

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING



**Experimental Study on Partial Replacement of
Coarse Aggregate with Crushed Clay Brick to
Produce C-25 Concrete**

**A Thesis Submitted to School of Civil and Environmental Engineering of
Addis Ababa Institute of Technology in Partial Fulfillment of the
Requirements for the Degree of Master of Science in Civil Engineering
(Construction Technology and Management)**


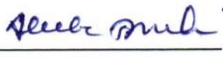

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January, 2022

Addis Ababa

Experimental Study on Partial Replacement of Coarse Aggregate with Crushed Clay Brick to Produce C-25 Concrete

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ACKNOWLEDGMENTS

First of all, I would like to give thanks and praise to God for who He is. Next, I want to express my gratitude for my advisor Dr. Biruktawit Taye. She has consistently dedicated her time to advise me in my thesis work and bring it to completion. She has always been available to review and give comments on the thesis work and I am very thankful of that. I am also very thankful of my co-advisor Mr. Natnael Beksissa for his valuable comments. I also want to give thanks to my sister, Hibist Markos, for helping me throughout the journey.

ABSTRACT

Concrete is a material that is composed of 60-80% of aggregates by volume. Natural crushed basaltic rock is extensively used in Addis Ababa as a coarse aggregate in concrete production. Studies have shown that extensive production of coarse aggregate from natural resources has negative impact on the landscape, water and atmosphere. To alleviate this negative impact, the experimental research aims to partially replace the basaltic coarse aggregate with waste crushed clay brick obtained from brick factories located in and around Addis Ababa, in concrete production.

The research studied the effect of replacing a C-25 grade concrete coarse aggregate with crushed clay brick by 10%, 20%, 30%, 40% and 100% by volume. The effect on workability, hardened density, compressive strength, flexural strength and water penetration depth were investigated. The clay bricks used as replacements were collected from four different brick factories that are found in and around Addis Ababa.

A total of twenty one concrete mixes were made that include the control and the replacement mixes. A water/cement ratio of 0.49 was used for all the mixes. In all the mixes the crushed clay bricks were used in a saturated surface dry condition. The findings of the experimental study showed that all the crushed clay bricks obtained from representative four different brick factories can be used as partial replacement of coarse aggregate up to 30% with a water/cement ratio of 0.49. Full replacement of coarse aggregate with crushed clay brick was made possible with a water/cement ratio of 0.40 though that particular concrete mixture was found to be uneconomical compared with the unit cost of the control mix.

It was found that the slump and flexural strength of the replacement mix decreased when the crushed clay aggregate replacement percentage increased. The hardened density of the concrete produced with 30% replacement amount decreased by 3% from the control mix. Based on the water penetration test, it was found that the water penetration depth of the concrete increased when the CCB aggregate replacement increased.

The amount of cost reduced when using 30% of CCB aggregates in replacement of crushed basalt stone is very insignificant only by 0.98% per one meter cube of concrete.

Key words: Coarse aggregate, crushed clay brick, partial replacement

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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ACV	Aggregate crushing value
AIV	Aggregate impact value
ASTM	American Society for Testing and Materials
BS EN	British Standard European Norm
BS	British Standards
CCB	Crushed Clay Brick
DOE	Department of the Environment
ES	Ethiopian Standards
Kg	kilogram
kPa	kiloPascal
mm	millimeter
MPa	MegaPascal
OPC	Ordinary Portland Cement
SSD	Saturated Surface Dry
U.S.	United States
Eq.	Equation
w/c	water to cement
kN	Kilonewton

LIST OF SYMBOLS

A	Area
B	Burayu brick factory
d₁	Lateral dimension 1
d₂	Lateral dimension 2
E	Ethio brick factory
F	Maximum load
f_c	Specified characteristic strength
f_{cf}	Flexural strength
f_m	Target mean strength
G	Great wall brick factory
K	Percentage defectives permitted below the characteristic strength
K_w	Coefficient of water permeability
L	Thickness of penetrated section
M	Margin
N	Nicola brick factory
ΔP	Pressure head
Q	Volume of water flowing
R	Reference mix
S	Standard deviation
T	Time

CHAPTER ONE - INTRODUCTION

1.1 Background

Concrete is one of the most widely used construction material basically made up of coarse aggregate, fine aggregate, cement and water [1]. As the aggregates make up 60-80% by volume of concrete, they are needed in bulk. But there is a disadvantage of using natural aggregates extensively as the quarrying and crushing processes are hazardous to the environment and the natural resources will also be depleted. For instance, crushed basalt stones used as coarse aggregates are obtained from naturally existing rocks through quarry and crushing [2].

Clay brick is one of the oldest and most popular construction material because of its durability, aesthetics, and ease to handle. Clay bricks are used for both exterior and interior walls, piers, footings, and other load-bearing structures [3]. These days, clay bricks are produced worldwide by using different production technologies. However substantial proportions of bricks produced get distorted, damaged, over or under burned and it is stocked up as a waste material [4].

One way of using waste materials in sustainable way is utilizing the materials in construction materials such as concrete. Different research studies have focused on replacing natural materials in concrete with waste products. In doing so, the environmental impact caused by using natural resources will be reduced significantly [5].

1.2 Statement of the problem

Natural aggregate consists of up to 80% of the volume of concrete where the coarse aggregate makes up 60-70% by volume [6]. Given the increasing depletion of natural aggregates, the concrete industry needs to have alternative sources from locally available aggregates [7].

Due to high urbanization in the main cities of Ethiopia and the growing demand of infrastructures, the production of coarse aggregate has been increasing for the last three decades [8]. The impact of increased production of coarse aggregate is seen on the destabilization of the landscape, pollution of water and atmosphere as coarse aggregates are produced by quarrying and crushing large mass of natural parent rocks [8].

Studies show that crushed aggregate from clay brick may be used to produce normal strength concrete with reduced weight in comparison to natural aggregate concrete [7]. Therefore the waste clay bricks obtained from brick factories found in and around Addis Ababa can be used to replace the natural coarse aggregate as it is the dominant constituent material in concrete production.

1.3 Objective

1.3.1 General Objective

The general objective of this research is to study the effect of using crushed clay bricks obtained from different brick factories in and around Addis Ababa as partial replacement of coarse aggregate in normal strength concrete.

1.3.2 Specific Objective

The research will have the following specific objectives:

1. To evaluate and compare the effect clay bricks of different brick factories have on slump, hardened density, compressive strength, flexural strength and water penetration depth of concrete when used in varying amount.
2. To find the best replacement percentage of clay brick that considers both the minimum strength requirement and cost.
3. To compare cost of concrete produced with and without crushed clay brick.

1.4 Scope and limitations of the study

The research is limited on studying the effect that is observed when using waste crushed clay bricks obtained from factories in and around Addis Ababa as a replacement of coarse aggregate. The clay bricks were obtained from four different brick factories. The 28th day characteristics cube compressive strength of the control mix is limited to 25 MPa which is the minimum range of normal strength concrete [9]. To evaluate the workability, strength and durability of concrete; slump test on the fresh concrete whereas density, compressive strength, flexural strength and water penetration depth test on the hardened concrete are conducted.

1.5 Significance of the study

The study is believed to contribute a new knowledge area on the effect of using waste clay bricks from brick factories in and around Addis Ababa in concrete as coarse aggregate. In doing so, it contributes its part in a sustainable use of the waste brick products from the brick factories. It also plays its part in alleviating the increasing usage of natural crushed basaltic coarse aggregate in concrete production and serve an alternative coarse aggregate material.

1.6 Thesis Organization

The thesis report is organized into five chapters.

Chapter one is the introduction part of the thesis that provides the background of the study, problem statement, objective, scope and limitations of the study and its significance.

Chapter two presents the literature review. Different literature works that are related with the thesis topic area are summarized in this chapter.

Chapter three deals with the methods and material characterization. It includes the experimental design and the results of the different tests carried out on the constituents of concrete including the preparation, chemical and physical properties of the waste clay brick. The mix design for the proportion of the concrete constituents is also included in this chapter.

Chapter four provides the test results conducted on the fresh and hardened concrete and the discussion and interpretation of those results. Slump test, compressive strength, flexural strength, density and water penetration test results are presented and discussed in this chapter.

Chapter five outlines the conclusions for the findings of the study and gives recommendation for further investigation on the study area.

CHAPTER TWO - LITERATURE REVIEW

2.1 Introduction

Clay is a geologic natural material which is mainly made up of fine-grained minerals. The mineral behave in such a way that, when exposed to water, it comes in to a plastic state, and when exposed to drying or firing it will harden [10].

Clay bricks have always been one of the widely used construction materials in the construction industry. The use of dried clay bricks was recorded as far back as 8000 BC, while fired clay bricks were used as early as 4500 BC [4]. Clay bricks are produced in large amount throughout the world and the demand for them is expected to continuously rise. Nowadays, advanced production technology is employed in producing these clay bricks. Nevertheless, significant proportion of bricks get distorted, damaged, broken, under or over burned [4].

In earlier times of construction, these waste clay bricks were used as concrete aggregate in crushed form [11]. 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 [12].

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., [11] 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 [11].

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].

2.2 Properties concrete

Concrete is mainly made up of aggregates and paste. The aggregates in turn can be comprised of sand and crushed stone. The paste, on the other hand is made up of cement and water. The aggregates stick together with the paste to form a rocklike structure when the paste hardens as a result of the hydration reaction between the water and cement [9].

Concrete is one of the most widely used construction material in the world. Concrete is used for many different construction works, such as buildings, dams, pavements, and bridges much more than any other construction materials [13]. The main properties of concrete which are workability, density, strength, and durability are discussed subsequently.

2.2.1 Workability of Concrete

The ACI definition of workability, given in ACI 116R-90 [14], is “that property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated, and finished.”

ASTM C125 [15] defines workability as “the property determining the effort required to manipulate freshly mixed quantity of concrete with minimum loss of homogeneity.”

Workability is a property of concrete at the fresh state; however, this property also plays a crucial role in the compaction of concrete to the maximum density possible with respect to a given working condition. This proper compaction of concrete greatly reduces the voids that can be formed within and let the concrete achieve the desired strength. The presence of voids in concrete significantly reduces its strength. For instance, the presence of 5 percent of voids can lower strength by as much as 30 percent, and even 2 percent voids can cause in a strength reduction of more than 10 percent [16].

The workability of concrete depends on numerous interrelated factors: water content, aggregate type and grading, aggregate/cement ratio, and presence of admixtures. The chief factor is the water content, as the water in the mix increases, the lubrication between the concrete particles also increases. As for the aggregate type and grading; the finer the aggregates get, their surface area will also increase. This will require more water to wet the aggregates. Angular aggregates with irregular shape and rough texture require more water than the rounded aggregates. For a given constant water/cement ratio, the workability increases as the aggregate/cement ratio decreases. This is due to the fact that the amount of water relative to the total surface of solids is increased [17].

2.2.2 Density of Concrete

Normal weight concrete used for conventional structure works has a density between 2200 and 2400 kg/m³. The density of concrete is mainly affected by the density of the aggregate, the amount of entrapped or entrained air, and the water and cement contents, which in turn are influenced by the maximum size of aggregate used. For instance, when the amount of cement paste content is decreased or when the aggregate volume is increased, the concrete's density will increase [9].

Concrete other than the normal weight concrete with varying density can be produced by using aggregates of different unit weight. For instance, ultra-lightweight concrete is one type of concrete with a bulk density that ranges between 800 and 1100 kg/m³, which can only be used for nonstructural members such as partition walls. This type of concrete is produced with aggregates which have a unit weight of less than 500 kg/m³. Lightweight concrete is another type of concrete that can be produced by using aggregates which have unit weights between 500 and 1120 kg/m³. The concrete made of lightweight aggregate has a bulk density between 1200 and 1800 kg/m³ which can either be used for a structural or nonstructural member, depending on the type of aggregate used. If the unit weight of aggregate used is greater than 2100 kg/m³, the aggregate is categorized as heavy-weight aggregate. The concrete produced with such aggregates will have a bulk density between 3200 and 4000 kg/m³. This kind of concrete is used for dangerous radiation shields in hospitals and nuclear plants [13].

2.2.3 Strength of Concrete

Compressive strength, which is the most common measure of concrete strength, may be defined as the measured maximum resistance of a concrete specimen to axial loading. The compressive strength of a concrete is mainly affected by the water-cement ratio, curing conditions, and the age of the concrete. The strength of concrete increases as the water-cement ratio decreases and vice versa. With proper curing of concrete, the strength increases rapidly at early ages and slowly afterwards for an indefinite time. The 28-days compressive strength of concrete, determined by a standard uniaxial compression test, is commonly used in different designs of structures [9].

The compressive strength that is measured can be affected by the loading rate. For a cube specimen, the British Standard Institution sets 0.2 – 0.4 MPa/sec as the standard loading rate. Due to the end restraint caused by the friction between the ends of the concrete specimen and the testing machine plate, an apparently higher compressive strength than the true strength of the specimen may be obtained. As for the size effect, smaller size specimens will give higher apparent compressive strengths because of the low probability for having large deficiencies, such as void and crack, which increases with size [13].

The flexural strength or modulus of rupture of concrete is another type of strength measurement that can be used in designing pavements and other slabs on ground. In this test, an unreinforced concrete beam will be subjected to a two-point symmetrical flexure loading to the point of failure. The two loads are set apart at one-third of the span of the beam; hence it is called a third-point loading test. The theoretical maximum tensile stress reached in the bottom fiber of the test beam is known as the modulus of rupture. British Standard BS EN12390-5: 2000 recommends third-point loading test on 150 by 150 by 750 mm beams supported over a span of 450mm but 100 by 100mm beams can also be used [16].

2.2.4 Durability of concrete

The durability of concrete can be defined as the extent to which a given concrete can resist different actions such as weathering actions, chemical attack and abrasion without affecting the needed engineering properties [6]. The durability of concrete is affected by its permeability since this permeability controls the degree to which moisture along with aggressive chemical enters concrete [18]. Permeability can indicate the amount of water that goes through concrete when water is applied by pressure. A concrete with a good ability to resist the ingress of liquid, gases and ions into the concrete has very less permeability [9].

The water permeability of concrete can be influenced by; the permeability and gradation of the aggregate, the permeability of the cement paste itself, the quality of the paste and aggregate transition zone and the proportion of paste to aggregate [9].

Water is among one of the main liquid that penetrate through concrete. Therefore if the permeability of concrete to water can be improved, the durability will also be improved.

Water permeability of concrete can be evaluated in the laboratory under steady state and non-steady state condition [6].

a) Steady state condition

In this condition of evaluating water permeability, water is allowed to move across the concrete specimen until steady state flow is reached. This can be attained by subjecting the specimen to specific pressures then recording the penetrated water until constant flow of water is attained. Then coefficient of permeability which shows the degree of ease for a liquid to move through the concrete specimen is calculated using Darcy's law as shown in Eq. 2.1 [19].

$$K_w = \frac{Q}{t} \cdot \frac{l}{A} \cdot \frac{1}{\Delta P} \quad (\text{Eq. 2.1})$$

Where K_w = coefficient of water permeability (m/s)
 Q = volume of water flowing (m³)
 t = time (s)
 l = thickness of penetrated section (m)
 A = penetrated area (m²)
 ΔP = pressure head (m)

b) Non-steady state condition

In this case, the depth of water penetration is measured without necessarily achieving a constant flow of water. According to the BS EN 12390-8:2000, “depth of penetration of water under pressure”, the concrete specimen which is to be at least 28 days of age shall be exposed to a water pressure of 500 ±50 kPa for a period of 72 ±2 hour. At the end of the 72 hours period, the specimens are removed from the test apparatus and split in to two halves. Then the maximum depth of penetration are visually observed and then measured and recorded to the nearest millimeters [20].

2.3 Components of Concrete

2.3.1 Cement

Cement has a property of setting and hardening when coming in to contact with water by a means of chemical reaction. 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 [16].

Portland cement is the most common type which is produced by crushing clinker which consists primarily of hydraulic calcium silicates. There are different types of Portland cement that are manufactured to meet various requirements for specific purposes. Type I Portland cement is a versatile cement type suitable for all uses where special requirements are not needed [9]. Type II cement is for general use especially when moderate sulphate resistance is needed. Whereas Type III cement type is used when high early strength is desired. Type IV is used when low heat of hydration is needed and Type V cement is used when high sulphate resistance is desired [21].

2.3.2 Aggregates

Aggregates can be defined as granular materials that can be crushed stone, gravel or sand that can be used with cement to form concrete or mortar [15].

Since up to 80% of the volume of concrete is occupied by aggregate, the type and quality used is of great importance. The aggregate used in concrete influences the strength of concrete produced. Additionally, aggregates which have adverse properties can affect the durability of concrete. Therefore aggregates have a huge factor in both the structural and durability performance of concrete [16].

In terms of material cost, aggregates are cheaper than cement. Therefore, it would be economical to put as much aggregates as possible into the mix and as little cement as possible. But economy is not merely the reason for using aggregates in concrete. Aggregates have substantial advantages in giving a higher volume stability and better durability when compared with cement paste alone. [16]

2.3.2.1 Classification of Aggregates

Concrete aggregates can be classified mainly based on their origin and physical characteristics such as particle size and bulk density. In terms of their origin, rocks are classified into three main groups namely igneous, sedimentary and metamorphic [22].

Based on their physical characteristics such as particle size, aggregates are mainly classified as coarse aggregates which usually have particle size of greater than 4.75 mm and fine aggregates with a particle size equal or less than 4.75 mm. Regarding density, aggregates are classified as lightweight, normal weight and heavy weight with a bulk density range of less than 1120 kg/m^3 , $1500\text{--}1700 \text{ kg/m}^3$ and greater than 2000 kg/m^3 respectively [22].

Lightweight aggregates can be obtained from natural resources or they can be synthetic, industrial by products and waste materials. Volcanic materials are the main natural resources for lightweight aggregates. Manmade aggregates on the other hand are produced by different processes in factories. These obtained lightweight aggregates can have a unit weight ranging from 50 kg/m^3 up to 1000 kg/m^3 . They are used in a wide range for the production of concrete and mortars. The property of concrete produced is associated to the properties of the aggregates used for the production. Again the properties of aggregates depends upon the type of material and the process used for producing them [23].

2.3.2.2 Physical properties of Aggregates

The origin of an aggregate has a huge factor on the properties of aggregates such as the mineral composition, hardness, and pore structure. The properties of these aggregates used in concrete production have effect on the quality and property of the fresh and hardened concrete produced [16].

i) Particle shape and surface texture

The shape characteristics of coarse aggregates has considerable effect on the properties of fresh and hardened concrete [24]. 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 [3].

Surface texture of aggregates can affect the surface frictional property in a concrete mix. Consequently, it influences concrete workability and water requirement with a lesser extent from that of the shape effect. Rougher texture aggregates improve the bond between aggregates and cement paste [22].

ii) Grading of Aggregates

Grading is the particle size distribution of aggregates that determines the paste requirement for a workable concrete since the amount of voids among aggregate particles requires the same amount of cement paste to fill out in the concrete mixture. Sieve analysis is required to obtain a grading curve for an aggregate [13].

If all of the particles in an aggregate are the same size, the compacted mass will have more voids, whereas an aggregate with a variety of particle sizes will have a mass with fewer voids. A mass of aggregate should have a particle size distribution in which the smaller particles fill the spaces between the bigger particles. Because good aggregate grading generates dense concrete that requires less fine aggregate and cement waste, it is critical that aggregates be well graded in order to make high-quality concrete [25].

If there are grading variations from batch to batch, the uniformity of the concrete produced will be greatly affected. Using very fine sands often leads to uneconomical mix and using very coarse aggregates can produce unworkable mixes. Generally, using aggregates that do not contain excess grading sizes or have aggregates that do not have a huge deficiency of any size gives a smooth grading curve that in turn produces suitable concrete mixtures [9].

iii) Moisture Content of Aggregates

There are four different moisture conditions in which aggregates usually attain. The first one is an oven dry condition where the aggregate loses the evaporable water within when it is exposed to a temperature between 100 and 110 °C. The second condition is an air dry condition where the aggregates are dry and balanced to the surrounding air and some internal moisture is taken by the aggregates. The third condition is a saturated surface dry (SSD) condition, where the aggregates contain water to the point of full saturation but there is no excess moisture on the surface. The fourth condition is a wet condition in which the aggregates are fully saturated and contain excess moisture on the surface. 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. From the four moisture conditions, the most useful state is the saturated surface dry condition. 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 [22].

iv) Strength of Aggregates

The test for strength of aggregates is not done often as it does not have much effect on the strength of normal weight conventional concrete. More than the strength of aggregates, the strength of the paste and the paste-aggregate bond has much effect on the strength of concrete produced. Nevertheless, the strength of aggregates becomes important in lightweight and high-strength concrete. [9].

v) Porosity and Absorption of Aggregates

Porosity of aggregates refers to the proportion of the volume of internal pores to the total volume of the solid matter [22]. The porosity, permeability, and absorption of aggregate have an impact on the bond between it and the cement paste, as well as the freezing and thawing resistance of concrete, chemical stability, abrasion resistance, and specific gravity. Aggregate pores come in a variety of sizes, but even the tiniest ones are larger than the gel pores in cement paste. 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 [17].

Absorption can easily be measured by making an aggregate in an oven-dry condition and then by letting it absorb water by immersion to achieve a saturated-surface-dry condition. 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 [22].

The absorption of water by lightweight aggregates is substantial in producing concrete due to the high porosity and absorption capacity of the aggregates. It is therefore appropriate to prevent such absorption during the process of concrete production. It is reasonable to soak aggregates with high absorption capacity before mixing [23].

vi) Bulk Density

The bulk density or unit weight of an aggregate is the ratio of the mass required to fill a given container to that of the specified unit volume of the container. The volume includes both that is occupied by aggregates and the voids between aggregate particles [9].

The bulk density evidently depends on how densely the aggregates are packed. This, in turn, is affected by the size distribution and shape of the aggregate particles for a material of given specific gravity. If the size distributions of the aggregate particles are of only one size, then the aggregates can only be packed to some degree. To increase the degree in which the aggregates are packed or to increase the bulk density of the aggregates, smaller particles can be added in the voids that are formed by the same large aggregate particles. If a coarse aggregate with a given specific gravity has a higher bulk density, then that means there are fewer voids to be filled with cement and fine aggregate [16].

2.3.3 Water

The main considerations on the quality of mixing water are related to the performance of concrete in fresh and hardened state [26]. The quality of mixing water in concrete is significant since it can alter setting time and strength of concrete. Almost all natural waters, fresh waters, and municipally treated waters are suitable for use as concrete mixing water if they have no discernible odor or flavor [27]. The presence of impurities in water may interfere with the setting of the cement, strength and durability of concrete [26].

2.4 Clay Brick

Clay brick is one of the most common and oldest building materials. Clay brick is easily made by firing the mix of clay soil and water at high temperature. Upon firing, the clay material is converted into a hard solid material that can be used as building material [28].

Clay brick is regarded as waste material when it has become a surplus material from different construction works and when it is rejected in the manufacturing process by being under standard or broken [12]. These waste clay bricks have to be reused in order to prevent the waste of potentially useful materials and to eliminate it from the waste stream in an environmentally friendly way [29].

2.4.1 Clay Brick Production Process

Basically, bricks are produced by mixing grounded clay with water, and forming the clay into the desired shape, then drying and firing. Even though individual manufacturing plants adapt their production method to fit their particular raw materials and operation, the basic principles of manufacturing are fairly uniform. The basic phases of brick manufacturing are; mining of raw materials, preparing raw materials, mixing and forming the brick, drying, firing and cooling [30].

i) Mining of raw materials

Usually brick factories are located in close proximity to a raw material quarry site. However, some clay soil variations could be sourced from other quarries to facilitate the production of a wide range of colors and technical characteristics. The equipment used to mine clay varies depending on the type of clay being extracted. Excavators are the machines most commonly used and are generally operated in combination with dump trucks [31].

ii) Preparing of raw materials

The preparation process involves stockpiling, crushing, grinding, screening of the raw materials. Jaw crushers are commonly used to reduce material size from one meter to a few millimeters in diameter during primary crushing. Secondary crushing, which reduces particle size to 3 mm or below, is done by rotating pan crushers, smooth roll crushers, and hammer mills. Screening is typically carried out on multiple vibrating deck screens [32].

iii) Mixing and forming the brick

In the forming and mixing phase, three primary processes are used. The clay is combined with water to make it plastic, then driven through a die that extrudes a column of clay like toothpaste squeezed from a tube in the stiff-mud technique. In the dry-pressing technique, clays with a low plasticity are used. The material is placed in steel molds with a minimum of water injected, and pressures up to 10,000 kilopascals are applied [33].

iv) Drying, firing and cooling the brick

Wet bricks from molding machines can contain 7 up to 30 percent moisture, depending upon the forming method. Before the firing process begins, most of this water is

evaporated in dryer chambers at temperatures from 38 °C to 204 °C. The extent of drying time, which varies with different clays, usually is between 24 to 48 hours [30].

During the firing process, the dried clay bricks are heated to a high temperature. The temperature of firing should normally be more than 930°C and the extent of firing depends on both time and temperature. The inter-particulate bond, strengths, pore structure, and color of the clay bricks are all developed during the firing process. The amount of time spent firing should be sufficient to achieve the degree of those qualities specified by the product's specifications [28]. After the firing temperature has peaked and is maintained for the prescribed time, the cooling process begins. This is an important stage in brick manufacturing because the rate of cooling has a direct effect on color [30].

2.4.2 Types of Clay Bricks

Clay bricks can be classified based on techniques of production and shape. According to the techniques of production, clay bricks are generally classified into two types: sun-dried (unfired) and burnt (fired) clay bricks. Unfired bricks are type of bricks that are molded and are left to the open air to dry. On the other hand, burnt bricks are molded and are fired to high temperature [34].

Clay bricks can also be classified based on their shape. Accordingly, solid bricks are one of the types which are rectangular in shape and solid throughout without any holes. Perforated bricks are another type that has holes with a volume that does not exceed one fourth of the total volume of the brick. There are also frogged brick types that have depression on the face of the brick. Similar to the perforated brick types, the depression in frogged bricks should not exceed one fourth of the total volume of the brick [34].

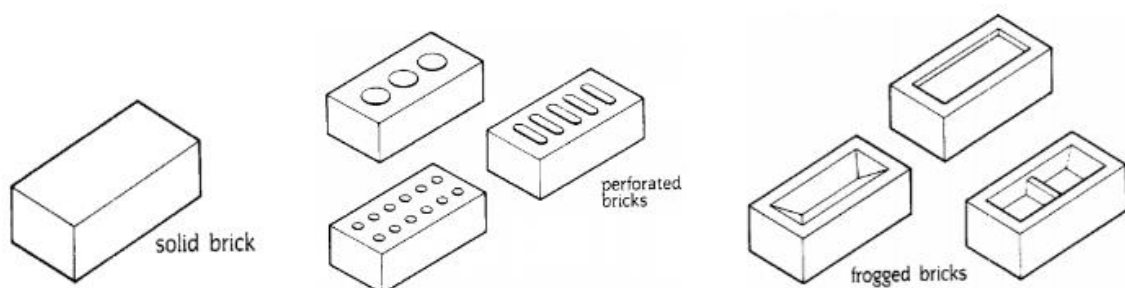


Figure 2.1 Different types of brick classified based on shape [34]

2.4.3 Chemical Composition of Clay Bricks

Clays are mostly composed of alumina and silica with different amounts of metallic oxides and other minor ingredients and impurities. Even though metallic oxides are regarded as impurities, they play a major role by serving as fluxes which facilitate fusion of clay particles at lower temperatures. The metallic oxides also influence the range of temperature in which the material consolidates, and give the required strength for burnt clay bricks so that it can be used for structural purposes. It is important to select the raw materials of clay brick carefully as the calcium, magnesium, and iron oxides that occur in varying amounts affect the color of fired clay. Additional to the careful selection, continuous testing of the raw materials should be done in the laboratory during production as the mineralogical composition of clay may vary with in a quarry when the depth of exploration increases [28].

Generally, a good brick must be hard, well burnt with 800-1100°C temperature range, uniform throughout, sound in texture and color, sharp in shape and dimension and should not break easily when struck against another brick or dropped from a height of about one meter [35].

The mineralogical compositions of a good brick raw material or clay are summarized in Table 2.1 [3]:

Table 2.1 Ingredients of a good clay brick [3]

No.	Ingredients/oxides	Proportions	Remark
1	Silica (SiO ₂)	50-60%	
2	Alumina (Al ₂ O ₃)	20-30%	
3	Lime (CaO)	< 10%	
4	Magnesia (MgO)	< 1%	The sum of these ingredients is less than 20%
5	Ferric oxide (Fe ₂ O ₃)	< 7%	
6	Alkalis (NaOH, KOH,...)	< 10%	
7	Carbon dioxide (CO ₂)		Very small percentage
8	Sulphur trioxide (SO ₃)		
9	Water (H ₂ O)		

The purposes of the different ingredients of clay bricks can be summarized as follows [3]:

Silica (SiO_2) allows the clay brick to maintain the shape and gives better durability. Additionally, silica prevents the shrinkage and distortions of clay bricks. However, the presence of high percentage of silica makes the brick weak during firing. Therefore, a large percentage of silica in clay is adverse.

Alumina (Al_2O_3) has an advantage of giving the clay its plasticity by absorbing water. The presence of alumina in higher percentage than the specified causes the clay brick to crack when it dries.

Lime (CaO) usually makes up less than 10% of clay. The presence of lime in clay brick reduces the shrinkage upon drying, lowers the fusion point when used in carbonated form and makes silica to melt and bind upon firing. On the other hand, excess lime makes the brick to melt and loses its shape.

Magnesia (MgO) only makes up to a maximum of 1% and it affects the color of the brick by giving it yellow color. It also causes the clay to soften at slow rate and reduces distortion during firing.

Iron (III) oxide (Fe_2O_3) making up less than 7% of clay, gives red color to brick during firing if excess oxygen is present. If excess oxygen is not available, a dark brown or black color can occur. It also decreases the permeability of clay and improves durability. When iron (III) oxide is present as ferrous oxide (FeO), it lowers the fusion point of the clay. Iron (III) oxide generally gives strength and hardness when available in the specified range. However, if it is present in excess, it gives the brick a dark blue color.

2.4.4 Physical properties of Clay Brick

Physical properties of clay bricks are useful to know the quality of bricks and decide whether the bricks can be used either as load bearing or non-load bearing. The main physical properties of clay bricks are; compressive strength, water absorption and saturation coefficient [36].

i) Compressive strength

Compressive strength of bricks is the resistance to compression load. It is the main property of clay bricks that affects the strength of the masonry built and is an essential

input for structural brick work design. Compressive strength can be measured in the laboratory by applying a compression load that is perpendicular to the largest face of the brick [28].

The compressive strength of a given brick shall not be less than the specified minimum strength for the respective class of brick. Common bricks have a minimum compressive strength of 3.5 MPa. For a given class of brick, the result of any single brick should not fall below the specified respective average compressive strength by a value greater than 20% [36].

ii) Water absorption

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 [28]. Water absorption is an essential factor for the durability of clay bricks, because when more water penetrates brick its durability decreases [37].

The porosity of clay bricks directly affects the tendency of water absorption. 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 [38].

iii) Saturation Coefficient

Saturation coefficient is a ratio that is used to show the relationship of two kinds of water absorption. The first one is the absorption that is determined by immersing the brick in cold water for a period of 24 hours. The second is determined by submerging the brick in boiling water for 5 hours. The ratio between the values of the two tests gives a rough indication of the vacant space in the brick to hold the expansive pressure of freezing of water. Therefore, if a brick has lower value of saturation coefficient then there is more space for the freezing pressure to be relieved. Thus the probability for the brick to be damaged is less likely [28].

2.4.5 Specifications for Clay Bricks

Standard specifications are carefully outlined documents that are used in the construction industry to assure and control the quality of materials and workmanship. Countries have

their own standard specifications for burnt clay bricks that mostly specify the physical properties such as compressive strength, water absorption and saturation coefficient [28].

In the British standard BS 3921:1985 bricks are classified based on compressive strength and water absorption. This classification of bricks is as shown in Table 2.2.

Table 2.2 Classification of bricks by compressive strength and water absorption [39]

Class	Compressive strength (N/mm ²)	Water absorption (% by mass)
Engineering A	≥ 70	≤ 4.5
Engineering B	≥ 50	≤ 7.0
Damp-proof course 1	≥ 5	≤ 4.5
Damp-proof course 2	≥ 5	≤ 7.0
All others	≥ 5	No limits

Similarly, the Ethiopian standard specification ES-86:2001 deals with compressive strength, water absorption and saturation coefficient for different classes of bricks. Table 2.3 deals with the required minimum compressive strength for a given class of brick. Similarly, maximum water absorption and saturation coefficient for the given brick classes are given in Table 2.4 and Table 2.5 respectively.

Table 2.3 Minimum compressive strength of solid clay bricks [40]

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

Table 2.4 Maximum water absorption of solid clay bricks (%) [40]

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

Table 2.5 Maximum saturation coefficients of solid clay bricks [40]

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

2.4.6 Effect of firing temperature on clay bricks

The firing temperature of clay bricks range between 800 and 1100°C depending on the nature of the clay raw material and the quality requirement of the fired brick. The quality and physical properties of fired bricks may vary within the same batch due to the variation of the temperature in the kiln. In order to get fired bricks with uniform and good quality, the firing temperature in the kiln should be as uniform as possible [41].

Over and under burnt clay bricks are the results of poor management of kiln temperature. When the firing temperature in the kiln is above the temperature range of 800-1100°C for an extended period of time, the clay will be over burnt and it will have a dark color that negatively affects the quality of the brick. On the other hand, under burnt clay bricks are fired below the temperature range of 800-1100°C which causes the brick not to develop the adequate strength and as a result the brick is easily broken [28].

Firing temperature is a crucial factor that affects the physical properties of clay bricks such as compressive strength, water absorption and density. Compressive strength of brick greatly improves when firing temperature increases because of the decrease in porosity. Similarly, water absorption of clay brick linearly decreases when firing temperature increases. The water absorption has an effect on the density of the brick as well. At high firing temperature the amount of water the brick absorbs will be less and therefore the pore sizes will be smaller. This will make the brick to have more density [42].

2.4.7 Sources of recycled clay brick

Recycled clay bricks can be obtained from two major sources. One is from construction and demolition waste and the second is from clay brick manufacturing factories. Construction and demolition wastes are the surplus material from construction activities such as demolition and new constructions. In developed countries, construction and demolition wastes are generated in hundreds of million tons annually. Even though it is

difficult to get such reliable data in developing countries, the construction and demolition waste amount could be expected to high due to the substantial infrastructural development in these countries. Recyclable fired clay bricks makes up a considerable amount in construction and demolition wastes in the European Union and US [12].

Since the discovery of the first fired bricks back in the years between 5000-4500 BC in the Mesopotamia region, fired bricks are still being manufactured and used in construction. Even though the manufacturing process has developed over the years, substantial amounts of products are rejected due to failing to conform the standards. For instance, improper firing of clay bricks may produce under burnt, over burnt or distorted bricks that do not meet the standard requirements [12].

In a typical technologically advanced brick factory found in the United States of America, the rejected fired material makes up 3% of the total production. Similarly, this figure is between 2-5% in some European countries. This percentage is expected to be higher in developing countries because of the low efficiency of the brick factories [43].

For example, the rejected material that is treated as waste in a single brick factory of Bangladesh is 10-15% of the total production stock. From these waste fired products, few are recycled to manufacturing process as an input of raw material to produce an inferior quality brick usually named clinker brick where the majority is dumped [44]. But fine waste clay bricks can be reused up to a certain percentage, which is determined after conducting test results, as a raw material to produce clay bricks [45].

2.4.8 Crushed clay brick as concrete aggregate

The systematic investigations on the use of crushed brick aggregate in concrete started in the year 1928. Nevertheless, the first major practical application of crushed brick aggregate started after the Second World War in Germany. After the war, the cities in Germany were ruined and changed in to pile of debris. Nearly 11.5 million cubic meters of crushed brick aggregate from the debris were used to build 175,000 dwellings. The reuse of the crushed brick aggregate had two advantages. The first was removing the masonry debris and the second was serving as an input for new construction. In the decades before this time the research on crushed brick aggregate was slow. However the research interest for recycling increased in the first decade of the 21st century. The reason for this was a

new intention for sustainability i.e. the construction industry was trying to reduce the effect of wastes on the environment and to prevent the depletion of natural resources [12].

The study of brick aggregate in concrete mostly involves the use of crushed brick as coarse aggregate. The physical property of the concrete produced with crushed brick depends on the characteristic of the parent brick. For instance, the unit weight of concrete decreases when it is produced with brick aggregate of high porosity. Again, the water demand of the concrete mix increases when the water absorption of the brick aggregate is high. For a given water to cement ratio, concrete produced with brick aggregate of higher strength, will also attain higher strength. The unit weight of concrete produced with brick aggregates will be reduced. The reason is that, brick has high porosity in nature and the bulk density of brick aggregate lies in between light weight and normal weight aggregate [12].

2.5 Literature summary and gap identification

The reuse of wastes from factories and construction works including crushed clay bricks has a positive contribution to the environment. Clay brick can be used as both coarse and fine aggregate to produce concrete with reduced density [46].

According to a study by Kareem et al. [46] that aimed to investigate the mechanical properties of structural lightweight concrete produced with replacement of both coarse and fine aggregate with crushed clay brick, the results showed that lightweight concrete with lower modulus of elasticity and strength and higher permeability can be produced by using crushed clay brick as coarse and fine aggregate.

Another study by Ahmed et al. [7] conducted a test on slump, compressive strength, density and water absorption properties of structural lightweight concrete produced by partial replacement of both the coarse and fine aggregate with yellow and/or red crushed clay brick (CCB) aggregate. The results of the research indicated the possible production of lightweight crushed clay brick aggregate concrete that is fit for structural applications.

Yet another study by Assefa et.al [47] investigated the properties of brick waste as coarse aggregate material in concrete around Jimma, Ethiopia area. The bricks under consideration were three types. The first one was collected from a demolished building that are eighteen years old age. The second type of brick was that which is broken on

production site and the third type of brick was that which is broken due to poor handling and transportation at vendors' hand. The findings from this research showed that the characteristics of brick around Jimma exhibits high moisture content and water absorption. Additionally the bricks show larger crushing and impact value which limits its usage in pavement works and highly reinforced structure. As for the hardened property of the concrete, the waste brick can be used as an aggregate replacement from 20-25% to produce a C-25 concrete. However if the desired concrete grade is less than C-25, the possible percentage replacement can increase.

The researches thus far showed that concrete with acceptable mechanical properties can be produced using crushed brick, mostly, as coarse aggregate [12]. Firing temperature is a crucial factor that affects the physical properties of clay bricks such as compressive strength, water absorption and density [42]. The properties of the aggregates used in concrete production have effect on the quality and property of the fresh and hardened concrete produced [16]. According to the conclusion of a research study by Tadesse [28] the brick factories found in and around Addis Ababa have no temperature sensor device to determine the kiln's firing temperature. The firing temperature is determined by the kiln operator in each brick factory. Therefore the firing temperature of the kiln varies from one brick factory to another. As a result the physical properties of the produced and waste bricks also vary. The effect of using these waste crushed bricks from the different factories in and around Addis Ababa as a replacement of coarse aggregate in producing concrete is yet not known. Therefore based on this gap, this research aims to study the possibility and the effect of using waste crushed clay bricks sourced from different brick factories in and around Addis Ababa as a coarse aggregate replacement to produce concrete.

CHAPTER THREE - MATERIALS AND METHODS

3.1 Introduction

The aim of this research is to study the effect of using waste crushed clay bricks obtained from different brick factories in and around Addis Ababa as partial replacement of coarse aggregate in normal strength concrete production.

The research is conducted through laboratory experimental works by replacing the crushed basaltic coarse aggregate of a reference concrete mix with crushed clay bricks by an amount of 10, 20, 30, 40 and 100% by volume.

The experimental study includes material characterization, mix design proportioning, concrete specimens preparation and conducting laboratory tests on the fresh and hardened concrete. On the fresh concrete, slump test was conducted. On the hardened concrete; density, compressive strength, flexural strength and water penetration tests were conducted.

All the laboratory works of the experimental study were conducted in Addis Ababa institution of Technology Construction Materials Laboratory except the chemical composition analysis test of the clay bricks, which was conducted in the Geochemical laboratory of Geological Survey of Ethiopia.

3.2 Materials

3.2.1 Cement

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

3.2.2 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 Langan area.

3.2.2.1 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% [48]. 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 [48].

The silt content of the sand was tested and it was found to be 3.33%, which is within the acceptable limit.

3.2.2.2 Gradation of fine aggregate

The sieve analysis for the fine aggregate was conducted and the result obtained is shown in Table 3.1 along with the grading requirement of the Ethiopian Standard, ES C.D3.201.

Table 3.1 Fine aggregate gradation

Sieve Size	Weight Retained (gm.)	Percent Retained (%)	Percent Passing (%)	Cumulative Percent Retained (%)	Percent passing per ES C D3.201
4.75 mm	0	0	100	0	95-100
2.36 mm	15.3	3.1	96.9	3.1	80-100
1.18 mm	72.7	14.6	82.4	17.6	50-85
600 µm	156.5	31.4	51.0	49.0	25-60
300 µm	179.6	36.0	15.0	85.0	10-30
150 µm	57.3	11.5	3.5	96.5	2-10
Pan	17.6	3.5	0.0	-	
Total	499			251.2	

$$\begin{aligned} \text{Fineness Modulus} &= \frac{\Sigma \text{Cumulative Retained (\%)}}{100} \\ &= \frac{251.2}{100} = 2.51 \end{aligned}$$

3.2.2.3 Unit weight, specific gravity, moisture content and absorption capacity of fine aggregate

The test results for the unit weight, specific gravity, moisture content and absorption capacity of the fine aggregate is summarized in Table 3.2.

Table 3.2 Summary of test results on fine aggregates

Bulk SSD specific gravity	Unit Weight (Kg/m ³)		Moisture Content (%)	Absorption Capacity (%)
	Loose	Compacted		
2.09	1230	1310	1.05	1.19

3.2.3 Coarse aggregate

3.2.3.1 Gradation of coarse aggregate

The sieve analysis for the coarse aggregate was conducted and the result obtained is shown below in Table 3.3 along with the grading requirement of the Ethiopian Standard, ES C.D3.201.

Table 3.3 Coarse Aggregate Gradation

Sieve Size (mm)	Weight Retained (gm.)	Percent Retained (%)	Percent Passing (%)	Cumulative Percent Retained (%)	Percent passing per ES C D3.201
37.5	0	0.0	100	0.0	100
19.0	91	4.6	95.4	4.6	95-100
12.5	573.2	28.7	66.8	33.2	
9.5	594.1	29.7	37.1	62.9	25-55
4.75	733.1	36.7	0.4	99.6	0-10
Pan	8.1	0.4	0.0	100.0	
Total	1999.5			300.3	

3.2.3.2 Unit weight, specific gravity, moisture content and absorption capacity of coarse aggregate

The test results for the unit weight, specific gravity, moisture content and absorption capacity of the coarse aggregate is summarized in Table 3.4.

Table 3.4 Summary of test results on coarse aggregates

Bulk SSD specific gravity	Unit Weight (Kg/m ³)		Moisture Content (%)	Absorption Capacity (%)
	Loose	Compacted		
2.85	1510	1590	0.94	1.76

3.2.4 Water

For concrete mixing and curing of specimens, drinkable tap water supplied in Addis Ababa institute of Technology campus was used.

3.2.5 Crushed Clay Brick

The crushed clay bricks used in this experimental study were collected from four different brick manufacturing factories found in and around Addis Ababa. The four brick factories are selected based on production capacity and location. There are six available brick factories found in and around Addis Ababa [28]. Among the six factories, four of them are located around Addis Ababa and the rest two are located in Addis Ababa. From the four brick factories located around Addis Ababa, three of them that have the highest production capacity were selected. From the remaining two brick factories located in Addis Ababa, one brick factory with higher production capacity was selected.

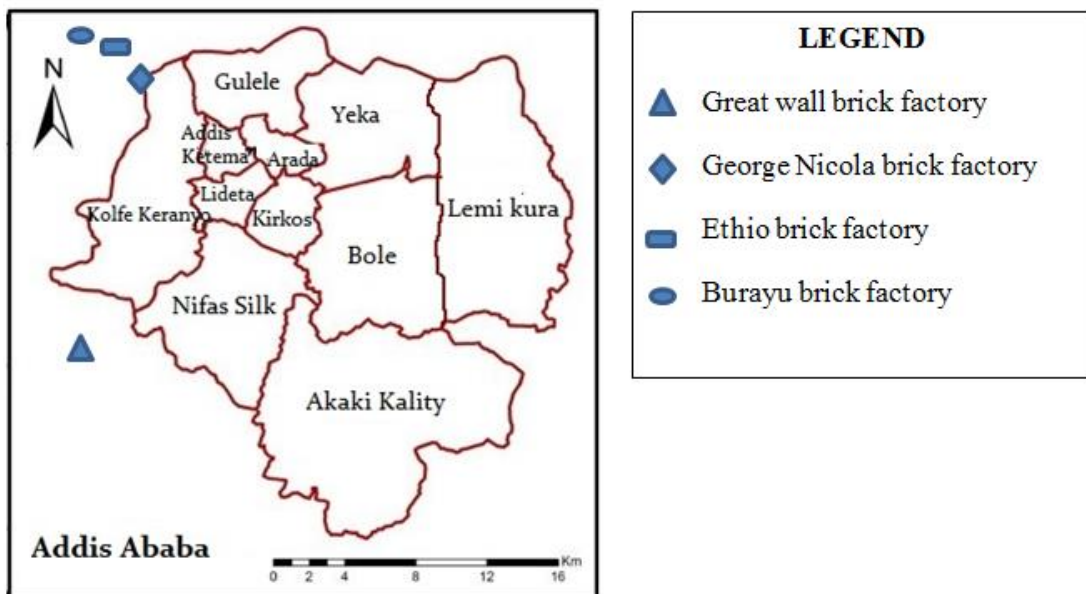


Figure 3.1 Selected brick factories location

The bricks were sampled from the factories' waste stock piles randomly from the top, middle, and bottom of the stock pile so as to collect a representative sample. Bricks that were visually discolored to black color due to over burning were not used for the experimental study so as to study their effect separately. The four brick factories from which the waste crushed clay bricks were obtained are listed in Table 3.5 along with the owner, location and annual production capacity of the factories. Brick waste pile in Ethio brick factory is shown in Figure 3.2.

Table 3.5 Selected brick factories in and around Addis Ababa

No.	Name of factory	Owner	Location	Present annual burnt clay production (pcs)
1	Great Wall Brick Factory	Private Chinese company	Along the asphalt road from Addis Ababa to Jimma at a place called Alemgena town.	18,000,000
2	Burayu Brick Factory	Brick Products processing S.C	At Burayu town along the road from Asco to Ambo	6,350,000
3	Ethio Brick Factory	Brick Products processing S.C	Midway along the asphalt road from Asco to Burayu at a place called Keta.	5,100,000
4	George Nicola Brick Factory	Private domestic company	Along the road from Winget roundabout to Asco at a place called Birchiqo	2,500,000



Figure 3.2 Piles of waste brick in Ethio brick factory

3.2.5.1 Chemical composition of crushed clay brick

Chemical composition analysis was done for the crushed clay bricks collected from the four brick factories to evaluate the chemical composition of the clay bricks and to test the existence of reactive elements such as chlorides and sulfates in the Geochemical laboratory of the Geological Survey of Ethiopia. The results are summarized in Table 3.6.

Table 3.6 Chemical composition test result for normal clay brick

Element names	Oxide contents (%)				Acceptable range
	Burayu	Ethio	Great wall	Nicola	
SiO ₂	65.50	61.72	61.60	58.70	50-60%
Al ₂ O ₃	20.64	20.84	25.58	24.10	20-30%
Fe ₂ O ₃	8.56	8.08	7.92	9.16	<7%
CaO	<0.01	<0.01	<0.01	<0.01	<10%
MgO	<0.01	<0.01	<0.01	<0.01	<1%
Na ₂ O	<0.01	1.76	1.40	0.88	Very small percentage
K ₂ O	<0.01	<0.01	<0.01	<0.01	
MnO	0.16	0.12	0.12	0.08	
P ₂ O ₅	0.20	1.60	0.75	0.66	
TiO ₂	0.37	0.37	0.39	0.38	
H ₂ O	0.49	0.96	0.42	1.79	
LoI	2.59	3.17	0.69	2.60	-
SO ₃	0.44	0.39	0.20	0.08	-
Cl ⁻¹	<0.01	<0.01	<0.01	<0.01	-

The silica (SiO_2) content of the brick from George Nicola factory is between the 50-60% ranges. The rest three are a little above this range. The alumina (Al_2O_3) content of all the brick types is within the 20-30% range. The ferric oxide (Fe_2O_3) for all brick types are slightly above 7% but for a good clay brick, the ferric oxide (Fe_2O_3) content is usually recommended less than 7%. The lime (CaO) for all four types of brick is below 0.01% and as given in table 2.1 the lime content for a good clay brick is up to 10%. The lime content for all four types of bricks is very small and insignificant. This shows all brick types 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 [49], all brick types have an LoI value less than 5% as specified in ASTM C330-99 [50]. Among the four types of brick, the brick obtained from the Great wall brick factory has the lowest loss on ignition.

Additional to the complete silicate analysis test, the existence of chloride (Cl^-) and Sulphur trioxide (SO_3) were tested because aggregates that contain such compounds known to react chemically with Portland cement producing volume instability and interfere with the normal hydration of cement can be harmful to concrete [9].

BS 3797:1996 recommends the Sulphur trioxide (SO_3) content to not be more than 1.0% [51]. All the brick types have sulphur trioxide (SO_3) content less than 1.0%. The chloride content is also negligible in all the four brick types.

To examine the possible differences that exist between the normal and the over burnt black clay brick, chemical composition analysis was also conducted on an over burnt clay brick sourced from Ethio brick factory. The result for the analysis is as presented in Table 3.7.

Table 3.7 Chemical composition test result for over burnt clay brick

Element names	Oxide contents (%)
SiO_2	61.26
Al_2O_3	28.42
Fe_2O_3	7.24
CaO	0.46
MgO	0.40

Element names	Oxide contents (%)
Na ₂ O	1.02
K ₂ O	1.24
MnO	0.06
P ₂ O ₅	0.16
TiO ₂	0.48
H ₂ O	0.31
LoI	0.01

According to the result presented in Table 3.7, the oxide contents of the over burnt clay brick is within similar ranges with that of the normal clay bricks presented in Table 3.6. However, the loss on ignition which is a measure of total volatiles in a material, has a much lower value.

3.2.5.2 Preparation of crushed clay brick

The same procedure was used to prepare all the four types of CCB coarse aggregates used for this experimental study. Enough amount of waste clay bricks to produce all the concrete mixes for the study were collected from each brick factories. The clay bricks were in the size as shown in Figure 3.3 when obtained from the factories' waste stock piles.



Figure 3.3 As received size of clay bricks from waste pile

The clay bricks were then slightly reduced in to smaller sizes as shown in Figure 3.4 manually using a steel hammer so as to fit it in the jaw crusher machine used.



Figure 3.4 Size of manually crushed clay brick

The jaw crusher machine used is as shown in Figure 3.5. The machine was located in the laboratory of Addis Ababa Institute of Technology, School of Chemical and Bio Engineering.



Figure 3.5 Jaw crusher used to crush clay bricks

The reduced sizes of the clay bricks were fed in to the jaw crusher and the output clay bricks were of different sieve sizes; therefore it was sieved and separated in to sieve sizes similar to the gradation of the crushed basaltic coarse aggregate as shown in Figure 3.6.



Figure 3.6 Crushed clay bricks retained on different sieve sizes

3.2.5.3 Unit weight, specific gravity and absorption capacity of CCB coarse aggregate

The test results of the unit weight, specific gravity and absorption capacity of the CCB coarse aggregate are summarized in Table 3.8.

Table 3.8 Summary of test results on CCB coarse aggregate

CCB aggregate ID	Bulk SSD specific gravity	Unit Weight (Kg/m ³)		Absorption Capacity (%)
		Loose	Compacted	
G	2.04	850	900	17.61
B	1.95	820	860	21.55
E	1.96	810	860	23.62
N	1.96	880	930	22.32

3.2.5.4 Aggregate crushing and impact test of CCB coarse aggregates

i. Aggregate crushing value (ACV)

Aggregate crushing test is used to measure the resistance of an aggregate to crushing load. The crushing value obtained from this test can be used as an indicator of aggregates strength for aggregates that have unknown performance. It can also be used to check aggregates' strength when a lower strength is anticipated. There is no clear relationship

between the aggregate crushing value and the compressive strength of concrete produced with that particular aggregate. Nevertheless, the results of the two tests are usually in agreement [16].

The aggregate crushing test was done according to BS 812-110:1990, “Methods for determination of aggregate crushing value (ACV)” [52]. The CCB aggregate used for the test was on surface dry condition and passed the 12.5 mm sieve and retained on the 9.5 mm sieve. The quantity of CCB aggregate (mass A) used for the test was measured by filling a cylindrical measure of internal diameter and depth of 115 mm and 180 mm respectively as shown in Figure 3.7. The cylindrical measure was filled in three layers of equal depth, each layer being tamped 25 times with a straight metal tamping rod of circular cross section 16 mm diameter.



Figure 3.7 CCB aggregate tamped in cylindrical measure

Then the sample was transferred in to an open ended cylinder with an internal diameter of 154 mm and depth of 132 mm. The cylinder was again filled in three layers of equal depth, each layer being tamped 25 times.



Figure 3.8 CCB aggregate tamped in open ended cylinder

Then the top of the open ended cylinder was capped with a metal piston and placed in the compression machine and it was loaded so that a force of 400 kN was reached in 10 mins.



Figure 3.9 Cylinder setup in the compression test machine

Then the crushed sample was sieved through 2.36 mm sieve and the weight that passed through the sieve (mass B) was recorded.



Figure 3.10 CCB aggregate passed and retained on 2.36 mm sieve

Then the ACV value is calculated as the percentage fraction of mass B divided by mass A. Accordingly, the ACV for the four types of CCB aggregates and the basaltic coarse aggregate was done and the results are summarized in Table 3.9.

Table 3.9 Aggregate crushing value test result

Aggregate type	Mass A (gm)	Mass B (gm)	ACV (B/A) ×100(%)
Basaltic coarse aggregate	2973.1	358.4	12.1
G	2055.6	689.2	33.5
B	1975.3	765.1	38.7
E	1945.9	792.4	40.7
N	1955.2	935.7	47.9

The ACV of aggregates used in cement concrete pavement is recommended up to 30% whereas, for wearing surface it shall not exceed 45% [53]. All the CCB aggregates have an ACV less than 45% except the CCB aggregate obtained from the George Nicola brick factory, which has an ACV slightly greater than the recommended value.

ii. Aggregate impact value (AIV)

The aggregate impact test is used to determine the impact value of bulk aggregate and toughness. The value obtained from this test is related to the crushing value and it is an alternative test that can easily be done on the field [16].

The aggregate impact test was also done for the basaltic coarse aggregate and the four types of CCB aggregates. It was done according to the BS 812-112:1990, “Methods for determination of aggregate impact value (AIV)” [54]. Similar to the ACV test procedure, the CCB aggregate was used in a surface dry condition which passed the 12.5 mm sieve and retained on the 9.5 mm sieve. The quantity of CCB aggregate (mass A) used for the test was measured by filling a cylindrical measure of internal diameter 75 mm and depth of 50 mm. The cylindrical measure was filled in three layers of equal depth, each layer being tamped 25 times with a straight metal tamping rod of circular cross section 16 mm diameter. Then the test sample was placed in the impact machine and the hammer of the machine was a dropped on the aggregate from a height of 380 mm 15 times.



Figure 3.11 Set up of aggregate impact value testing apparatus

Then the crushed aggregate was sieved on the 2.36 mm sieve and the weight (mass B) that passed the sieve size was recorded. Then the AIV is calculated as the percentage fraction of mass B divided by mass A. The AIV for the basaltic coarse aggregate and the four types of CCB aggregate is summarized in Table 3.10.

Table 3.10 Aggregate impact value test result

Aggregate type	Mass A (gm)	Mass B (gm)	AIV (B/A) ×100 (%)
Basaltic coarse aggregate	657.6	40.3	6.1
G	485.7	277.3	57.1
B	479.2	304.3	63.5
E	466.5	308.7	66.2
N	474.1	344.2	72.6

The BS 882:1992 recommends a maximum AIV of 45% for aggregates used in concrete works other than heavy duty concrete floor finishes and pavement wearing surfaces. All the CCB aggregates have higher AIV compared with the maximum recommended value.

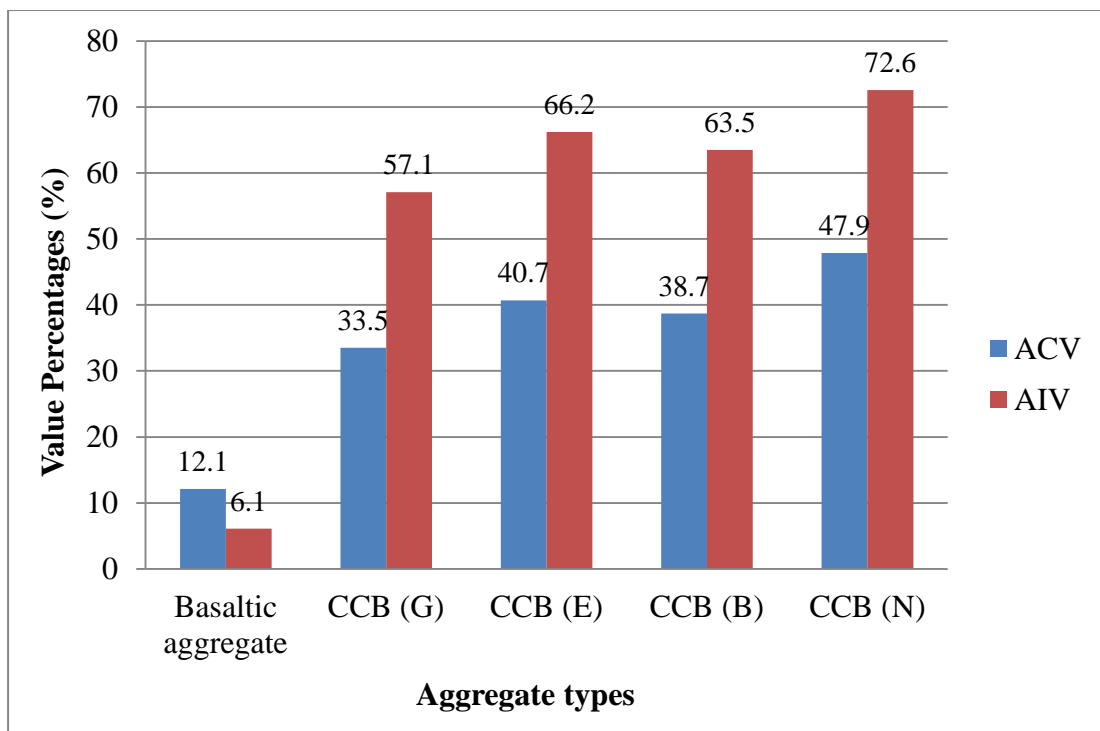


Figure 3.12 Aggregate crushing and impact value test result

3.2.6 Mix Design

The mix proportioning was done following the procedures of British Department of the Environment (DOE), Design of normal concrete mixes [55]. The detailed mix design calculation is presented in Annex A.

According to the mix design, the quantities of the constituent materials for trial mix concrete per m³ for a W/C ratio of 0.59 are:

Cement	347 kg
Water	215 kg
Fine aggregate	779 kg
Coarse aggregate	1069 kg

Two trial mixes were prepared based on the result of the mix design and by adjusting the W/C ratio until the required compressive strength was attained. The results obtained for the two trial mixes are presented in Table 3.11.

Table 3.11 Compressive test results for trial mix

Mix type	Slump (mm)	Average 3 rd day compressive strength (MPa)	Average 7 th day compressive strength (MPa)
Trial 1R	85	8.86	13.23
Trial 2R	80	21	24.46

The water/cement ratio for the final reference (control) mix that satisfied the compressive strength requirement was found to be 0.49 and the quantities of the constituent material used per one cubic meter of concrete for the control mix is as follows:

Cement	461 kg
Water	226 kg
Fine aggregate	695 kg
Coarse aggregate	953 kg

The amount of cement, water and fine aggregate used for all the replacement mixes are the same as that of the control mix. The basaltic coarse aggregate is replaced with 10%, 20%,

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30%, 40% and 100% of the four types of CCB aggregates. The proportion of the coarse basaltic and CCB aggregate for all replacement mixes is summarized in Table 3.12.

Table 3.12 Coarse aggregate proportion for replacement concrete mixes (W/C=0.49)

Mix type	Mix designation	Coarse aggregate Proportion (kg/m ³)	
		Basaltic	CCB
10% replacement with CCB aggregate sourced from Great wall brick factory	G10	885	68
20% replacement with CCB aggregate sourced from Great wall brick factory	G20	817	136
30% replacement with CCB aggregate sourced from Great wall brick factory	G30	748	205
40% replacement with CCB aggregate sourced from Great wall brick factory	G40	680	273
100% replacement with CCB aggregate sourced from Great wall brick factory	G100	0	682
10% replacement with CCB aggregate sourced from Burayu brick factory	B10	888	65
20% replacement with CCB aggregate sourced from Burayu brick factory	B20	823	130
30% replacement with CCB aggregate sourced from Burayu brick factory	B30	757	196
40% replacement with CCB aggregate sourced from Burayu brick factory	B40	692	261
100% replacement with CCB aggregate sourced from Burayu brick factory	B100	0	652
10% replacement with CCB aggregate sourced from Ethio brick factory	E10	887	66
20% replacement with CCB aggregate sourced from Ethio brick factory	E20	822	131
30% replacement with CCB aggregate sourced from Ethio brick factory	E30	756	197
40% replacement with CCB aggregate sourced from Ethio brick factory	E40	691	262
100% replacement with CCB aggregate sourced from Ethio brick factory	E100	0	655
10% replacement with CCB aggregate	N10	887	66

Mix type	Mix designation	Coarse aggregate Proportion (kg/m ³)	
		Basaltic	CCB
sourced from Nicola brick factory			
20% replacement with CCB aggregate sourced from Nicola brick factory	N20	822	131
30% replacement with CCB aggregate sourced from Nicola brick factory	N30	756	197
40% replacement with CCB aggregate sourced from Nicola brick factory	N40	691	262
100% replacement with CCB aggregate sourced from Nicola brick factory	N100	0	655

3.3 Methods

The study was carried out by conducting laboratory tests on fresh and hardened concrete of two sets of concrete mixes. The first was the control mix and the second set included the replacement mixes. In all the mixes produced, the water/cement ratio and the amount of fine aggregate used were kept constant while the crushed basaltic coarse aggregate was replaced by 10%, 20%, 30%, 40% and 100% by volume. The waste clay brick was crushed and sieved in to the same particle size as that of the basaltic coarse aggregate. Moreover, the CCB aggregate was used in an SSD condition in the concrete mix.

To test the 7th and 28th day compressive strength and the hardened density of the concrete produced with 10%, 20%, 30%, 40% and 100% of CCB aggregate, waste clay bricks were used from all the four brick factories selected. Whereas, the flexural strength and water penetration tests were conducted on concrete specimens that were prepared with the same replacement percentages of CCB aggregates sourced from the factory that gave the maximum compressive strength.

3.3.1 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 mixing water was added and the mixer ran for 2 minutes. 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. 150 mm cubic molds were used to cast concrete for compressive and water penetration tests. Whereas 100×100×500 mm beam molds were used to cast concrete for flexural strength test. The molds were vibrated on a table vibrator 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 required day of the test.



Figure 3.13 Casted concrete molds

3.3.2 Slump test

Slump test was conducted for each mix of concrete to determine the workability of the fresh concrete as per BS EN 12350-2:2009, “Testing fresh concrete, slump-test.” The crushed clay bricks were used in a saturated surface dry condition in order to prevent the absorption of water from the mix as the CCB aggregates have high absorption capacities. In addition, the crushed clay bricks were used with the same gradation as the basaltic coarse aggregate in order to avoid the slump difference between the control and replacement mixes.



Figure 3.14 Slump cone test for the control mix (R)

3.3.3 Compressive strength

The 7th and 28th day compressive strength test was conducted on all the concrete mixes as per EN 12390-3:2001, “Compressive strength of test specimens.” The test was carried out on 150 mm cubic concrete specimens with a loading rate of 0.28 MPa/s. For each concrete mix three specimens were tested and the average value is reported to nearest 0.5 N/mm².



Figure 3.15 Cube specimen in compression test machine

3.3.4 Flexural strength

The 28th day flexural strength test for the control and replacement mixes was conducted as per BS EN 12390-5:2009, “Flexural strength of test specimens.” For the replacement mix, the CCB aggregate sourced from the Great wall brick factory was used since the concrete mix prepared with that particular CCB aggregate yielded the maximum compressive strength. For each mix the flexural strength was done on three concrete beam specimen having width and depth of 100 mm and length of 500 mm. The loading rate used for the test was 0.28 MPa/s. The strength was determined by the two point loading technique and calculated using the expression in Eq. 3.1 [56]:

$$f_{cf} = \frac{F \times L}{d_1 \times d_2^2} \quad (\text{Eq. 3.1})$$

where

- f_{cf} is the flexural strength, in MPa (N/mm²);
- F is the maximum load, in N;
- L is the distance between the supporting rollers, in mm;
- d_1 and d_2 are the lateral dimensions of the specimen, in mm

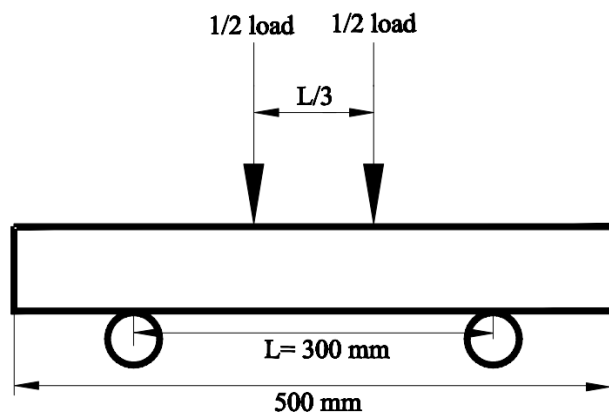


Figure 3.16 Two point loading setup for flexure test

3.3.5 Water penetration test

The test for the depth of water penetration of both the control and replacement mixes was conducted in a non-steady condition as per the BS EN 12390-8:2000. The CCB aggregate sourced from the Great wall brick factory was used since the concrete mix prepared with that particular CCB aggregate yielded the maximum compressive strength. Three 150 mm concrete cubic specimens were used for each mix on the 42nd day. The concrete specimens were exposed to a water pressure of 500 ± 50 kPa for a period of 72 ± 2 hour.



Figure 3.17 Concrete specimens setup on water penetration test apparatus

At the end of the 72 hours period, the specimens were removed from the test apparatus and were split in to two halves using a compression strength testing machine by applying a load perpendicular to the direction in which water pressure was applied.



Figure 3.18 Set up for concrete specimen in compression machine for splitting
Then the maximum depth of penetration is visually observed, marked and the maximum value for depth of penetration was measured and recorded to the nearest millimeters.



Figure 3.19 Measuring maximum water penetration depth from split concrete specimen

CHAPTER FOUR- TEST 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 basaltic coarse aggregate with crushed clay brick. Slump test for the fresh property was tested. For the hardened property; density, compressive strength, flexural strength and water penetration tests were conducted.

4.1 Slump test

The results obtained for the slump test are reported to the nearest 10 mm and are presented in Figure 4.1.

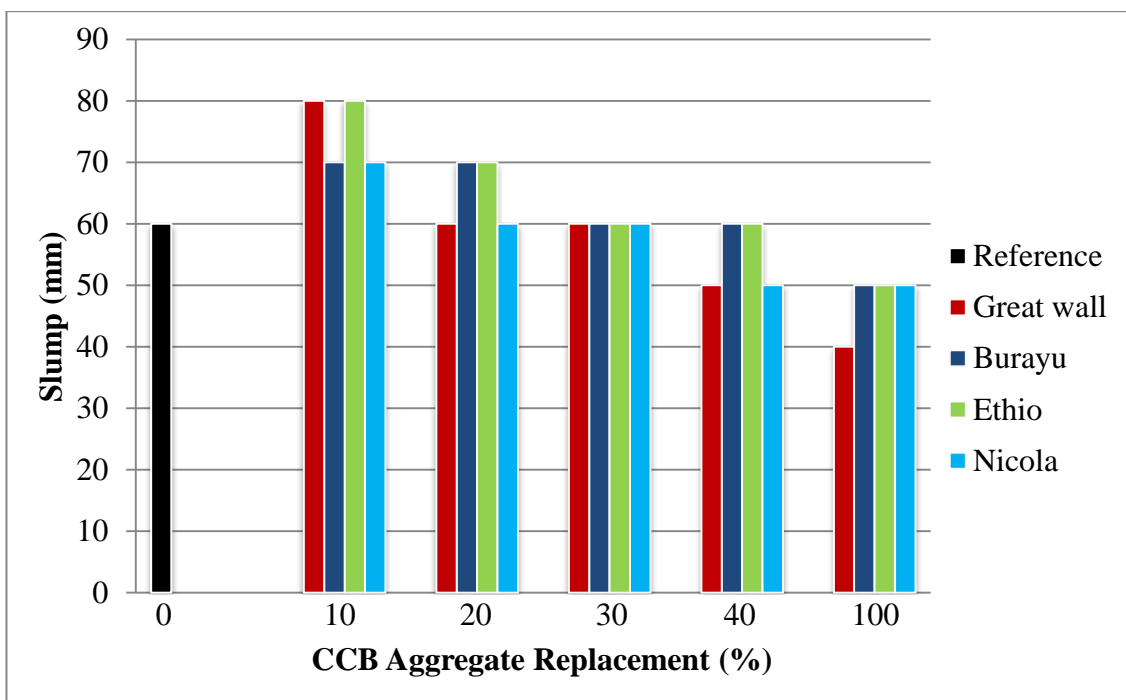


Figure 4.1 Slump test results

As shown in Figure 4.1, the slump values of the replacement concrete mixtures vary from the control mix only in the range of ± 20 mm. ASTM C94 [57] specifies a slump value tolerance of ± 25 mm for slump ranges between 50 to 100 mm. The small variation in slump value could be due to the fact that the CCB aggregates were used in the mix with saturated surface dry condition. But as compared within the replacement concrete mixtures, the slump showed a slight decrease as the percentage of CCB aggregate replacement increased. Regardless of the slight decrease in slump, since the values are still

within the acceptable range, the concrete mixtures produced could be used for normal concreting practice. The reason for this could be the roughness and angularity of the CCB coarse aggregates as rough and angular aggregates require more water to produce workable concrete [9]. Since the water-cement ratio was kept constant the slump showed a decrease as the amount of CCB aggregate increased.

4.2 Density of concrete

The hardened density of the control and replacement concrete mixtures was determined at the 28th day before conducting compressive strength test. The densities were determined according to BS EN 12390-7:2000 “Testing hardened concrete-density of hardened concrete”. Accordingly the 150 mm cube specimens were made air dried at room temperature until the surface moisture was removed. The results obtained are shown in Table 4.1.

Table 4.1 Densities of 150 mm cube specimens at 28th day

Specimen ID	Average weight (kg)	Average density (kg/m ³)	Reduction in density
R	7.890	2340	0%
G-10	7.828	2320	1%
G-20	7.774	2300	2%
G-30	7.668	2270	3%
G-40	7.490	2220	5%
G-100	7.126	2110	11%
B-10	7.843	2320	1%
B-20	7.807	2310	1%
B-30	7.755	2300	2%
B-40	7.720	2290	2%
B-100	7.003	2070	13%
E-10	7.843	2320	1%
E-20	7.817	2310	1%
E-30	7.692	2280	3%
E-40	7.655	2270	3%
E-100	7.001	2070	13%
N-10	7.840	2320	1%
N-20	7.767	2300	2%

Specimen ID	Average weight (kg)	Average density (kg/m ³)	Reduction in density
N-30	7.735	2290	2%
N-40	7.620	2260	4%
N-100	7.153	2120	10%

From the results shown in Table 4.1, the hardened density of the concrete decreased as the CCB aggregate replacement increased. This is true for all concrete mixes produced from the CCB aggregates obtained from the four brick factories. The reason is that the unit weight of the CCB aggregates is less than that of the crushed basaltic coarse aggregate. As it can be seen from the result, the hardened density of the four mixes of concrete does not vary greatly from each other. This is due to the relatively close values of the unit weights of the four types of CCB aggregates. None of the concrete mixes including the 100% replacement mix satisfy the requirement for a lightweight concrete which has a maximum hardened density of 1850 kg/m³ [16] since the unit weight values of the CCB aggregates are close to the maximum margin of light weight aggregates which is 1120 kg/m³. The density of the replacement concrete mixes was able to be reduced between the ranges of 10-13%. Similarly, Khaloo [58] reported a density reduction of 9.5% when using 100% of CCB aggregates to produce concrete. This is in close agreement with the findings of this experimental study.

4.3 Compressive strength of concrete

For this study, the 28th day characteristics strength of concrete used was C25 class of concrete based on 150 mm cubic specimen. Based on this characteristics strength, the target mean strength, which includes a margin or risk factor, was calculated to be 38 MPa, which is used in the mix design and proportioning of the concrete mixtures. The 7th and 28th day compressive strength test results are presented in Figure 4.2 and Figure 4.3 respectively.

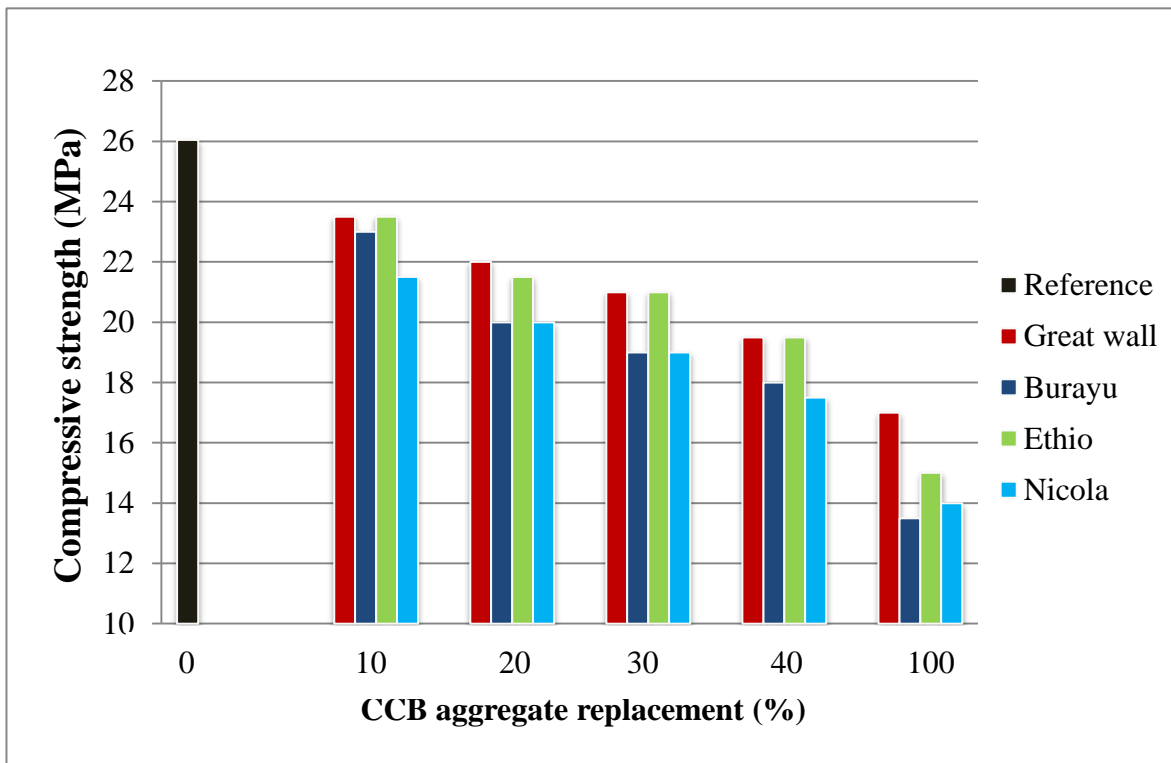


Figure 4.2 7th day compressive strength test result (W/C=0.49)

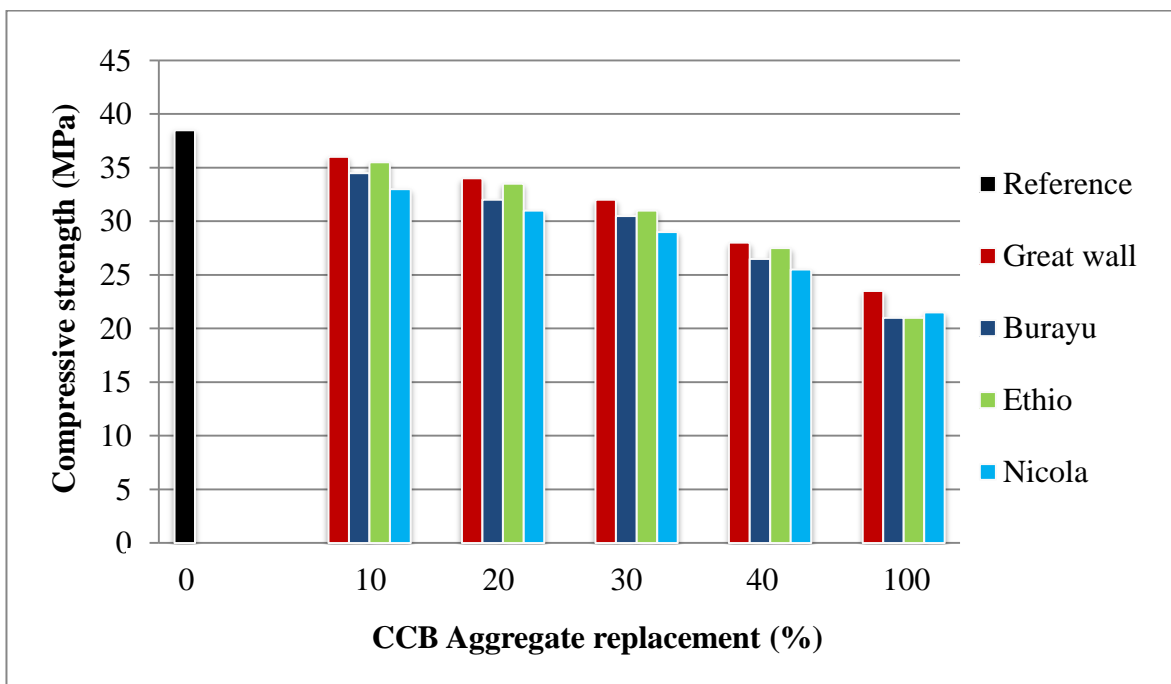


Figure 4.3 28th day compressive strength test result (W/C=0.49)

As shown in Figure 4.3, the 28th day compressive strength of concrete for all types of mixes showed a reduction as the CCB aggregate replacement increases. This could be due

to the relatively lower strength of the CCB aggregates from the crushed basalt stone. When compared between the four types of mixes for a given percentage of CCB aggregate replacement, the concrete produced with the CCB that is sourced from the Great Wall brick factory has the highest compressive strength, whereas the George Nicola brick factory has the lowest compressive strength. This could be due to the difference in the strength of the four types of CCB aggregates. The CCB aggregate obtained from the Great Wall brick factory has the lowest ACV and AIV which indicates highest aggregate strength whereas the George Nicola brick factory has the highest ACV and AIV among the CCB aggregates which indicates lowest aggregate strength. The compressive strength showed consistent results with the ACV and AIV test results. The CCB aggregate with the lowest ACV and AIV produced concrete with the highest compressive strength and vice versa for the experimental study. Even though there is no clear correlation between the aggregate crushing value of an aggregate and the compressive strength of concrete produced with that particular aggregate, the results of the two are sometimes in agreement [59] as it is the case for this experimental study.

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 four concrete mixes produced with 30% replacement percentage had compressive strength ranging between 75-83% of the control mix. Whereas the 100% replacement concrete mixes had compressive strength values between 55-61% of the control mix. According to a study by Zayia [60], the compressive strength of concrete produced with 100% replacement of CCB aggregate ranged between 53-69% of the compressive strength of normal aggregate concrete which have close range value with that of the experimental study.

Moreover, a study by Abdur et al. [61] indicated that when using CCB aggregate as replacement of basaltic aggregate, the compressive strength of concrete showed a strength reduction of 33%. However the strength reduction for this experimental study ranged between 39-45% which is a relatively higher percentage reduction.

According to the 28th day compressive strength test results, the 100% replacement for all four types of mixes do not satisfy the minimum characteristics strength of 25 MPa with the water/cement ratio of 0.49. In order to make the possible use of 100% of CCB aggregate in concrete that satisfies the minimum strength requirement, a lower water/cement ratio

was further examined. As a first trial mix a water/cement ratio of 0.45 was used with an adjusted cement content and the 7th day compressive strength was conducted. The mix was prepared with the CCB aggregate that gave the lowest compressive strength when replaced 100%. Therefore, the CCB aggregate sourced from the Ethio Brick Factory was used and the result is as shown in Table 4.2.

Table 4.2 The 7th day compressive strength test result for trial mix (W/C=0.45)

Mix type	Slump (mm)	Average 7 th day compressive strength (MPa)
Trial mix	50	16.50

Since the 7th day compressive strength is not satisfactory, a lower water/cement ratio of 0.40 was taken and a second trial mix was prepared. The second trial mix gave a satisfactory result. The result of the compressive strength is as shown in Table 4.3.

Table 4.3 7th and 28th day compressive strength results (W/C= 0.40)

Specimen ID	Slump (mm)	7 th day	28 th day
		Average compressive strength (MPa)	Average compressive strength (MPa)
E-100	50	19	29

If 100% replacement of CCB aggregate is needed to produce a concrete with 28th day characteristics strength of 25 MPa, then a lower water/cement ratio of 0.40 has to be used and the quantities of the constituent materials per m³ are as follows:

Cement	512 kg
Water	205 kg
Fine aggregate	650 kg
CCB Coarse aggregate	620 kg

Even though it was possible to utilize 100% of CCB aggregates with this particular mix proportion, the cement content was too high.

4.4 Flexural strength of concrete

The flexural strength tests were conducted on the 28th day and the test results are expressed to the nearest 0.1 MPa (N/mm²) and presented in Table 4.4 and Figure 4.4.

Table 4.4 The 28th day flexural strength test result

Specimen ID	Average Weight (kg)	Average Load of failure (kN)	Flexural Strength (MPa)	Reduction in strength (%)
R	12.35	13.10	3.93	0
G-10	12.15	12.44	3.74	5
G-20	12.04	12.08	3.63	8
G-30	11.86	11.72	3.52	11
G-40	11.65	11.39	3.42	13
G-100	10.82	11.07	3.02	23

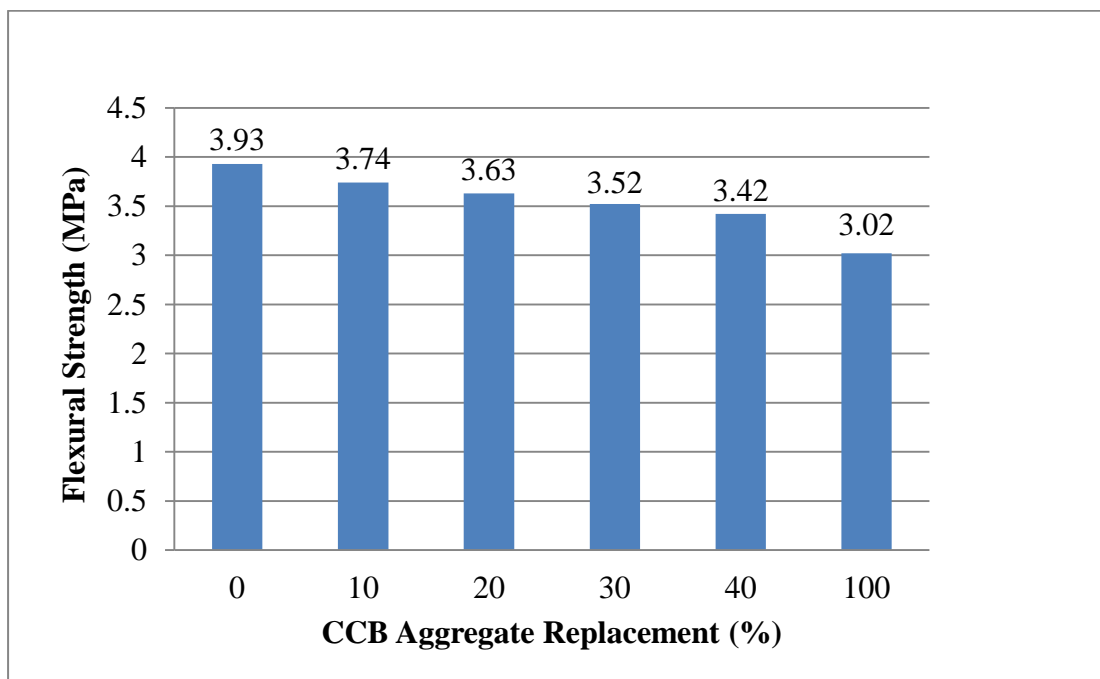


Figure 4.4 28th day flexural strength test result

According to the 28th day flexural strength test result, the flexural strength of the concrete decreased when the CCB aggregate replacement increased. For 100% replacement the flexural strength decreased by 23% from the reference mix. This reduction in flexural

strength is less than the compressive strength reduction which was between 39-45%. The flexural strength of the control mix was 10% of the compressive strength whereas the replacement mixes' flexural strength ranged between 10-13% of the respective compressive strength. This indicates the bond between the CCB aggregate and the paste behaves in similar way as that of basaltic coarse aggregate concrete in bending action.

The study finding researched by Tahir [62] showed that the flexural strength of concrete with CCB aggregate varied from 8 to 11% of the compressive strength. Whereas, for normal aggregate concrete the range was found to be 9 to 11% of the compressive strength. These flexural strength ranges are similar with that of the experimental study.

The European code (CEN, 2002) [63] standardized the relationship to estimate the flexural strength as $0.342 f_c^{2/3}$ MPa for compressive strength less than 50 MPa. Based on this relationship, the experimental study flexural test results are plotted along with the corresponding compressive strength as shown in Figure 4.5.

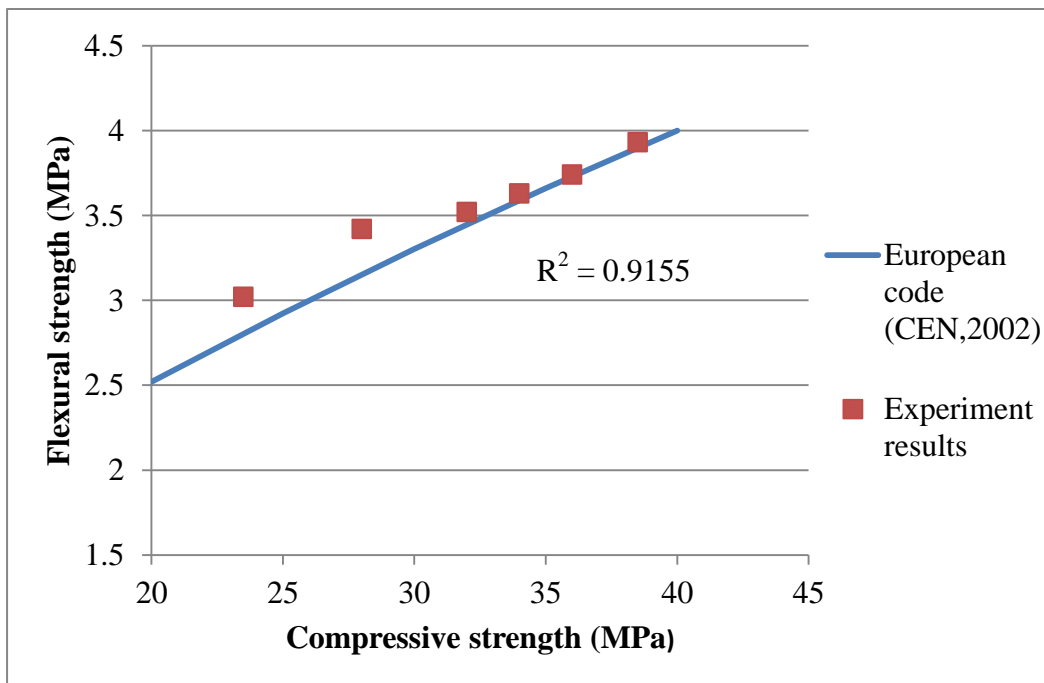


Figure 4.5 Relationship between compressive and flexural strength

According to Figure 4.5, the flexural and compressive strength relationship of the experimental study has good agreement with that specified by the European code.

4.5 Water penetration test

The water penetration test results for the control and replacement mixes are presented in Table 4.5 and Figure 4.6.

Table 4.5 42nd day water penetration test result

Specimen ID	Average of maximum water depth penetration (mm)	Water depth penetration increase from the control mix (%)
R	17.21	0
G-10	20.68	20
G-20	21.87	27
G-30	23.46	36
G-40	25.62	49
G-100	29.31	70

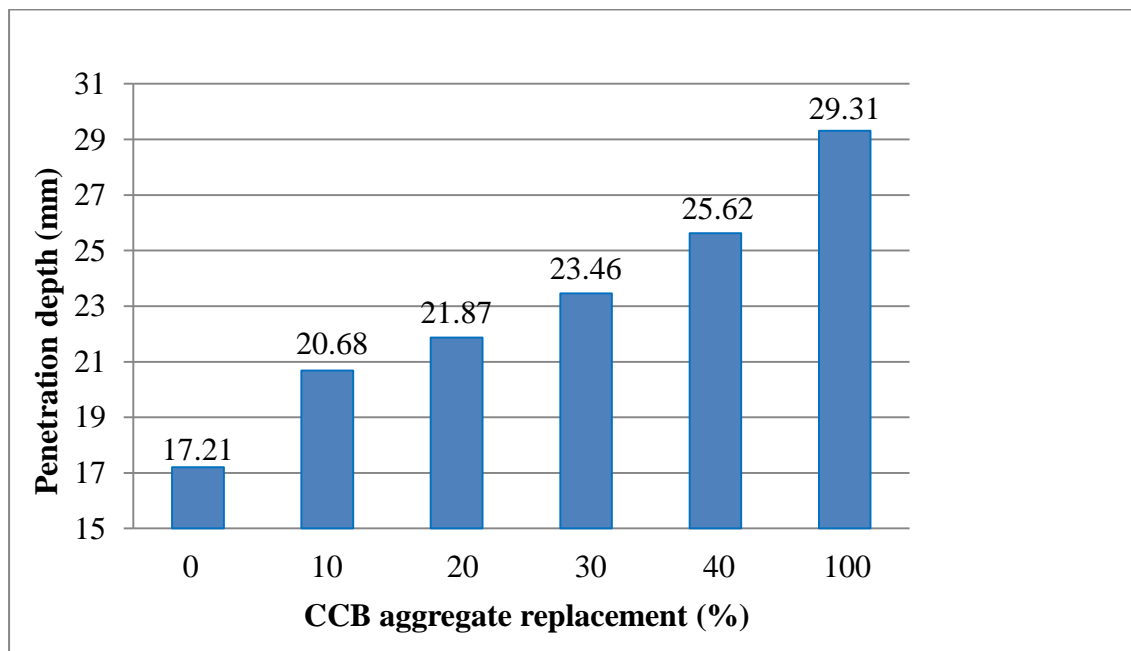


Figure 4.6 42nd day water penetration test result

According to the water penetration test result, the depth of water penetration increased as the CCB aggregate replacement increased. For 30% CCB aggregate replacement, the water penetration depth increased by 36% from the control mix. When the basaltic aggregate is fully replaced with CCB aggregate, the depth of water penetration increased by 70%. This could be because of the porous nature of the CCB aggregate.

As suggested by Yang [64] the toughness of concrete containing brick aggregate may be decreased due to the increase of water penetration depth of concrete which is caused due to the porous nature of the aggregate.

Even though the water depth penetration increased with the increasing replacement percentage, it has not exceeded the 30 mm depth mark. A concrete with penetration depth less than 30 mm is classified as an impermeable concrete under aggressive conditions [16]. Therefore the concrete produced even with 100% replacement of CCB aggregate can be categorized as an impermeable concrete under aggressive conditions.

4.6 Cost Comparison

The concrete production cost comparison between the control and 30% replacement mix, which is the best percentage replacement and for 100% replacement is done. All production costs except the material cost are taken constant for both the control and the replacement mixes. The unit cost per one cubic meter of concrete production for both water/cement ratios of 0.49 and 0.40 are presented in Table 4.6 and 4.8 respectively based on the current market price in Addis Ababa.

Table 4.6 Cost of concrete for reference mix per one cubic meter (W/C= 0.49)

Constituent	Unit	Quantity	Birr per Unit	Cost (Birr)
Cement (OPC)	Qtl	4.61	700	3,227.00
Coarse aggregate	m ³	0.34	850	289.00
Fine aggregate	m ³	0.33	1100	363.00
TOTAL				3,879.00

Table 4.7 Cost of concrete for 30% replacement mix per one cubic meter (W/C= 0.49)

Constituent	Unit	Quantity	Birr per Unit	Cost (Birr)
Cement (OPC)	Qtl	4.61	700	3,227.00
Coarse aggregate	m ³	0.26	850	221.00
Fine aggregate	m ³	0.33	1100	363.00
TOTAL				3,811.00

As shown in Tables 4.6 and 4.7 the cost of concrete that is produced by 30% replacement of coarse aggregate with crushed clay brick was able to be reduced with only 0.98% from the control mix per one cubic meter of concrete.

Experimental Study on Partial Replacement of Coarse Aggregate with Crushed Clay Brick to Produce C-25 Concrete

Table 4.8 Cost of concrete for 100% replacement mix per one cubic meter (W/C= 0.40)

Constituent	Unit	Quantity	Birr per Unit	Cost(Birr)
Cement (OPC)	Qtl	5.12	700	3,584.00
Coarse aggregate	m ³	0.00	850	0.00
CCB aggregate	Kg	682	0.00	0.00
Fine aggregate	m ³	0.31	1100	341.00
TOTAL				3,925.00

As can be seen from Table 4.8 the cost of concrete production with 100% CCB aggregate replacement is higher than that of the control and the 30% replacement mix. Even though it was made possible to use 100% of CCB aggregates in a concrete mix that satisfied the minimum strength requirement with a w/c ratio of 0.40, this particular mix was uneconomical.

CHAPTER FIVE- CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions are made based on the findings of this experimental study.

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

- The CCB aggregates in concrete mix do not change the slump significantly when used in saturated surface dry condition. However the slump value decreased as the CCB aggregate replacement increased due to the roughness and angularity of the aggregates.
- The CCB aggregates decrease the hardened density of concrete when the replacement amounts increase. The concrete density can be decreased up to 3% by replacing 30% of the coarse aggregate with CCB aggregate.
- Even though the CCB aggregates from all brick factories 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. The inclusion of the CCB aggregates reduces the flexural strength of concrete. However the percentage of reduction is smaller when compared with the compressive strength reduction.

The CCB aggregates increase the water penetration depth of concrete. However the concrete that is produced even at full replacement is still an impermeable concrete under aggressive conditions.

3. It is possible to use CCB aggregates from all brick factories as a replacement of coarse aggregate up to 30% in normal strength concrete of 25 MPa.

4. The amount of cost reduced when using CCB aggregates instead of crushed basalt stone is very insignificant.

5.2 Recommendations

The following areas can be further investigated related with the experimental study of this research.

- The effect of overburnt clay bricks as a replacement of coarse aggregates to produce concrete.
- The use of clay bricks as replacement of both fine and coarse aggregate in concrete production.
- The utilization of CCB coarse aggregate to produce concrete with different grade other than C-25.

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ANNEXES

ANNEX-A

Mix design

The mix proportioning was done following the procedures of British Department of the Environment (DOE), Design of normal concrete mixes [55].

Stage 1: Selection of target water/cement ratio

The target mean strength is calculated as:

$$f_m = f_c + M$$

Where f_m = the target mean strength

f_c = the specified characteristic strength

M = the margin

The margin M is used in designing the mix to have a mean strength greater than the specified characteristic strength so as to account the variability of concrete in production and it is determined as:

$$M = k \times s$$

Where M = the margin

k = a value appropriate to the percentage defectives permitted below the characteristic strength

s = the standard deviation

The constant k is derived from the mathematics of the normal distribution and is taken a value of 1.64 for 5% defectives.

The standard deviation, s, is read from the graph of the DOE mix design found in Figure 3, "Relationship between standard deviation and characteristic strength". For a value of 25 MPa characteristic strength the standard deviation value is 8 MPa.

Therefore the margin, M, will be $1.64 \times 8 \approx 13$ MPa

The target mean strength, f_m , will be $25+13=$ **38 MPa**

Now by using the target mean strength and the approximate compressive strengths of concrete mixes made with a free-water/cement ratio of 0.5 as given in Table 2 of the DOE mix design, the target free water/cement ratio can be taken from the graph given in Figure 4 of the DOE mix design, which shows the relationship between compressive strength and free-water/cement ratio. Therefore the free water/cement ratio is found to be 0.59.

Stage 2: Selection of free-water content

The free-water content is determined from Table 3 of the DOE mix design which depends upon the type and maximum size of the aggregate to give a concrete of the specified slump.

The nominal slump of the concrete for this study is 75mm which is taken from the recommendation given for Normal reinforced concrete in slabs, beams, walls and columns in Table 11 of the BS 5328:Part 1:1997, guide to specifying concrete. The table gives the workabilities suitable for different uses of in situ concrete [65].

Therefore based on the slump selected and the type and maximum aggregate size specified for the study, the free-water content is found to be 205 kg/m³.

Stage 3: Determination of cement content

The cement content can easily be determined by dividing the free-water content by the free-water/cement ratio.

$$\text{Cement content} = \frac{\text{free-water content}}{\text{free-water /cement ratio}}$$

Accordingly the cement content is found to be 347 Kg/m³.

According to BS 5328: Part 1:1997, the maximum cement content is restricted to 550 kg/m³ due to potential cracking caused by drying shrinkage.

Stage 4: Determination of total aggregate content

The total aggregate content in a saturated and surface dry condition can be computed by using equation

$$\text{Total aggregate content} = D - C - W$$

(Saturated and surface-dry)

Where D = the wet density of concrete (kg/m^3)

C = the cement content (kg/m^3)

W = the free-water content (kg/m^3)

The wet density of the fully compacted concrete can initially be taken from Figure 5 of the DOE mix design; accordingly the wet density of concrete is taken to be 2410 kg/m^3 .

Therefore the total aggregate content is $= 2410 - 347 - 205 = 1858 \text{ kg/m}^3$

Stage 5: Selection of fine and coarse aggregate contents

The fine aggregate content can be determined by multiplying the total aggregate content with the proportion of fines:

Fine aggregate content = Total aggregate content \times proportion of fines

The recommended value for proportion of fines can be taken from Figure 6 of the DOE mix design by using the maximum size of aggregate, the workability level, the grading of fine aggregate that is defined by the percentage passing a $600\mu\text{m}$ sieve and the free-water/cement ratio. Accordingly, the proportion of fines is found to be 42%.

Fine aggregate content $= 1858 \times 42\% = 780 \text{ kg/m}^3$.

The coarse aggregate content is then:

Total aggregate content - fine aggregate content $= 1858 - 780 = 1078 \text{ kg/m}^3$

Thus the quantities of the constituent materials per m^3 are:

Cement	347 kg
Water	205 kg
Fine aggregate	780 kg (saturated surface-dry)
Coarse aggregate	1078 kg (saturated surface-dry)

Even though the mix proportion for both the fine and coarse aggregate is done on a saturated surface-dry condition the aggregates actually batched were in an air-dry condition. Therefore an adjustment on the mass of the aggregates is done based on the difference between the absorption capacity and moisture content of both the fine and coarse aggregates which is 0.14 and 0.82% respectively. Therefore;

$$\text{Mass of air-dry fine aggregate} = 780 \text{ Kg} \times 100/100.14 = 779 \text{ kg}$$

$$\text{Mass of air-dry coarse aggregate} = 1078 \text{ Kg} \times 100/100.82 = 1069 \text{ kg}$$

The water required for absorption will be the sum of the differences between the saturated surface-dry and air-dry masses of the aggregates.


$$\text{Water required for absorption} = (780 - 779) + (1078 - 1069) = 10 \text{ kg}$$

Thus the adjusted quantities of the constituent materials per m^3 for a W/C ratio of 0.59 are:

Cement	347 kg
Water	215 kg
Fine aggregate	779 kg
Coarse aggregate	1069 kg

ANNEX- B

Chemical Composition test result for normal clay brick

	GEOLOGICAL SURVEY OF ETHIOPIA	Doc.Number: GLD/F5.10.2	Version No: 1
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title:	Complete Silicate Analysis Report	Effective date:	May, 2017

Customer Name:-Wengelawi Markos Dinberie

Sample type :-Crushed Clay Brick

Date Submitted :-07/04/2021

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

Analytical Method: LiBO₂ FUSION, HF attack, GRAVIMETRIC, COLORIMETRIC and AAS

Issue Date: -20/05/2021

Request No:- GLD/RQ/862/21

Report No:- GLD/RN/466/21

Sample Preparation: - 200 Mesh

Number of Sample:- Four (04)

Collector's code	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	P ₂ O ₅	TiO ₂	II ₂ O	LOI	SO ₃	Cl ¹
B01	65.50	20.64	8.56	<0.01	<0.01	<0.01	<0.01	0.16	0.20	0.37	0.49	2.59	0.44	<0.10
E01	61.72	20.84	8.08	<0.01	<0.01	1.76	<0.01	0.12	1.60	0.37	0.96	3.17	0.39	<0.10
G01	61.60	25.58	7.92	<0.01	<0.01	1.40	<0.01	0.12	0.75	0.39	0.42	0.69	0.20	<0.10
N01	58.70	24.10	9.16	<0.01	0.64	0.88	<0.01	0.08	0.66	0.38	1.79	2.60	0.08	<0.10


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

Analysts

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Tezita Zemene


Approved By


Yohannes Getachew



ANNEX-C

Chemical Composition test result for over burnt clay brick

	GEOLOGICAL SURVEY OF ETHIOPIA	Doc.Number: GLD/F5.10.2	Version No: 1
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of 1
Document Title:	Complete Silicate Analysis Report	Effective date:	May, 2017

Customer Name:- Wengelowi Markos Dinberie

Sample type : Burnt clay

Date Submitted:-07/10/2021

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

Analytical Method: LiBO₂ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS.

Collector's code	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	P ₂ O ₅	TiO ₂	H ₂ O	LOI
Burnt clay	61.26	28.42	7.24	0.46	0.40	1.02	1.24	0.06	0.16	0.48	0.31	0.01

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

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Quality Control


Gosa Haile



ANNEX-D

7th day compressive strength test result for control and replacement mixes

Specimen ID	Casting date	Specimen No.	Weight (kg)	Failure load (kN)	Compressive strength(MPa)
R	15/07/2021	1	7.865	586.8	26.08
		2	7.871	584.8	25.99
		3	7.925	586.9	26.08
G-10	29/07/2021	1	7.840	517.7	23.01
		2	7.853	541.7	24.08
		3	7.861	530.7	23.59
G-20	29/07/2021	1	7.804	487.6	21.67
		2	7.791	501.7	22.3
		3	7.82	502.8	22.35
G-30	29/07/2021	1	7.7	477.7	21.23
		2	7.677	462.7	20.56
		3	7.655	465.2	20.68
G-40	15/09/2021	1	7.530	441.0	19.6
		2	7.461	429.7	19.1
		3	7.580	450.2	20.01
G-100	09/08/2021	1	7.042	382.7	17.01
		2	7.053	375.4	16.68
		3	7.062	371.8	16.52
B-10	02/08/2021	1	7.842	514.3	22.86
		2	7.854	536.9	23.86
		3	7.839	484.3	21.53
B-20	02/08/2021	1	7.826	456.9	20.31
		2	7.811	446.5	19.85
		3	7.831	464.3	20.64
B-30	02/08/2021	1	7.753	430.9	19.15
		2	7.664	435.6	19.36
		3	7.711	440.8	19.59

Experimental Study on Partial Replacement of Coarse Aggregate with Crushed Clay Brick to Produce C-25 Concrete

Specimen ID	Casting date	Specimen No.	Weight (kg)	Failure load (kN)	Compressive strength(MPa)
B-40	15/09/2021	1	7.701	412.6	18.34
		2	7.767	410.1	18.23
		3	7.612	397.1	17.65
B-100	09/08/2021	1	6.935	303.6	13.49
		2	6.939	295.4	13.13
		3	6.964	310.3	13.79
E-10	03/08/2021	1	7.858	496.1	22.05
		2	7.838	541.7	24.08
		3	7.843	551.1	24.49
E-20	03/08/2021	1	7.802	490.3	21.89
		2	7.755	472.5	21
		3	7.848	478.2	21.45
E-30	03/08/2021	1	7.702	454.5	20.2
		2	7.673	472.7	21.01
		3	7.636	470.3	20.9
E-40	15/09/2021	1	7.647	437.6	19.45
		2	7.639	429.7	19.1
		3	7.635	447.1	19.87
E-100	09/08/2021	1	6.997	344.0	15.29
		2	6.891	346.3	15.39
		3	6.958	330.3	14.68
N-10	05/08/2021	1	7.860	498.0	22.13
		2	7.825	443.5	19.71
		3	7.858	514.2	22.85
N-20	05/08/2021	1	7.757	454.81	20.21
		2	7.74	442.88	19.68
		3	7.814	440.18	19.56
N-30	05/08/2021	1	7.752	420.6	18.69
		2	7.685	409.7	18.21
		3	7.745	432.0	19.20

Experimental Study on Partial Replacement of Coarse Aggregate with Crushed Clay Brick
to Produce C-25 Concrete

Specimen ID	Casting date	Specimen No.	Weight (kg)	Failure load (kN)	Compressive strength(MPa)
N-40	15/09/2021	1	7.636	402.5	17.89
		2	7.618	380.4	16.91
		3	7.607	388.1	17.25
N-100	09/08/2021	1	7.149	320.6	14.25
		2	7.089	302.8	13.46
		3	6.971	322.4	14.33

ANNEX-E

28th day compressive strength test result for control and replacement mixes

Specimen ID	Casting date	Specimen No.	Weight (kg)	Failure load (kN)	Compressive strength(MPa)
R	15/07/2021	1	7.913	862.4	38.33
		2	7.861	882.2	39.21
		3	7.898	870.5	38.69
G-10	29/07/2021	1	7.852	806.2	35.83
		2	7.822	819.9	36.44
		3	7.809	821.7	36.52
G-20	29/07/2021	1	7.786	768.9	34.17
		2	7.763	782.2	34.77
		3	7.773	762	33.87
G-30	29/07/2021	1	7.686	752.1	33.42
		2	7.649	701.5	31.18
		3	7.668	719.5	31.98
G-40	15/09/2021	1	7.450	641.3	28.50
		2	7.620	630.5	28.02
		3	7.390	622.1	27.65
G-100	09/08/2021	1	7.109	517.1	22.98
		2	7.167	524.5	23.31
		3	7.102	547.7	24.34
B-10	02/08/2021	1	7.846	755.1	33.56
		2	7.853	785.9	34.93
		3	7.829	799.1	35.51
B-20	02/08/2021	1	7.798	707.6	31.45
		2	7.817	720.2	32.01
		3	7.805	719.6	31.98
B-30	02/08/2021	1	7.726	669.1	29.74
		2	7.778	684.2	30.41
		3	7.762	702.7	31.23

Experimental Study on Partial Replacement of Coarse Aggregate with Crushed Clay Brick to Produce C-25 Concrete

Specimen ID	Casting date	Specimen No.	Weight (kg)	Failure load (kN)	Compressive strength(MPa)
B-40	15/09/2021	1	7.62	597.4	26.55
		2	7.86	582.9	25.91
		3	7.69	601.8	26.75
B-100	09/08/2021	1	7.014	487.2	21.65
		2	6.991	462.0	20.53
		3	7.005	469.8	20.88
E-10	03/08/2021	1	7.85	814.9	36.22
		2	7.832	805.9	35.82
		3	7.848	770.2	34.23
E-20	03/08/2021	1	7.845	746.6	33.18
		2	7.79	750.2	33.34
		3	7.815	774.6	34.43
E-30	03/08/2021	1	7.728	711.2	31.61
		2	7.733	734.2	32.63
		3	7.615	669.1	29.74
E-40	15/09/2021	1	7.671	626.4	27.84
		2	7.645	604.5	26.87
		3	7.65	617.6	27.45
E-100	09/08/2021	1	6.952	459.8	20.44
		2	6.947	469.6	20.87
		3	7.104	493.7	21.94
N-10	05/08/2021	1	7.826	765.7	34.03
		2	7.852	738.23	32.81
		3	7.841	748.13	33.25
N-20	05/08/2021	1	7.759	702.0	31.2
		2	7.78	688.1	30.58
		3	7.761	684.2	30.41
N-30	05/08/2021	1	7.726	635.6	28.25
		2	7.76	630.2	28.01
		3	7.719	666.9	29.64

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Specimen ID	Casting date	Specimen No.	Weight (kg)	Failure load (kN)	Compressive strength(MPa)
N-40	15/09/2021	1	7.638	588.41	26.15
		2	7.624	575.5	25.58
		3	7.608	562.9	25.02
N-100	09/08/2021	1	7.185	470.5	20.9
		2	7.142	492.5	21.89
		3	7.133	498.2	22.14

ANNEX-F

28th day flexural strength test result for control and replacement mix of 10, 20, 30, 40 and 100%.

Specimen ID	Casting date	Specimen No.	Weight (kg)	Failure load (kN)	Compressive strength(MPa)
R	20/09/2021	1	12.45	12.79	3.84
		2	12.32	13.09	3.93
		3	12.27	13.42	4.03
G-10	20/09/2021	1	12.15	12.65	3.80
		2	12.06	12.49	3.75
		3	12.24	12.19	3.66
G-20	22/09/2021	1	12.10	12.05	3.62
		2	11.98	12.35	3.71
		3	12.03	11.82	3.55
G-30	22/09/2021	1	11.74	11.95	3.59
		2	11.89	11.49	3.45
		3	11.95	11.72	3.52
G-40	22/09/2021	1	11.67	11.19	3.36
		2	11.58	11.39	3.42
		3	11.71	11.59	3.48
G-100	20/09/2021	1	10.83	10.02	3.01
		2	10.75	9.82	2.95
		3	10.87	10.36	3.11

ANNEX-G

42nd day water penetration test result for control and replacement mix of 10, 20, 30, 40 and 100%.

Specimen ID	Water depth penetration(D) taken at intervals (mm)									
	D ₁	D ₂	D ₃	D ₄	D ₅	D ₆	D ₇	D ₈	D ₉	D ₁₀
(R) ₁	11.81	13.79	15.60	15.03	12.93	12.96	11.64	17.23	14.53	13.79
(R) ₂	10.85	12.87	10.32	15.69	12.52	13.45	11.32	10.85	9.75	8.52
(R) ₃	11.81	14.23	17.85	16.26	12.37	18.70	13.74	12.68	16.99	18.45
(G-10) ₁	10.79	14.67	21.17	19.45	14.77	8.24	9.59	14.34	17.53	14.28
(G-10) ₂	9.70	5.60	18.33	13.43	15.72	16.63	14.33	19.71	12.72	20.15
(G-10) ₃	7.21	14.45	13.04	17.95	15.40	13.56	6.57	9.78	16.01	20.73
(G-20) ₁	11.63	15.63	23.56	18.75	15.66	9.32	10.25	16.21	17.89	15.32
(G-20) ₂	10.28	6.98	19.10	14.23	15.98	16.78	15.05	19.83	13.65	21.12
(G-20) ₃	8.89	15.65	13.98	18.21	16.12	13.96	10.32	10.89	16.57	20.93
(G-30) ₁	12.56	16.67	22.91	18.56	15.12	9.35	12.96	16.02	18.69	16.35
(G-30) ₂	11.82	8.36	20.45	15.36	17.02	18.96	19.91	23.73	14.72	22.05
(G-30) ₃	9.65	16.78	15.96	19.02	17.65	16.03	8.73	11.49	18.73	23.73
(G-40) ₁	15.96	19.18	25.82	24.16	18.39	10.73	13.60	18.26	21.67	19.60
(G-40) ₂	13.52	10.36	22.16	17.39	19.20	21.09	26.13	23.46	16.61	25.03
(G-40) ₃	12.09	18.37	17.61	22.16	19.64	17.90	10.19	13.34	20.48	24.90
(G-100) ₁	19.93	22.62	29.45	27.30	23.06	15.76	18.13	23.17	27.83	23.72
(G-100) ₂	17.81	14.34	26.91	22.14	23.67	24.57	23.19	27.67	21.37	29.76
(G-100) ₃	16.30	23.92	21.73	25.34	23.37	22.73	15.07	18.25	24.30	28.72

ANNEX-G (Continued)

Specimen ID	Avg (mm)	D_{max} (mm)	(Avg)_{max} (mm)
(R) ₁	13.93	17.23	17.21
(R) ₂	11.61	15.69	
(R) ₃	15.31	18.70	
(G-10) ₁	14.48	21.17	20.68
(G-10) ₂	14.63	20.15	
(G-10) ₃	13.47	20.73	
(G-20) ₁	15.42	23.56	21.87
(G-20) ₂	15.30	21.12	
(G-20) ₃	14.55	20.93	
(G-30) ₁	15.92	22.91	23.46
(G-30) ₂	17.24	23.73	
(G-30) ₃	15.78	23.73	
(G-40) ₁	18.74	25.82	25.62
(G-40) ₂	19.50	26.13	
(G-40) ₃	17.67	24.90	
(G-100) ₁	23.10	29.45	29.31
(G-100) ₂	23.14	29.76	
(G-100) ₃	21.97	28.72	

ANNEX-H

Pictures



(a)



(b)



(c)



(d)

- (a) Clay brick after being crushed with a jaw crusher machine
- (b) Unit weight determination of CCB aggregate
- (c) Specific gravity determination of CCB aggregate
- (d) Soaked CCB aggregate ready to be surface dried

Experimental Study on Partial Replacement of Coarse Aggregate with Crushed Clay Brick to Produce C-25 Concrete



(a)



(b)



(c)



(d)

(a) 10% CCB aggregate along with sand and coarse aggregate in pan mixer

(b) Concrete constituents after being thoroughly mixed

(c) 150mm cube specimens after cast and vibrated

(d) 100×100×500mm specimens after cast and vibrated

Experimental Study on Partial Replacement of Coarse Aggregate with Crushed Clay Brick to Produce C-25 Concrete



(a)



(b)



(c)



(d)

(a) Concrete specimens covered with plastic sheet

(b) Concrete specimens in curing tank

(c) Setup for flexural strength test

(d) Beam specimen split apart



(a)



(b)



(c)

(a) Concrete specimens set up on water penetration test machine

(b) Splitting 150mm cube specimen after 72 hours on water penetration test machine

(c) Marking and measuring water penetration depth