Water Absorption Result at 28th Day			
Sample No.	Weight of before Dry (Kg)	Weight of after Dry (Kg)	Water Absorption (%)
1	7.922	7.376	7.402
2	7.887	7.402	6.552
3	8.167	7.717	5.701

APPENDIX-D Stress versus strain relationship of cube test on 28th day

Table D-1 -Stress versus strain of cube test on 28th day for control

0% Compressive stress Vs strain(natural coarse aggregate by waste brick aggregate @ 28 days							
Load ,KN			Area,mm^2	Compressive stress, Mpa		Av.Stress, Mpa	Av Strain
0	0	0	22500	0.000	0.000	0.000	0
20	20	22	22500	0.889	0.889	0.889	0.0000259
34	30	31	22500	1.511	1.333	1.422	0.0000416
49	43	40	22500	2.178	1.911	2.044	0.00006
62	51	53	22500	2.756	2.267	2.511	0.0000739
75	98	71	22500	3.333	4.356	3.844	0.0001143
95	114	96	22500	4.222	5.067	4.644	0.000139
112	137	110	22500	4.978	6.089	5.533	0.0001665
128	145	144	22500	5.689	6.444	6.067	0.0001832
145	185	161	22500	6.444	8.222	7.333	0.0002236
156	219	199	22500	6.933	9.733	8.333	0.0002561
174	237	230	22500	7.733	10.533	9.133	0.0002825
249	274	269	22500	11.067	12.178	11.622	0.0003669
275	311	297	22500	12.222	13.822	13.022	0.0004161
297	372	325	22500	13.200	16.533	14.867	0.0004832
320	405	353	22500	14.222	18.000	16.111	0.0005299
337	427	367	22500	14.978	18.978	16.978	0.0005632
357	465	379	22500	15.867	20.667	18.267	0.000614
378	497	396	22500	16.800	22.089	19.444	0.0006619
399	520	403	22500	17.733	23.111	20.422	0.0007028
422	556	421	22500	18.756	24.711	21.733	0.0007595
448	585	403	22500	19.911	26.000	22.956	0.0008144
488	619	435	22500	21.689	27.511	24.600	0.0008919
521	633	471	22500	23.156	28.133	25.644	0.0009435
557	652	496	22500	24.756	28.978	26.867	0.0010068
578	665	530	22500	25.689	29.556	27.622	0.0010476

655	691	557	22500	29.111	30.711	29.911	0.0011811
687	712	586	22500	30.533	31.644	31.089	0.001257
708	725	613	22500	31.467	32.222	31.844	0.0013091
727	737	664	22500	32.311	32.756	32.533	0.0013593
746	767	694	22500	33.156	34.089	33.622	0.0014454
765	787	727	22500	34.000	34.978	34.489	0.0015217
783	798	791	22500	34.800	35.467	35.133	0.0015842
797	805	825	22500	35.422	35.778	35.600	0.0016339
824	817	831	22500	36.622	36.311	36.467	0.0017397
834	832	812	22500	37.067	36.978	37.022	0.0018222
838	841	806	22500	37.244	37.378	37.311	0.0018732
847	863	790	22500	37.644	38.356	38.000	0.0020503
850	869	781	22500	37.778	38.622	38.200	0.00221
848	865	762	22500	37.689	38.444	38.067	0.0023402
842	861	758	22500	37.422	38.267	37.844	0.0024231
831	859	736	22500	36.933	38.178	37.556	0.0024966
830	842	710	22500	36.889	37.422	37.156	0.0025749
825	834	699	22500	36.667	37.067	36.867	0.0026223
821	819	685	22500	36.489	36.400	36.444	0.0026832
810	801	681	22500	36.000	35.600	35.800	0.0027632

Table D-2 -Stress versus strain of cube test on 28th day for 10% WBA

10% Compressive stress Vs strain(natural coarse aggregate by waste brick aggregate @ 28 days								
Load ,KN			Area,mm^2	Compressive stress,Mpa			Av.Stress,Mpa	Av Strain
0	0	0	22500	0	0	0	0	0
20	18	19	22500	0.889	0.800	0.844	0.8444	0.0000252
32	27	26	22500	1.422	1.200	1.156	1.3111	0.0000392
45	39	42	22500	2.000	1.733	1.867	1.8667	0.0000561
58	50	51	22500	2.578	2.222	2.267	2.4000	0.0000724
73	64	68	22500	3.244	2.844	3.022	3.0444	0.0000923
89	82	85	22500	3.956	3.644	3.778	3.8000	0.000116
106	99	102	22500	4.711	4.400	4.533	4.5556	0.0001399
120	120	121	22500	5.333	5.333	5.378	5.3333	0.0001649
175	134	154	22500	7.778	5.956	6.844	6.8667	0.0002152
163	149	160	22500	7.244	6.622	7.111	6.9333	0.0002174
163	165	164	22500	7.244	7.333	7.289	7.2889	0.0002293
200	190	194	22500	8.889	8.444	8.622	8.6667	0.0002761
219	210	215	22500	9.733	9.333	9.556	9.5333	0.0003062
241	228	235	22500	10.711	10.133	10.444	10.4222	0.0003376
269	246	254	22500	11.956	10.933	11.289	11.4444	0.0003746
299	265	285	22500	13.289	11.778	12.667	12.5333	0.0004148
328	290	312	22500	14.578	12.889	13.867	13.7333	0.0004604
364	315	346	22500	16.178	14.000	15.378	15.0889	0.0005136
385	339	364	22500	17.111	15.067	16.178	16.0889	0.000554
418	360	384	22500	18.578	16.000	17.067	17.2889	0.0006041
453	387	425	22500	20.133	17.200	18.889	18.6667	0.0006638
479	410	464	22500	21.289	18.222	20.622	19.7556	0.0007128
505	438	499	22500	22.444	19.467	22.178	20.9556	0.000769
538	464	512	22500	23.911	20.622	22.756	22.2667	0.0008333
565	485	540	22500	25.111	21.556	24.000	23.3333	0.0008882
591	510	568	22500	26.267	22.667	25.244	24.4667	0.0009494

618	530	591	22500	27.467	23.556	26.267	25.5111	0.0010088
639	552	602	22500	28.400	24.533	26.756	26.4667	0.0010662
658	573	615	22500	29.244	25.467	27.333	27.3556	0.0011225
682	595	631	22500	30.311	26.444	28.044	28.3778	0.0011916
701	620	680	22500	31.156	27.556	30.222	29.3556	0.0012629
719	645	701	22500	31.956	28.667	31.156	30.3111	0.0013387
729	659	710	22500	32.400	29.289	31.556	30.8444	0.0013843
739	674	729	22500	32.844	29.956	32.400	31.4000	0.001435
749	689	753	22500	33.289	30.622	33.467	31.9556	0.0014896
758	704	764	22500	33.689	31.289	33.956	32.4889	0.0015466
768	710	784	22500	34.133	31.556	34.844	32.8444	0.0015879
775	725	773	22500	34.444	32.222	34.356	33.3333	0.0016501
782	738	764	22500	34.756	32.800	33.956	33.7778	0.0017142
787	749	759	22500	34.978	33.289	33.733	34.1333	0.0017731
789	762	723	22500	35.067	33.867	32.133	34.4667	0.0018378
790	774	714	22500	35.111	34.400	31.733	34.7556	0.0019068
788	789	701	22500	35.022	35.067	31.156	35.0444	0.0020024
780	799	689	22500	34.667	35.511	30.622	35.0889	0.0020227
772	814	665	22500	34.311	36.178	29.556	35.2444	0.0021732
760	821	658	22500	33.778	36.489	29.244	35.1333	0.0022944
754	824	645	22500	33.511	36.622	28.667	35.0667	0.0023286
743	825	641	22500	33.022	36.667	28.489	34.8444	0.0024099
726	816	630	22500	32.267	36.267	28.000	34.2667	0.0025472

Table D-3 -Stress versus strain of cube test on 28th day for 20% WBA

20% Compressive stress Vs strain(natural coarse aggregate by waste brick aggregate @ 28 days								
Load ,KN			Area,mm^2	Compressive stress,Mpa			Av.Stress,Mpa	Av Strain
0	0	0	22500	0	0	0	0	0
20	19	20	22500	0.889	0.844	0.889	0.874	0.0000264
29	29	27	22500	1.289	1.289	1.200	1.259	0.0000381
39	43	41	22500	1.733	1.733	1.822	1.763	0.0000536
47	51	49	22500	2.089	2.089	2.178	2.119	0.0000647
60	62	61	22500	2.667	2.667	2.711	2.681	0.0000822
73	73	70	22500	3.244	3.244	3.111	3.200	0.0000986
84	84	81	22500	3.733	3.733	3.600	3.689	0.0001141
94	98	93	22500	4.178	4.178	4.133	4.163	0.0001293
107	110	108	22500	4.756	4.756	4.800	4.770	0.000149
122	122	120	22500	5.422	5.422	5.333	5.393	0.0001695
134	132	130	22500	5.956	5.956	5.778	5.896	0.0001861
148	147	145	22500	6.578	6.578	6.444	6.533	0.0002075
162	162	160	22500	7.200	7.200	7.111	7.170	0.0002291
173	176	174	22500	7.689	7.689	7.733	7.704	0.0002475
187	192	189	22500	8.311	8.311	8.400	8.341	0.0002696
202	210	205	22500	8.978	8.978	9.111	9.022	0.0002937
216	219	217	22500	9.600	9.600	9.644	9.615	0.0003149
230	238	235	22500	10.222	10.222	10.444	10.296	0.0003396
242	253	249	22500	10.756	10.756	11.067	10.859	0.0003603
257	268	261	22500	11.422	11.422	11.600	11.481	0.0003836
276	287	283	22500	12.267	12.267	12.578	12.370	0.0004174
294	307	302	22500	13.067	13.067	13.422	13.185	0.000449
313	322	315	22500	13.911	13.911	14.000	13.941	0.000479
335	343	339	22500	14.889	14.889	15.067	14.948	0.0005199
355	360	356	22500	15.778	15.778	15.822	15.793	0.0005552
360	377	369	22500	16.000	16.000	16.400	16.133	0.0005696
389	396	391	22500	17.289	17.289	17.378	17.319	0.0006211
410	417	411	22500	18.222	18.222	18.267	18.237	0.0006624
427	438	431	22500	18.978	18.978	19.156	19.037	0.0006994
443	457	449	22500	19.689	19.689	19.956	19.778	0.0007347
464	471	467	22500	20.622	20.622	20.756	20.667	0.0007783
482	492	489	22500	21.422	21.422	21.733	21.526	0.0008219
507	511	509	22500	22.533	22.533	22.622	22.563	0.0008768
522	528	525	22500	23.200	23.200	23.333	23.244	0.0009143
540	544	541	22500	24.000	24.000	24.044	24.015	0.0009583
577	560	569	22500	25.644	25.644	25.289	25.526	0.0010502
597	578	585	22500	26.533	26.533	26.000	26.356	0.0011043
615	594	608	22500	27.333	27.333	27.022	27.230	0.0011648
627	611	615	22500	27.867	27.867	27.333	27.689	0.0011982
645	622	637	22500	28.667	28.667	28.311	28.548	0.0012644
659	635	647	22500	29.289	29.289	28.75556	29.111	0.0013107

674	651	667	22500	29.956	29.956	29.64444	29.852	0.0013762
687	666	683	22500	30.533	30.533	30.35556	30.474	0.0014361
699	671	692	22500	31.067	31.067	30.75556	30.963	0.0014871
711	690	705	22500	31.600	31.600	31.33333	31.511	0.0015496
723	698	713	22500	32.133	32.133	31.68889	31.985	0.0016096
733	707	725	22500	32.578	32.578	32.22222	32.459	0.0016775
742	710	732	22500	32.978	32.978	32.53333	32.830	0.0017386
752	718	741	22500	33.422	33.422	32.93333	33.259	0.0018233
759	722	749	22500	33.733	33.733	33.28889	33.585	0.0019068
764	725	751	22500	33.956	33.956	33.37778	33.763	0.0019677
767	726	754	22500	34.089	34.089	33.51111	33.896	0.0020314
771	721	750	22500	34.267	34.267	33.33333	33.956	0.0020753
773	716	749	22500	34.356	34.356	33.28889	34.000	0.002157
768	718	744	22500	34.133	34.133	33.06667	33.778	0.0023419
749	721	741	22500	33.289	33.289	32.93333	33.170	0.0025161
733	723	738	22500	32.578	32.578	32.8	32.652	0.0026157
720	724	724	22500	32.000	32.000	32.17778	32.059	0.0027086
715	718	718	22500	31.778	31.778	31.91111	31.822	0.0027418
701	714	710	22500	31.156	31.156	31.55556	31.289	0.0028105

Table D -4 -Stress versus strain of cube test on 28th day for 30% WBA

30% Compressive stress Vs strain(natural coarse aggregate by waste brick aggregate @ 28 days								
Load ,KN			Area,mm^2	Compressive stress,Mpa			Av.Stress,Mpa	Av Strain
0	0	0	22500	0	0	0	0	0
20	20	19	22500	0.889	0.889	0.844	0.874	0.0000277
27	38	32	22500	1.200	1.689	1.422	1.437	0.0000458
39	58	45	22500	1.733	2.578	2.000	2.104	0.0000675
54	75	62	22500	2.400	3.333	2.756	2.830	0.0000916
67	93	81	22500	2.978	4.133	3.600	3.570	0.0001166
79	113	95	22500	3.511	5.022	4.222	4.252	0.0001399
99	137	128	22500	4.400	6.089	5.689	5.393	0.00018
116	159	138	22500	5.156	7.067	6.133	6.119	0.0002061
137	185	159	22500	6.089	8.222	7.067	7.126	0.0002431
154	210	195	22500	6.844	9.333	8.667	8.281	0.0002869
176	230	210	22500	7.822	10.222	9.333	9.126	0.0003198
197	250	235	22500	8.756	11.111	10.444	10.104	0.000359
224	271	254	22500	9.956	12.044	11.289	11.096	0.0004
248	292	289	22500	11.022	12.978	12.844	12.281	0.0004508
270	318	312	22500	12.000	14.133	13.867	13.333	0.0004977
298	342	324	22500	13.244	15.200	14.400	14.281	0.0005416
319	366	335	22500	14.178	16.267	14.889	15.111	0.0005814
344	386	356	22500	15.289	17.156	15.822	16.089	0.0006301
369	410	391	22500	16.400	18.222	17.378	17.333	0.0006951
390	427	405	22500	17.333	18.978	18.000	18.104	0.0007374
416	450	426	22500	18.489	20.000	18.933	19.141	0.0007971
437	471	445	22500	19.422	20.933	19.778	20.044	0.000852
462	492	475	22500	20.533	21.867	21.111	21.170	0.000925
489	511	508	22500	21.733	22.711	22.578	22.341	0.0010073
510	527	519	22500	22.667	23.422	23.067	23.052	0.0010611
537	543	544	22500	23.867	24.133	24.178	24.059	0.0011436
555	562	560	22500	24.667	24.978	24.889	24.844	0.0012143
577	577	574	22500	25.644	25.644	25.511	25.600	0.0012893
597	591	592	22500	26.533	26.267	26.311	26.370	0.001375
616	608	614	22500	27.378	27.022	27.289	27.230	0.001487
640	616	631	22500	28.444	27.378	28.044	27.956	0.0016037
654	626	641	22500	29.067	27.822	28.489	28.459	0.0017072
664	632	650	22500	29.511	28.089	28.889	28.830	0.0018092

669	638	663	22500	29.733	28.356	29.467	29.185	0.0019801
675	640	659	22500	30.000	28.444	29.289	29.244	0.002085
682	642	640	22500	30.311	28.533	28.444	29.096	0.0022537
692	644	637	22500	30.756	28.622	28.311	29.230	0.0021362
699	638	630	22500	31.067	28.356	28.000	29.141	0.0022255
702	627	628	22500	31.200	27.867	27.911	28.993	0.0023053
705	612	621	22500	31.333	27.200	27.600	28.711	0.0024077
706	591	614	22500	31.378	26.267	27.289	28.311	0.0025143

Table D -5 -Stress versus strain of cube test on 28th day for 40% WBA

40% Compressive stress Vs strain(natural coarse aggregate by waste brick aggregate @ 28 days								
Load ,KN			Area,mm^2	Compressive stress,Mpa			Av.Stress,Mpa	Av Strain
0	0	0	22500	0	0	0	0	0
32	34	30	22500	1.422	1.511	1.333	1.422	0.000054
45	45	43	22500	2.000	2.000	1.911	1.970	0.000076
53	56	55	22500	2.356	2.489	2.444	2.430	0.0000949
65	67	66	22500	2.889	2.978	2.933	2.933	0.0001161
74	78	76	22500	3.289	3.467	3.378	3.378	0.0001354
93	89	95	22500	4.133	3.956	4.222	4.104	0.000168
115	98	117	22500	5.111	4.356	5.200	4.889	0.0002049
120	112	125	22500	5.333	4.978	5.556	5.289	0.0002244
135	124	131	22500	6.000	5.511	5.822	5.778	0.000249
150	135	145	22500	6.667	6.000	6.444	6.370	0.0002798
167	147	153	22500	7.422	6.533	6.800	6.919	0.0003096
176	158	167	22500	7.822	7.022	7.422	7.422	0.000338
189	173	182	22500	8.400	7.689	8.089	8.059	0.0003756
204	187	197	22500	9.067	8.311	8.756	8.711	0.0004161
224	198	211	22500	9.956	8.800	9.378	9.378	0.00046
240	213	224	22500	10.667	9.467	9.956	10.030	0.0005056
251	230	237	22500	11.156	10.222	10.533	10.637	0.0005507
271	245	243	22500	12.044	10.889	10.800	11.244	0.0005989
284	262	269	22500	12.622	11.644	11.956	12.074	0.0006705
293	276	277	22500	13.022	12.267	12.311	12.533	0.0007135
306	293	289	22500	13.600	13.022	12.844	13.156	0.0007765
324	304	295	22500	14.400	13.511	13.111	13.674	0.0008338
336	323	315	22500	14.933	14.356	14.000	14.430	0.0009277
347	335	329	22500	15.422	14.889	14.622	14.978	0.0010059
356	346	337	22500	15.822	15.378	14.978	15.393	0.0010729
364	358	349	22500	16.178	15.911	15.511	15.867	0.0011607
369	371	354	22500	16.400	16.489	15.733	16.207	0.0012344

375	384	367	22500	16.667	17.067	16.311	16.681	0.0013616
378	395	375	22500	16.800	17.556	16.667	17.007	0.0014806
381	405	389	22500	16.933	18.000	17.289	17.407	0.0018633
371	414	383	22500	16.489	18.400	17.022	17.304	0.0020494
365	423	371	22500	16.222	18.800	16.489	17.170	0.0021569
354	429	365	22500	15.733	19.067	16.222	17.007	0.0022536
341	438	356	22500	15.156	19.467	15.822	16.815	0.0023466
332	432	345	22500	14.756	19.200	15.333	16.430	0.0024994

APPENDIX-E Stress versus strain relationship of cube test of optimum percentage on 28th day

Table E -1-Compressive strength test result of optimum percentage on 28th day after burning at 200 temperature.

Optimum percentage Compressive stress Vs strain(AT 200) @ 28 days								
Load ,KN			Area,mm^2	Compressive stress,Mpa			Av.Stress,Mpa	Av Strain
0	0	0	22500	0	0	0	0	0
19	22	20	22500	0.844	0.978	0.889	0.904	3.03E-05
37	41	47	22500	1.644	1.822	2.089	1.852	6.29E-05
50	58	71	22500	2.222	2.578	3.156	2.652	9.12E-05
66	87	100	22500	2.933	3.867	4.444	3.748	0.000131
82	107	127	22500	3.644	4.756	5.644	4.681	0.000166
100	123	152	22500	4.444	5.467	6.756	5.556	0.0002
119	142	183	22500	5.289	6.311	8.133	6.578	0.000241
139	156	206	22500	6.178	6.933	9.156	7.422	0.000276
158	180	234	22500	7.022	8.000	10.400	8.474	0.000322
176	199	257	22500	7.822	8.844	11.422	9.363	0.000362
204	220	278	22500	9.067	9.778	12.356	10.400	0.00041
222	241	304	22500	9.867	10.711	13.511	11.363	0.000458
242	261	332	22500	10.756	11.600	14.756	12.370	0.000509
258	282	358	22500	11.467	12.533	15.911	13.304	0.00056
275	309	377	22500	12.222	13.733	16.756	14.237	0.000613
289	327	403	22500	12.844	14.533	17.911	15.096	0.000665
308	348	426	22500	13.689	15.467	18.933	16.030	0.000725
324	371	451	22500	14.400	16.489	20.044	16.978	0.00079
339	397	473	22500	15.067	17.644	21.022	17.911	0.000858
358	417	497	22500	15.911	18.533	22.089	18.844	0.000933
370	437	522	22500	16.444	19.422	23.200	19.689	0.001008
386	459	544	22500	17.156	20.400	24.178	20.578	0.001095
405	480	573	22500	18.000	21.333	25.467	21.600	0.00121
418	499	598	22500	18.578	22.178	26.578	22.444	0.001324
430	521	623	22500	19.111	23.156	27.689	23.319	0.001473
444	541	630	22500	19.733	24.044	28.000	23.926	0.001616
456	562	629	22500	20.267	24.978	27.956	24.400	0.001799
469	577	612	22500	20.844	25.644	27.200	24.563	0.001991
480	575	593	22500	21.333	25.556	26.356	24.415	0.00218
486	557	580	22500	21.600	24.756	25.778	24.044	0.002349
497	523	566	22500	22.089	23.244	25.156	23.496	0.002511

Table E -2-Compressive strength test result of optimum percentage on 28th day after burning at 400 temperature.

Optimum percentage Compressive stress Vs strain(AT 400) @ 28 days								
Load ,KN			Area,mm^2	Compressive stress,Mpa			Av.Stress,Mpa	Av Strain
0	0	0	22500	0	0	0	0	0
19	17	21	22500	0.844	0.756	0.933	0.844	0.0000274
28	32	33	22500	1.244	1.422	1.467	1.378	0.0000451
39	42	42	22500	1.733	1.867	1.867	1.822	5.9E-05
53	53	53	22500	2.356	2.356	2.356	2.356	0.000078
65	68	73	22500	2.889	3.022	3.244	3.052	0.000102
74	84	95	22500	3.289	3.733	4.222	3.748	0.0001265
88	98	123	22500	3.911	4.356	5.467	4.578	0.0001563
98	113	142	22500	4.356	5.022	6.311	5.230	0.000180
110	127	158	22500	4.889	5.644	7.022	5.852	0.0002034
118	139	184	22500	5.244	6.178	8.178	6.533	0.0002294
118	154	206	22500	5.244	6.844	9.156	7.081	0.0002506
128	175	221	22500	5.689	7.778	9.822	7.763	0.0002777
139	191	248	22500	6.178	8.489	11.022	8.563	0.0003101
151	211	266	22500	6.711	9.378	11.822	9.304	0.000341
162	226	287	22500	7.200	10.044	12.756	10.000	0.0003708
178	241	308	22500	7.911	10.711	13.689	10.770	0.0004046
193	255	323	22500	8.578	11.333	14.356	11.422	0.0004341
208	269	354	22500	9.244	11.956	15.733	12.311	0.0004755
223	285	371	22500	9.911	12.667	16.489	13.022	0.0005098
233	297	394	22500	10.356	13.200	17.511	13.689	0.0005429
248	318	418	22500	11.022	14.133	18.578	14.578	0.0005886
260	331	444	22500	11.556	14.711	19.733	15.333	0.0006291
275	348	468	22500	12.222	15.467	20.800	16.163	0.0006755
288	368	488	22500	12.800	16.356	21.689	16.948	0.0007213
307	385	511	22500	13.644	17.111	22.711	17.822	0.000775
317	402	532	22500	14.089	17.867	23.644	18.533	0.0008209
335	418	555	22500	14.889	18.578	24.667	19.378	0.0008785
351	432	577	22500	15.600	19.200	25.644	20.148	0.0009344
370	445	599	22500	16.444	19.778	26.622	20.948	0.0009965
383	458	622	22500	17.022	20.356	27.644	21.674	0.0010571
398	471	638	22500	17.689	20.933	28.356	22.326	0.0011157
418	488	657	22500	18.578	21.689	29.200	23.156	0.0011975
431	499	670	22500	19.156	22.178	29.778	23.704	0.0012571
448	514	686	22500	19.911	22.844	30.489	24.415	0.0013435
464	522	699	22500	20.622	23.200	31.067	24.963	0.0014195
477	533	713	22500	21.200	23.689	31.689	25.526	0.0015106

488	541	722	22500	21.689	24.044	32.089	25.941	0.001591
507	551	725	22500	22.533	24.489	32.222	26.415	0.0017085
518	560	728	22500	23.022	24.889	32.356	26.756	0.0018343
528	569	723	22500	23.467	25.289	32.133	26.963	0.0020392
520	557	669	22500	23.111	24.756	29.733	25.867	0.002532
512	543	657	22500	22.756	24.133	29.200	25.363	0.0026384
503	537	643	22500	22.356	23.867	28.578	24.933	0.0027173

Table E -3-Compressive strength test result of optimum percentage on 28th day after burning at 600 temperature.

Optimum percentage Compressive stress Vs strain(AT 600) @ 28 days								
Load ,KN			Area,mm^2	Compressive stress,Mpa			Av.Stress,Mpa	Av Strain
0	0	0	22500	0	0	0	0	0
20	20	19	22500	0.889	0.889	0.844	0.874	0.0000277
27	38	32	22500	1.200	1.689	1.422	1.437	0.0000458
39	58	45	22500	1.733	2.578	2.000	2.104	0.0000675
54	75	62	22500	2.400	3.333	2.756	2.830	0.0000916
67	93	81	22500	2.978	4.133	3.600	3.570	0.0001166
79	113	95	22500	3.511	5.022	4.222	4.252	0.0001399
99	137	128	22500	4.400	6.089	5.689	5.393	0.00018
116	159	138	22500	5.156	7.067	6.133	6.119	0.0002061
137	185	159	22500	6.089	8.222	7.067	7.126	0.0002431
154	210	195	22500	6.844	9.333	8.667	8.281	0.0002869
176	230	210	22500	7.822	10.222	9.333	9.126	0.0003198
197	250	235	22500	8.756	11.111	10.444	10.104	0.000359
224	271	254	22500	9.956	12.044	11.289	11.096	0.0004
248	292	289	22500	11.022	12.978	12.844	12.281	0.0004508
270	318	312	22500	12.000	14.133	13.867	13.333	0.0004977
298	342	324	22500	13.244	15.200	14.400	14.281	0.0005416
319	366	335	22500	14.178	16.267	14.889	15.111	0.0005814
344	386	356	22500	15.289	17.156	15.822	16.089	0.0006301
369	410	391	22500	16.400	18.222	17.378	17.333	0.0006951
390	427	405	22500	17.333	18.978	18.000	18.104	0.0007374
416	450	426	22500	18.489	20.000	18.933	19.141	0.0007971
437	471	445	22500	19.422	20.933	19.778	20.044	0.000852
462	492	475	22500	20.533	21.867	21.111	21.170	0.000925
489	511	508	22500	21.733	22.711	22.578	22.341	0.0010073
510	527	519	22500	22.667	23.422	23.067	23.052	0.0010611
537	543	544	22500	23.867	24.133	24.178	24.059	0.0011436
555	562	560	22500	24.667	24.978	24.889	24.844	0.0012143

577	577	574	22500	25.644	25.644	25.511	25.600	0.0012893
597	591	592	22500	26.533	26.267	26.311	26.370	0.001375
616	608	614	22500	27.378	27.022	27.289	27.230	0.001487
640	616	631	22500	28.444	27.378	28.044	27.956	0.0016037
654	626	641	22500	29.067	27.822	28.489	28.459	0.0017072
664	632	650	22500	29.511	28.089	28.889	28.830	0.0018092
669	638	663	22500	29.733	28.356	29.467	29.185	0.0019801
675	640	659	22500	30.000	28.444	29.289	29.244	0.002085
682	642	640	22500	30.311	28.533	28.444	29.096	0.0022537
692	644	637	22500	30.756	28.622	28.311	29.230	0.0021362
699	638	630	22500	31.067	28.356	28.000	29.141	0.0022255
702	627	628	22500	31.200	27.867	27.911	28.993	0.0023053
705	612	621	22500	31.333	27.200	27.600	28.711	0.0024077
706	591	614	22500	31.378	26.267	27.289	28.311	0.0025143

Table E -4-Compressive strength test result of optimum percentage on 28th day after burning at 800 temperature.

Optimum percentage Compressive stress Vs strain(AT 800) @ 28 days								
Load ,KN			Area,mm^2	Compressive stress,Mpa			Av.Stress,Mpa	Av Strain
0	0	0	0	0	0	0	0	0
16	21	21	22500	0.711	0.933	0.933	0.859	2.74E-05
21	29	29	22500	0.933	1.289	1.289	1.170	3.74E-05
28	47	44	22500	1.244	2.089	1.956	1.763	5.68E-05
36	59	56	22500	1.600	2.622	2.489	2.237	7.25E-05
48	74	72	22500	2.133	3.289	3.200	2.874	9.38E-05
63	88	86	22500	2.800	3.911	3.822	3.511	0.000116
76	106	101	22500	3.378	4.711	4.489	4.193	0.000139
89	119	123	22500	3.956	5.289	5.467	4.904	0.000164
104	133	144	22500	4.622	5.911	6.400	5.644	0.000191
123	148	159	22500	5.467	6.578	7.067	6.370	0.000217
137	172	184	22500	6.089	7.644	8.178	7.304	0.000252
154	189	199	22500	6.844	8.400	8.844	8.030	0.00028
172	209	223	22500	7.644	9.289	9.911	8.948	0.000316
188	219	244	22500	8.356	9.733	10.844	9.644	0.000344
203	240	265	22500	9.022	10.667	11.778	10.489	0.000379
219	266	282	22500	9.733	11.822	12.533	11.363	0.000417
233	279	298	22500	10.356	12.400	13.244	12.000	0.000444
248	295	326	22500	11.022	13.111	14.489	12.874	0.000484

261	315	344	22500	11.600	14.000	15.289	13.630	0.000519
279	333	368	22500	12.400	14.800	16.356	14.519	0.000561
296	354	387	22500	13.156	15.733	17.200	15.363	0.000603
309	369	407	22500	13.733	16.400	18.089	16.074	0.000603
323	387	427	22500	14.356	17.200	18.978	16.844	0.000681
342	402	448	22500	15.200	17.867	19.911	17.659	0.000726
356	422	471	22500	15.822	18.756	20.933	18.504	0.000775
374	441	488	22500	16.622	19.600	21.689	19.304	0.000823
389	463	507	22500	17.289	20.578	22.533	20.133	0.000876
402	476	528	22500	17.867	21.156	23.467	20.830	0.000923
416	495	552	22500	18.489	22.000	24.533	21.674	0.000983
432	512	573	22500	19.200	22.756	25.467	22.474	0.001044
446	528	594	22500	19.822	23.467	26.400	23.230	0.001106
458	547	614	22500	20.356	24.311	27.289	23.985	0.001173
466	562	633	22500	20.711	24.978	28.133	24.607	0.001232
479	571	646	22500	21.289	25.378	28.71111	25.126	0.001286
491	584	665	22500	21.822	25.956	29.55556	25.778	0.00136
497	595	678	22500	22.089	26.444	30.13333	26.222	0.001416
509	603	689	22500	22.622	26.800	30.62222	26.681	0.001481
518	614	705	22500	23.022	27.289	31.33333	27.215	0.001567
529	622	719	22500	23.511	27.644	31.95556	27.704	0.001663
539	628	727	22500	23.956	27.911	32.31111	28.059	0.001752
544	633	738	22500	24.178	28.133	32.8	28.370	0.001860
553	635	743	22500	24.578	28.222	33.02222	28.607	0.002076
541	622	734	22500	24.044	27.644	32.62222	28.104	0.00239
535	614	727	22500	23.778	27.289	32.31111	27.793	0.002478
521	608	718	22500	23.156	27.022	31.91111	27.363	0.002577

Table E -5- Compressive strength test result of optimum percentage on 28th day after burning at 1000 temperature.

Optimum percentage Compressive stress Vs strain(AT 1000) @ 28 days								
Load ,KN			Area,mm^2	Compressive stress,Mpa			Av.Stress,Mpa	Av Strain
0	0	0	22500	0	0	0	0	0
21	21	21	22500	0.933	0.933	0.933	0.933	0.0000294
36	30	28	22500	1.600	1.333	1.244	1.393	0.0000442
59	44	42	22500	2.622	1.956	1.867	2.148	0.0000687
78	68	51	22500	3.467	3.022	2.267	2.919	0.0000941
97	91	68	22500	4.311	4.044	3.022	3.793	0.0001235
115	105	79	22500	5.111	4.667	3.511	4.430	0.0001454
133	129	91	22500	5.911	5.733	4.044	5.230	0.0001732

156	147	105	22500	6.933	6.533	4.667	6.044	0.0002022
176	169	121	22500	7.822	7.511	5.378	6.904	0.0002334
197	186	137	22500	8.756	8.267	6.089	7.704	0.0002632
219	206	147	22500	9.733	9.156	6.533	8.474	0.0002924
233	223	161	22500	10.356	9.911	7.156	9.141	0.0003182
254	237	172	22500	11.289	10.533	7.644	9.822	0.0003452
279	251	191	22500	12.400	11.156	8.489	10.681	0.0003799
301	272	207	22500	13.378	12.089	9.200	11.556	0.0004163
325	285	229	22500	14.444	12.667	10.178	12.430	0.0004537
334	306	245	22500	14.844	13.600	10.889	13.111	0.0004836
369	325	264	22500	16.400	14.444	11.733	14.193	0.0005326
392	344	272	22500	17.422	15.289	12.089	14.933	0.0005674
414	362	298	22500	18.400	16.089	13.244	15.911	0.0006149
429	377	320	22500	19.067	16.756	14.222	16.681	0.0006537
457	398	337	22500	20.311	17.689	14.978	17.659	0.0007049
484	415	351	22500	21.511	18.444	15.600	18.519	0.000752
507	439	372	22500	22.533	19.511	16.533	19.526	0.0008099
528	465	395	22500	23.467	20.667	17.556	20.563	0.000873
549	472	416	22500	24.400	20.978	18.489	21.289	0.0009197
569	486	431	22500	25.289	21.600	19.156	22.015	0.0009687
593	499	451	22500	26.356	22.178	20.044	22.859	0.001029
615	516	472	22500	27.333	22.933	20.978	23.748	0.0010973
639	531	498	22500	28.400	23.600	22.133	24.711	0.001178
652	544	516	22500	28.978	24.178	22.933	25.363	0.0012377
668	556	533	22500	29.689	24.711	23.689	26.030	0.0013041
681	568	551	22500	30.267	25.244	24.489	26.667	0.001374
689	579	572	22500	30.622	25.733	25.422	27.259	0.0014466
693	586	588	22500	30.800	26.044	26.133	27.659	0.0015013
696	595	606	22500	30.933	26.444	26.933	28.104	0.00156940
695	603	625	22500	30.889	26.800	27.778	28.489	0.00163720
690	612	644	22500	30.667	27.200	28.622	28.830	0.00170800
681	618	660	22500	30.267	27.467	29.333	29.022	0.00175470
675	626	675	22500	30.000	27.822	30.000	29.274	0.00182900
670	632	689	22500	29.778	28.089	30.622	29.496	0.00192040
663	637	702	22500	29.467	28.311	31.200	29.659	0.00208630
657	625	697	22500	29.200	27.778	30.978	29.319	0.0023479
645	613	689	22500	28.667	27.244	30.622	28.844	0.0024901

APPENDIX-F Stress-strain curves

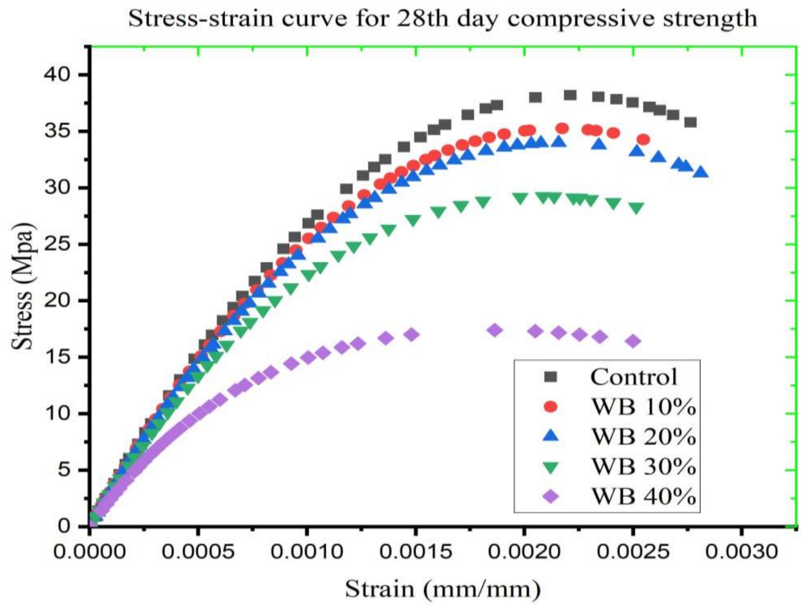

Figure F-1: Stress-strain curve for 28th day

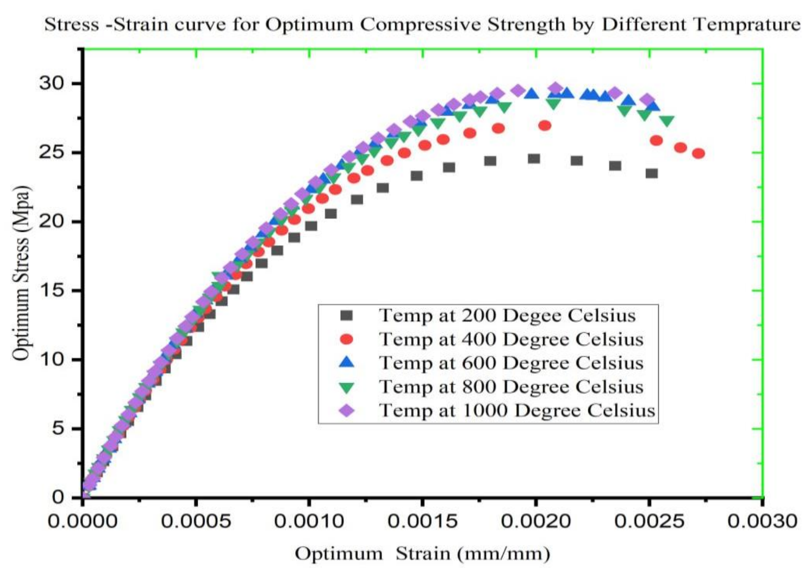

Figure F-2: Stress-strain curve for optimum percentage for 28th day

APPENDIX-G Strength and deformation characteristics for concrete

Table G-1 Strength and deformation characteristics for concrete[35]

Strength classes for concrete															Analytical relation / Explanation
f_{ck} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90	
$f_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105	
f_{cm} (MPa)	20	24	28	33	38	43	48	53	58	63	68	78	88	98	$f_{cm} = f_{ck} + 8$ (MPa)
f_{ctm} (MPa)	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4.1	4.2	4.4	4.6	4.8	5.0	$f_{ctm} = 2.12 \ln(1+(f_{cm}/10)) \geq$ C50/60
$f_{ctk,0.05}$ (MPa)	1.1	1.3	1.5	1.8	2.0	2.2	2.5	2.7	2.9	3.0	3.1	3.2	3.4	3.5	$f_{ctk,0.05} = 0.7 \times f_{ctm}$ 5 % fractile
$f_{ctk,0.95}$ (MPa)	2.0	2.5	2.9	3.3	3.8	4.2	4.6	4.9	5.3	5.5	5.7	6.0	6.3	6.6	$f_{ctk,0.95} = 1.3 \times f_{ctm}$ 95 % fractile
E_{cm} (GPa)	27	29	30	31	33	34	35	36	37	38	39	41	42	44	$E_{cm} = 22[(f_{cm})/10]^{0.3}$ (f_{cm} in MPa)
ε_{c1} (‰)	1.8	1.9	2.0	2.1	2.2	2.25	2.3	2.4	2.45	2.5	2.6	2.7	2.8	2.8	See Figure 3.2 ε_{c1} (‰) $= 0.7 f_{cm}^{0.31} \leq 2.8$
ε_{cu1} (‰)	3.5									3.2	3.0	2.8	2.8	2.8	See Figure 3.2 for $f_{ck} \geq 50$ MPa ε_{cu1} (‰) $= 2.8 + 27[(98 - f_{cm})/100]^4$
ε_{c2} (‰)	2.0									2.2	2.3	2.4	2.5	2.6	See Figure 3.3 for $f_{ck} \geq 50$ MPa ε_{c2} (‰) $= 2.0 + 0.085[(f_{ck} - 50)^{0.53}$
ε_{cu2} (‰)	3.5									3.1	2.9	2.7	2.6	2.6	See Figure 3.3 for $f_{ck} \geq 50$ MPa ε_{cu2} (‰) $= 2.6 + 35[(90 - f_{ck})/100]^4$
n	2.0									1.75	1.6	1.45	1.4	1.4	for $f_{ck} \geq 50$ MPa $n = 1.4 + 23.4 [(90 - f_{ck})/100]^4$
ε_{c3} (‰)	1.75									1.8	1.9	2.0	2.2	2.3	See Figure 3.4 for $f_{ck} \geq 50$ MPa ε_{c3} (‰) $= 1.75 + 0.55[(f_{ck} - 50)/40]$
ε_{cu3} (‰)	3.5									3.1	2.9	2.7	2.6	2.6	See Figure 3.4 for $f_{ck} \geq 50$ MPa ε_{cu3} (‰) $= 2.6 + 35[(90 - f_{ck})/100]^4$

APPENDIX-H Chemical Properties of Waste Brick

	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1of 1
Document Title:-	Complete Silicate Analysis Report	Effective date:	Nov. 2022

Customer Name:- Ribka Alemu Dbabaa

Issue Date:-22/09/2023

Sample type :-Powder

Request No:- GLD/RQ/1635/23

Sample Preparation: -200 Mesh

Report No:- GLD/RN/2288/23

Date Submitted:- 27/07/2023

Number of Sample:- One (01)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	Weight of Sample
RA-21	83.40	8.86	4.19	0.20	0.41	<0.01	0.50	0.09	0.15	1.39	0.33	0.54	1.00Kg

Note:- This result represent only for the sample submitted to the laboratory.

- LOI = Loss on Ignition

Analysts
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Lidet Endeshaw

Approved By
Yohannes Getachew

Quality Control
Negash Worku

Geological Survey of Ethiopia Central Geological Laboratory

Geochemical Laboratory Desk

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APPENDIX-I Photo Gallery

Photo-1 Collecting waste brick from Qofe brick production site

Photo-2 Crushing, sieving, transporting and washing waste brick

Photo-3 Sieve Analysis

Photo-4 Unit weight of coarse aggregate

Photo-5 Specific gravity test for fine and coarse aggregate

Photo-6 Prepared molds, Mix and casting

Photo-7 fresh concrete properties slump test

photo-8 Adjustment and reading dial gauge

Photo-9 During hardened concrete test