School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Construction Engineering and Management Chair

Partial Replacement of Cement by Coffee Husk Ash for C-25 Concrete Production

A Thesis submitted to the School of Graduate Studies of Jimma University of Jimma Institution of Technology, in Partial Fulfillment of the Requirements for the Degree of Master of Science in Construction Engineering and Management

By:

Abebe Demissew Gashahun

October 2017

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DECLARATION

I, Abebe Demissew, the undersigned, declare that this MSc thesis entitled “Partial Replacement of Cement by Coffee Husk Ash for C-25 Concrete Production” is my original work, and had not been presented by any other person for an award of a degree in this or any other University, and all sources of materials used for theses have been duly acknowledged.

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As Master research Advisors, we hereby certify that we have read and evaluated this MSc. research prepared under our guidance, by ABEBE DEMISSEW entitled: “Partial Replacement of Cement by Coffee Husk Ash for C-25 Concrete Production” We recommend that it can be submitted as fulfilling the MSc Thesis requirements.

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ABSTRACT

Concrete is mixture of aggregates and binders. From concrete ingredients the binder and the most costly and environmental unfriendly element is cement and it is one of the environmental unfriendly processes due to the release of CO_2 gases to the atmosphere and environmental degradations Coffee husk is an agricultural by product of coffee bean, which is a result of dry process. Coffee husk usually considered as a type of agriculture waste; as its quantity rises, the treatment/disposal of it will become an environmental problem. In Ethiopia enormous amounts of coffee husk is generated annually from different coffee pulpler. Conversely, it have poorly been utilized or left to decomposed or otherwise dumped in the environment. As a result, this research was conducted to produce coffee husk ash concrete from coffee husk. Due to the booming of the construction activity in the country, there is high demand of cement.

This research was therefore, amid to examine the potential of coffee husk ash as partial replacement for ordinary Portland cement (OPC) in C-25 concrete production with investigation of optimum ratio of replacement and engineering properties of C-25 concrete.

Coffee husk samples were collected from different coffee treatment centres in Jimma Zone, Jimma City and it was carbonized at 550 ^oC temperature for 3 hours in an oxygen-deficient environment and its chemical and physical properties were investigated. After that, the pastes containing OPC and coffee husk ash at 2, 3, 5, 10 and 15 % of replacement were investigated with zero percept of coffee husk ash as a control mix.

Six different concrete mixes were prepared for 25MPa concrete with water to cement ratio of 0.5 and 360 kg/m3 cement content. The properties of these mixes have then been assessed both at the fresh and hardened state.

The results of the concrete work have shown that, up to 10% replacement of the coffee husk ash achieved a higher compressive strength at all test ages i.e. 7, 14, and 28 days of age by compressive test machines. However, the results of the cube compressive strength and densities show that the compressive strength and density reduces as the percentage of coffee husk ash increases.

It can therefore, be concluded that 10% replacement of cement by coffee husk ash results in a similar concrete properties with control test and it is the optimum replacement.

Keywords: *Coffee husk ash, Compressive strength, Concrete, Environment*

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ABREVIATIONS

AAS	Atomic Absorption Spectrophotometer
ACI	American Concrete Institute
ASG	Apparent specific gravity
ASTM	American Society for Testing and Materials
C-25	25 Mega Pascal compressive strength
CAVM	Collage of Agriculture and Veterinary Medicine
CH	Coffee husks
CHA	Coffee husk ash
CO_2	Carbondioxid
CP	Coffee pulp
CSH	Calcium silicate hydrate
ES	Ethiopian standards
ESA	Ethiopian standard agency
GGBFS	Ground granulated blast furnace slag
GTP	Growth and Transformation Plan
hrs.	Hours
mln	million
MT	Metric ton
MPa	Mega Pascal
MRTC	Materials Research and Testing Center

OPC	Ordinary Portland cement
PLC	Portland lime cement
PPC	Portland pozzolan cement
RHA	Rise husk ash
SNNPR	Southern Nations, Nationalities, and People Region
W/C	Water to cement ratio
W/B	Water to binder ratio
WA	water absorption
PGRPD office	Post graduate research and publication director

CHAPTER ONE

INTRODUCTION

1.1 Background

Now a day's construction has become the most vital components to develop our country and it plays a critical role on social, economy especially to decrease unemployment. When we take about construction, it directly or indirectly related with concrete productions.

Concrete is the most commonly used construction material in the world. It is composite material composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space among the aggregate particles and glues them together (Monteiro, 2006). The paste contains cement and water and sometimes-other cementitious and chemical admixtures, whereas the aggregate contains sand and gravel or crushed stone. The paste binds the aggregates together. The aggregates are relatively filler materials, which occupy 70 to 80% of the concrete and can therefore be expect to have influence on its properties (Hailu, 2011). The proportion of these components, the paste and the aggregate is control by the strength and durability of the desired concrete, the workability of the fresh concrete and the cost of the concrete.

Concrete is a multipurpose and most popular construction material in our planet. To make concrete with recommended strength it needs proper proportioning of the ingredients and the right selections of materials to ensure a long-lasting concrete structure that does not require excessive maintenance in the future. The compressive strength of concrete is one of the most important and useful properties that quantify the quality of concrete.

Cement that is one of the components of concrete plays a great role, but is the most expensive and environmentally unfriendly material. Therefore, requirements for economical and more environmental-friendly cementing materials have extended interest in other cementing materials that can be used as partial replacement of OPC. Ground granulated blast furnace slag, fly ash; silica fume, etc. have used successfully for this purpose. Recently coffee husk ash, which is a byproduct of agricultural waste of coffee production have been tested in some parts of the world for its pozzolanic property and has been found to improve some of the properties of the paste, mortar and concrete like compressive strength and water tightness in certain replacement percentages and fineness

(Hsu, 2016). The strength of CHA concrete depends on the degree of burning temperature of coffee husk ash (Hsu, 2016). However, nothing has been done to check the feasibility of the coffee husk ash produced in Ethiopia for concrete productions.

The pozzolanic property of CHA came from the silicate content of the ash. This silicate under goes a pozzolanic reaction with the hydration products of the cement and results a reduction of the free lime in the concrete. The silicate content in the ash may vary from ash to ash depending on the burning temperature and other properties of the raw materials like the soil on which the coffee tree was grown.

Therefore, this research endeavors to make use of the CHA produced in Ethiopia, particularly in Jimma Zone, as a pozzolanic material to replace cement partially. An experimental exploration was carried out to examine the impact of adding coffee husk ash to the mechanical and physical properties of pastes and concretes such as consistency, setting time, workability, unit weighs and compressive strength.

1.2 Statements of the problem

Making concrete is not an easy task, especially to achieve the desired strength of concrete. Numbers of scholar's and researchers have been conducting different researches to find out suitable and environmental friendly ingredients to produce different types of concrete with acceptable strength. The strength developed by a concrete made with given materials and given proportions increases for many months under favorable conditions, but in the majority of specifications the strength is specify at an age of 28 days (Marsh, 1997). It has known that the strength of concrete in depending on the quality of ingredients used.

Among those ingredients the binder and the most costly and environmental unfriendly element is cement. As a result, the need to reduce the high cost of OPC in order to provide sustainable and cost efficient structure for the public and private sectors has strengthens researches in to the use of some locally available construction materials that shall be uses as partial replacement for OPC in construction industries. Various research works have been carried out on the binary blends of Ordinary Portland Cement with different cementitious materials such as fly ash, blast furnace slag, silica fume, rice husk ash, CHA and metakaolin in making cement composites proof to be effective in meeting most of the requirements of environmental friendly, sustainable and durable concrete structures (Obilade, 2014).

Cement production is one of the environmental unfriendly processes due to the release of CO_2 gases to the atmosphere and environmental degradations. It is believed that Portland cement clinker production is one of the major sources of CO_2 and other greenhouse gases within the contribution of 5 % of the annual global atmospheric CO_2 emission (MOI, 2016). In addition to its releases of different gases, its raw material extraction is environmental unfriendly due to degradation and disturbance of existing natural environment. This shows that the cement industry contributes to today’s worldwide concern, which is global warming. This endangers the sustainability of the cement industry and that of concrete.

Beyond to its adverse environmental impact cement is also one of the most expensive materials when compared to the other ingredients of concrete due to its huge energy consumption for productions. 20 -40 % of the total production cost of cement is attributed by energy (MOI, 2016). The raw materials for the cement production like lime is also being exploited in large amount that may result in running out of them, as it is predicted to happen in some places of the world and in the same way also in Ethiopia (Hailu, 2011).

Coffee husk is usually considered as a type of agriculture waste; as its quantity rises, the treatment/disposal of CH will become an environmental problem especially around coffee purple centres. The residue from coffee processing factories particularly coffee processing effluent and discharge from the factory can cause considerable pollution to water sources and people living around coffee processing stations have complains about pollution of rivers and its associated health impact (Ayele, 2011).

This research adopted the popular and normal agricultural waste material, coffee husk, to produce the ash of coffee husk through a high temperature combustion procedure and applied it to C-25 concrete specimen for examining the fresh and hardened concrete properties with different percentages of CHA as partial replacement of cement. The experiment has conducted to analyze the feasibility of CHA recycling in terms of partial replacement of cement for concrete material as alternative sustainable construction materials.

1.3 Research Questions

The research questions that this study was gone to explain were as follows:

1. What are the major chemical compositions of the CHA?

2. What is the optimum percentage of CHA for C-25 concrete production as a partial replacement of OPC?
3. Does CHA as partial replacement of OPC meet engineering properties of C-25 concrete?
4. Does CHA as partial replacement of cement has significant benefits in economic and environmental protection?

1.4 Objectives

1.4.1 General objective

The general objective of this study was to determine the suitability of CHA as a cement partial replacement for of C-25 concrete production.

1.4.2 Specific Objectives:

- To check the major chemical composition of the CHA.
- To determine the optimum ratio of CHA as a partial replacement of OPC for C-25 concrete productions.
- To investigate the engineering properties of C-25 concrete with CHA as a partial replacement of OPC.
- To assess economic and environmental benefits of CHA as partial replacement of OPC in C-25 concrete production.

1.5 Justification of the study

The study was conducted to investigate, an innovative and alternative concrete material that possesses feasibility and practicality was critical and significant for mitigating environmental impact and promoting energy-saving performance and sustainable development.

Consequently, this research was carried out with checking the feasibility of locally available agricultural byproduct, *CH*, which is produce as a waste in different part of the country for using it as OPC partial replacement material for C-25 concrete production. Addition to that it encourages uses of locally available resources, to reduce environmental pollution due to disposal of coffee husk, to minimize environmental pollution due to dust and CO_2 emission from cement production and to produce environmental friendly, sustainable and cost efficient cement products. Finally, recycled wastes help in the protection of environment and lowering of construction cost.

1.6 Scope of the Study

The scope of study would be a partial replacement of cement by Jimma Zone CHA for C-25 concrete production on the strength related properties of concrete which reflects the compressive strength of concrete as well as the investigation of the relation between density of concrete and strength.

All the CH waste collected were chosen from those coffee processing units in Jimma zone to avoid any inconsistent properties that may arise by mixing materials from different sources. The properties of CH waste from other coffee processing units in the country were not included in this study.

The research was done on C-25 grades of concrete. The influence of using waste of CH in high strength concrete was not covered in the present study. The percentage replacements were limited to 6 categories of 2, 3, 5, 10 and 15% replacement of the cement with one control mix. The different effects like durability and permeability which can be observed in different percentages of replacements, were not included in the present study.

CHAPTER TWO

LITERATURES REVIEW

2.1 Introduction

In the past moony years, numbers of researchers had done several researches on the cement and concrete technology advancements. One of the best advancement is the use of by-product materials as a cement replacement to improve environmental and economic impact of cement production. These cement-replacing materials were reported to improve different properties of the concrete.

Coffee husk ash is one of these by-product materials found from coffee pulping. Recently it has been studied for its feasibility as a cement replacing material in some parts of the world and has been found to improve some of the properties of mortar and concrete. The performance of mortar and concrete were assessed by different tests on both the fresh and hardened concrete. These include workability, density and compressive strength.

This chapter is, therefore dedicated in discussing about concrete making materials, different performance criteria of concrete, Pozzolanas and coffee husk and coffee husk ash.

2.2 Theoretical Reviews

Concrete is arguably the most important building material, playing a part in all building and other structures (Macginley and choo, 1990). Its virtue is its versatility, i.e. its ability to be mold to take up the shapes required for the various structural forms. It is also very durable and fire resistant when specification and construction procedures are correct.

The most widely used construction material is concrete, commonly made by mixing Portland cement with sand, crushed rock, and water. According to Monteiro (2006), it gets its popularity due to the following three primary reasons. Which are-

1. Due to its excellent resistance to water- Unlike wood and ordinary steel, the ability of concrete to withstand the action of water without serious deterioration makes it an ideal material for building structures to control, store, and transport water.
2. Due to its easiness to form into a variety of shapes and sizes- This is because freshly made concrete has a plastic consistency, which enables the material to flow into prefabricated formwork.

3. It is usually the cheapest and most readily available material on the engineering job. This is due to the principal components for making concrete, namely aggregate, water, and Portland cement are relatively inexpensive and are commonly available in most parts of the world.

Concrete is basically, a mixture of two components: aggregates and paste. The paste, comprised of Portland cement and water, binds the aggregates (usually sand and gravel or crushed stone) into a rocklike mass as the paste hardens because of the chemical reaction of the cement and water. Supplementary cementitious materials and chemical admixtures may also be included in the paste.

Concrete can be made to possess different properties that comprise strength, elasticity, water-tightness, durability and the likes. Concrete strength comprises compressive, tensile and shear Strengths; the elasticity stands for modulus of elasticity and creep; and durability of concrete is the ability of concrete to maintain its quality throughout its designed service life.

Since the primary function of practically all structures is to carry loads or resist applied forces of whatever nature, concrete used for such purposes must have strength. Hence, although in some cases other characteristics may be more important, the strength of concrete is commonly considered as its most valuable property. Furthermore, strength usually gives an overall picture of the quality of concrete, and it is considered as good index whether direct or inverse, of most of the other properties (Azaria, 2005).

Performance of concrete depends on the quality of the constituent materials as well as on their proportion and on the class of construction that comprises placing, compaction, and curing. Hence, to discuss about the performance of concrete it is mandatory to study about the concrete making materials and some other factors affecting this performance.

Concrete is mainly composed of cement, aggregate and water. Cementitious materials, pozzolanic materials, filler materials, chemical admixtures, and some other additives may also be the constituents of concrete depending on the need and their availability. All the constituents have their own purpose in the concrete. Cement with water acts as a binding medium in which the aggregates of the concrete are bound together to form the concrete. Economy, dimensional stability and wear resistance are the main reasons behind using aggregates. Different types of admixtures are used to modify the properties of ordinary concrete to make it suitable for any situation.

As a result, this wide speared in-use of concrete for buildings, dam, bridge, tunnels, highway and other infrastructures of necessity made concrete an important element of construction industry.

If a concrete is to be suitable for a particular purpose, it is necessary to select the constituent materials and combine them in such a manner as to develop the special qualities required as economical as possible. Therefore, the selection of constituents of concrete depends on the quality and economy of the particular concrete required.

2.2.1 Strength of concrete

Strength of concrete commonly considered as its most valuable property, although in many practical cases other characteristics, such as durability and permeability, may in fact be more important. Nevertheless, strength usually gives an overall picture of the quality of concrete because it is directly related to the structure of the hardened cement paste (Neville, 2000).

Concrete strength related to the stress required causing failure and it defined as the maximum stress the concrete sample can withstand. In tension testing, the fracture of the test piece usually signifies failure. In compression, the test piece is considered to have failed even when no signs of external fracture are visible; however, the internal cracking has reached such an advanced state that the specimen is unable to carry a higher load(E. Abebe, 2005).

Many properties of concrete, such as elastic modulus, water tightness or impermeability, and resistance to weathering agents including aggressive waters, are believed to be dependent on strength and may therefore be deduced from the strength data. Generally, the compressive strength of concrete is several times greater than other types of strength; therefore, majorities of concrete elements are designed to take advantage of the higher compressive strength of the material. Although in practice most concrete is subjected simultaneously to a combination of compressive, shearing, and tensile stresses in two or more directions and the 28-day compressive strength of concrete determined by a standard uniaxial compression test is accepted universally as a general index of the concrete strength (Monteiro, 2006).

The following properties of concrete have an effect on the strength of concrete such are hydration reaction, water to Cement ratio, aggregate type, amount and size, water content, cement content, curing condition, cement type, compaction method used etc.. Strength at any W/C ratio depends on the degree of hydration of the cement and its physical and chemical properties. The decrease in the water content of the concrete results in a higher strength of the concrete. The water required for the hydration reaction is less than that of the mixing water; the extra water provided used to make the concrete more workable. The compaction of the fresh concrete reduces the amount of entrapped air and therefore increases the strength of the concrete. It is found that for each 1 % of air entrapped there will be a 5 to 6 % loss on strength (D. Abebe, 2002). Curing temperature affects the hydration of cement and hence the duration of strength gains. Cubes kept at about 10^oC will have their 7 day strength reduced by 30% and their 28 day strength by 15% (D. Abebe, 2002). Different pozzolanic materials have different effect on strength of concrete.

2.2.2 Workability of concrete

Workability is the measure of how easy or difficult it is to place, consolidate and finish concrete. It contains in it different aspects like consistency, flow ability, mobility, compact ability, finish ability, and harshness (M. Sidney, 2003). In addition, it also defined in terms of the amount of mechanical work, or energy required producing full compaction of the concrete without segregation. A number of factors like water content of the mix, mix proportions, aggregate properties, time, temperature, characteristics of the cement and admixtures affects property of concrete:.

Workability is the property of freshly mixed concrete that determines the homogeneity with which it can be mixed, placed, compacted and finished. The properties related to workability include consistency, segregation, mobility, pump ability, bleeding, and finish ability (Leta, 2013).

Water content is the most important factor affecting the workability of concrete. Increasing the amount of water will increase the workability of the concrete. However, the increase in water content of the mix will decrease the strength and result in segregation and bleeding.

When considering the effect of aggregate the amount of aggregate, the proportion of coarse and fine aggregate and the shape and texture of the aggregate particles affect the workability of concrete. Keeping the water content and cement content constant increasing the amount of aggregate reduces the workability of concrete. Spherical and smooth aggregate result in a more workable mix, whereas flat, elongated and rough aggregate particles will result in reduction of workability. The increase in the ambient temperature will reduce the workability of the concrete, due to increase of evaporation and rate of hydration caused by the higher temperature. The cement content and cement replacing materials also affect the workability. Higher cement content reduces workability. The effect of cement replacing materials depends on their nature. Finer materials result in reduction of workability while spherical materials increase it (Monteiro, 2006).

According to ASTMC143/C143M (2011), workability of concrete can be assessed by slump test. Three different kinds of possible slumps exist, true slump, shear slump, and collapse slump. Conventionally, when shear or collapse slump occur, the test considered as invalid. However, due to recent development of self-compact concrete, the term of collapse slump has to be used with caution. Additions to that concretes having slumps less than 1⁄2 in. [15 mm] may not be adequately plastic and concretes having slumps greater than about 9 in. [230 mm] may not be adequately cohesive for this test to have significance.

2.3 Concrete making materials

2.3.1 Cement

Cement is a hydraulic binder, i.e. a finely ground inorganic materials which, when mixed with water, forms a paste which sets and hardens by means of hydration reaction and processes and which after hardening, retains its strength and stability even under water (ESA, 2013).

Cement is the prime ingredient used in the construction industry. Cement consumption has a direct correlation to economic growth and improvement in the living standards of society. Energy and capital intensity nature of the industry necessitate large investments that require a long-term perspective on financing and returns. Besides, production and consumption of cement are mainly subject to economic and construction cycles, resulting in volatility of operating costs and revenues (MOI, 2015).

Cement is a finely ground inorganic material which has cohesive (the tendency of a material to maintain its integrity without separating or rupturing within itself when subject to external forces) & adhesive (the tendency of a material to bond to another material) properties; able to bind two or more materials together into a solid mass. When it mixed with water form a paste that sets and hardens by means of hydration reactions, and which after hardening retain its strength and stability even under water. Cement is a fine grey powder which when reacted with water hardens to form a rigid chemical mineral structure which holds the aggregates together acting as glue and gives concrete its strengths (Lea's, 2004).

In a concrete mixture, the function of the cement is to react with water forming a plastic mass when the concrete is fresh and a solid mass when the concrete is hard. The properties of the hardened paste are affected by the characteristics of the cement and, the completeness of chemical combination between the cement and water.

Generally, cementing materials are of two types:

A. **Non-hydraulic cements**: are cements, which are either, not able to set and harden in water (E.g. Non-hydraulic lime) or which are not stable in water (e.g. gypsum plasters).

B. **Hydraulic cements**: are cements that are able to set and harden in water, and give a solid mass which does not disintegrate, i.e. remain stable in water example Portland cement.

2.3.1.1 Types of Portland cement

There are different types of cement depending on their composition, method of manufacturing (grinding, burning, etc.) and based on the relative proportion of the different compounds. One of these types and the most commonly used one is ordinary Portland cement, which in turn is divided into many types. The other common type of cement is Portland pozzolana cement that contains some amount of pozzolanic materials. Additions to these there are different types of cement that are used for special purpose of construction activities. From those classes of cement, ordinary Portland cement and Portland-pozzolana cement are the most widely produced and available type of cement in Ethiopia market. Addition to that currently Portland lime cement also produced in same cement factories here in Ethiopia like Messebo cement factory. For this reason, the discussion of cement in this thesis is mainly about the Portland cement.

According to ESA (2013), ” Portland cement means the product obtained by grinding clinker with the possible addition of a small quantity of calcium sulphates and/or water and it is manufactured by thoroughly mixing together calcareous or other lime – bearing materials with argillaceous and/ or other silica, alumina or iron oxide bearing materials burning them at a clinkering temperature and grinding the resulting clinker so as to produce a cement capable of complying with the requirements stipulated in the same standard”.

Portland cements are hydraulic cements composed primarily of hydraulic calcium silicates. Hydraulic cements set and harden by reacting chemically with water. During this reaction, called hydration, cement combines with water to form a stone like mass, called paste. When the paste (cement and water) is added to aggregates (sand and gravel, crushed stone, or other granular material) it acts as an adhesive and binds the aggregates together to form concrete, the world's most versatile and most widely used construction material (H. Kosmatka, 2003).

Portland cement is by far the most important member of the family of hydraulic cements that is hardened through chemical interaction with water. The history of cementing material is as old as the history of engineering constructions. The invention of Portland cement is credited to Joseph Aspdin, an English mason, in 1824. He named his product Portland cement, because it produced a concrete which resembled a natural limestone quarried on the Isle of Portland (Leta, 2013; Marsh, 1997).

The crucial ingredients of Portland cement are materials, which must contain the proper proportions of lime (CaO), silica (SiO_2), alumina (Al_2O_3), iron (Fe_20_3) with minor amounts of magnesia and sulfur trioxide (Domone, 2002).

The major constituents of cement are the tricalcium silicate (C3S), Dicalcium silicate (C2S), tricalciu aluminate (C3A) and tetracalcium alumino ferrite or iron compound (C4AF).

Table 2.1 Approximate oxide composition limits of Portland cement

Major Oxide	**Content in percent**
CaO	60 -67
SiO_2	17-25
Al_2O_3	3 – 8
Fe_2O_3	0.5 – 6
MgO	0.1 - 4.0
Alkalis	0.2 - 1.3
SO_3	1-3

Sources (E. Abebe, 2005; Domone, 2002; ESA, 2013)

Table 2.2 A typical composition of general-purpose OPC

Chemical Name	**Chemical formula**	**Shorthand Notation**	**Weight percentage**
Tricalcium silicate	3CaO.SiO2	C3S	55
Dicalcium silicate	2CaO.SiO2	C2S	18
Tricalcium aluminate	3CaO.Al2O3	C3A	10
Tetracalcium aluminoferrite	4CaO.Al2O3.FeO3	C4AF	8
Calcium sulfate dehydrate (gypsum)	CaSO4.2H2O	CSH2	6

Sources (Domone, 2002)

Of these compounds, C3S and C3A are mainly responsible for early strength of concrete. High percentages of C3S (low C2S) results in high early strength but also high heat generation as the concrete sets. The reverse combination, that is, low C3S and high C2S develops strength more slowly and generates less heat. C3A causes undesirable heat and rapid reacting properties, which can be prevented by adding $CaSO_4$ to the final product (Monteiro, 2006).

Different types of Portland cement are manufactured to meet different physical and chemical properties requirement for specific purposes. The American Society for Testing and Materials designation ASTMC150/C150M (2011) provides for eight types of Portland cements using Roman numeral designations as follows.

TYPE I

Type I is general-purpose Portland cement suitable for all uses where the special properties of other types are not required. It used where cement or concrete is not subject to specific exposures, such as sulfate attack from soil or water, or to an objectionable temperature rise due to heat generated by hydration. Its uses include pavements and sidewalks, reinforced concrete buildings, bridges, railway structures, tanks, reservoirs, culverts, sewers, water pipes and masonry units.

TYPE II

Type II Portland cement is used where precaution against moderate sulfate attack is important, as in drainage structures where sulfate concentrations in ground waters are higher than normal but not unusually severe. Type II cement will usually generate less heat at a slower rate than Type I. With this moderate heat of hydration (an optional requirement), Type II cement can be used in structures of considerable mass, such as large piers, heavy abutments, and heavy retaining walls. Its use will reduce temperature rise that is especially important when the concrete placed in warm weather. Type II cement has moderate sulfate resistant properties because it contains no more than 8% tricalcium aluminate (C3A).

TYPE III

Type III is a high-early strength Portland cement that provides high strengths at an early period, usually a week or less. It used when forms are to be removed as soon as possible, or when the structure must be put into service quickly. In cold weather, its use permits a reduction in the controlled curing period. Although richer mixtures of Type I cement can be used to gain high early strength, Type III, high early- strength Portland cement, may provide it more satisfactorily and more economically (ASTMC150/C150M, 2011).

TYPE IA, IIA, IIIA

Specifications for three types of air-entraining Portland cement (Types IA, IIA, and IIIA) are given in ASTM C 150. They correspond in composition to ASTM Types I, II, and III, respectively, except that small quantities of air-entraining materials are inter ground with the clinker during manufacture to produce minute, well distributed, and completely separated air bubbles. These cements produce concrete with improved resistance to freeze-thaw action.

TYPE IV

Type IV is a low heat of hydration cement for use where the rate and amount of heat generated must be minimized. It develops strength at a slower rate than Type I cement. Type IV Portland cement intended for use in massive concrete structures, such as large gravity dams, where the temperature rise resulting from heat generated during curing is a critical factor.

TYPE V

Type V is sulfate-resisting cement used only in concrete exposed to severe sulfate action principally where soils or ground waters have high sulfate content. It gains strength more slowly than Type I cement.

A. Ordinary Portland cement

Portland cement is one of the most widely used cement and is the most important hydraulic cement. It can also be used for mortar & plaster production. It used in all types of structural concrete like walls, floors, bridges, tunnels, etc. It further used in all types of masonry works like foundations, footings, dams, retaining walls, and pavements. When OPC mixed with sand and lime, it serves as mortar for laying brick and stone; and when it mixed with coarse aggregate and fine aggregate (sand) together with enough water, to ensure a good consistency, we get concrete.

B. Portland Pozzolanic cement

Portland Pozzolanic cement (PPC) is manufactured by the inter-grinding of OPC clinker with 15 to 35 % of pozzolanic materials (H. Kosmatka, 2003). Pozzolanic materials are siliceous or aluminous materials, which by themselves possess little or no cementitious properties. However, in the presence of water they react with calcium hydroxide that is liberated from the hydration of cement to form a compound possessing cementitious property. The reaction of the pozzolanic materials with calcium hydroxide results in many advantages of PPC over OPC. If these pozzolanic materials were not reacted with the calcium hydroxide, free calcium hydroxide would have been present in the concrete resulting in higher permeability of the concrete and susceptibility to other attacks. The pozzolanic reaction reduces the porosity of the concrete by producing cementitious compound. It also reduces the heat of hydration since its reaction is slower than that of OPC, which implies that it has slower rate of strength than OPC, making it suitable for masse concrete construction.

2.3.1.2 Physical properties of cement

Specifications for cement place limits on its physical properties. An understanding of the significance of some of the physical properties is helpful in interpreting results of cement tests. Tests of the physical properties of the cements should be used to evaluate the properties of the cement, rather than the concrete. Cement specifications limit the properties with respect to the type of cement. Cement should be sampled in accordance with ASTM C 183.

2.3.1.2.1 Fineness

The finesse of cement to which cement is ground during its production can have considerable effect on the behavior of cement during hydration. Although it is, true that if cement does meet normal specification changing the cement finesse is nonetheless an important parameter of greater importance. The rate of hydration increases with increasing fineness. This leads to both higher rate of strength gain and higher rate of evolution of heat. Since hydration takes place at the surface of the cement particles and further hydration is hindered by the formation of the reaction products, finer particles will be more completely hydrated than coarser particles. Larger cement particles probably never hydrate completely. Increase fineness tends to decrease the amount of bleeding, but at high finesse the amount of water required for workability for non- air entrained concrete is increased, which results in increased drying shrinkage. It is also worth noting that high cement finesse requires a greater amount of gypsum for proper set control, owing to the increase availability of C3A for reaction, and reduces the durability of concrete to freeze-thaw cycles.

These properties of the cement in turn affect many other properties, like normal consistency, setting time, strength, etc. Fineness of cement can be measured mainly by specific surface area method and particle size distribution.

According to the Ethiopian standard ESA (2013), OPC shall have a specific surface area of not less than 2250 cm^2/g, whereas the ASTMC150/C150M (2011) standard recommends a minimum of 2800 cm^2/g. and for particle size distribution both standards stated that, the residue by weight on sieve not to exceed 10 % of original weight for OPC.

2.3.1.2.2 Consistency of cement paste

Many of the properties of concrete are affected by its water content. The physical requirements of cement paste like setting and soundness depends on the water content of the neat cement paste. Therefore, it is necessary to define and study the water content at which to do these tests. This is defined in terms of the normal consistency of the paste, which is measured according to (ASTMC187, 2011). The amount of water required to achieve a normal consistency as defined by a penetration of 10 ± 1 mm of the Vicat plunger is expressed as a percentage by weight of the dry cement, the usual range being about 26 to 33 % (ASTMC187, 2011). The test is very sensitive to the conditions under which it is being carried out, particularly the temperature and the way the cement is compacted into the mold. The test does not correlate to the quality of the cement; it only measures the plasticity of cement paste.

2.3.1.2.3 Setting time

Setting is a process in which cementitious mixtures of plastic consistency is converted into a set material which has lost its deformability and crumbles under the effect of sufficiently great external force (Hailu, 2011). It is preceded by, a stiffening of the paste in which the apparent viscosity of the material increases without losing its plastic character. There are two types of setting time i.e. initial and final setting times. The initial setting time indicates the time at which the paste begins to stiffen considerably and cannot longer be molded; while the final setting time indicates the time at which the paste has hardened to the point at which it can sustain some load. Like normal consistency, these tests are also used for quality control. Ethiopian standard recommends that the initial setting time for cement not to be less than 45 minutes and the final setting time not to exceed 10 hours (ESA, 2013).

2.3.1.3 Cement production in Ethiopia

In terms of consumption and production of cement in the world, China leads the way due to the large-scale developments and infrastructure buildup projects that the Chinese government is undertaking. According to 2014 estimates, the Chinese production was 2430 Million tons per annum (see Table 2.3) covers around 57.8% of world total while the second closest rival, India covers around 6.7% (MOI, 2015).

The construction industry is giving a special focus in the policies of the many developing countries. In Ethiopia, due to its critical role in the overall economic development, the cement industry is identified as one of the areas of the first and second Growth and Transformation Plan (GTP) as a sector of special consideration. Unlike the case in developed and emerging economics, concrete industry has not yet emerged as a significant consuming of cement. The energy cost of Ethiopian cement firms account nearly 50-60 % the total production structure as contrast to 30 to 40 % of global standards (Aklilu, 2016).

Table 2.3 The top eleven nations in the world in production of cement (MT)

No.	**Country**	**2010**	**2011**	**2012**	**2013**	**2014**
1	China	1880	2080	2220	2350	2430
2	India	224.7	240.5	246.7	272.0	300.0
3	USA	66.5	67.9	74.4	82.7	92.8
4	Iran	61.6	66.4	73.2	76	78
5	Brazil	59.1	64.1	68.0	73.3	77.9
6	Turkey	66.2	667.8	69.0	71.0	73.5
7	Russia	50.4	56.1	60.0	63.0	65.0
8	Egypt	48.0	45.4	55.2	58.0	62.0
9	Japan	56.6	56.4	59.0	60.0	60.0
10	Vietnam	50.5	52.0	47.0	48.4	51.2
11	South Korea	47.4	48.3	48.9	48.4	48.1
12	Ethiopia	2.08	3.55	1.91	2.14	6.11

Source (MOI, 2015)

In Ethiopia, Given the vast geographical size and massive population, various construction activities are being undertaken by the Federal Government, Regional Governments, Public Sector Undertakings and other organizations, including the private sector that generates a huge demand for cement. The major factors that are causing a huge demand for cement are heavy investments on housing projects, universities, infrastructures, power generation plants and irrigation, industrial zones, airport fields, railways and road construction projects.

The increasing demand for cement has also provided the desired boost to the cement industry leading to a quite visible growth of additional production capacity. Due to the rapid economic growth in general and construction activities in particular, cement consumption has risen by an average growth rate of 30 % , well above the growth rates seen during this period for both overall GDP growth (11 %) and the construction sector (10 %) and for least five years it is on the breakeven point of demand and supply perspectives. This increase in cement consumption which is triggered by huge projects in the construction sector has led to extensive private sector domestic and foreign investments to establish cement manufacturing industries (MoFD, 2010).

In Ethiopia, Italians established the first cement factory in 1936 during the five-year fascist occupation of the Country (Getaneh, 2010). This was the Dire Dawa cement factory. Due to the rise in concrete construction in Ethiopia, the demand for cement has been growing since then and in 2008 there were four cement plants with a combined production capacity of about 2.85 million metric tons per year as reported by Ethiopian investment agency. Currently there are around 26 functional cement factories with total production capacity of 26.21 million tones.

Currently, in Ethiopia, cement is mainly produced in three forms: Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC) and Portland lime cement (PLC). OPC is the most common type of cement in general use around the world because it is a basic ingredient of concrete. PPC is ordinary Portland cement blended with pozzolanic materials like fly ash, burnt clays, ash from burnt plant material or silicious earths, either together or separately. PLC is produced by incorporated huge percentage of lime and currently it is produced by Messebo cement factory. In Ethiopia, approximately 18 percent of the total production was historically OPC, while 81.1 percent was PPC and 0.9 percent of PLC (MOI, 2016). The construction industry is growing in a shocking rate. Ethiopia historically has low cement per capita consumption as low as 39 Kg in 2011 whereas it reached 62 kg in 2014 which is still low compared to the global average of 500 kg/ year (MOI, 2015).

According to Getaneh (2010), cement industry needs high capital investment. It is also energy intensive. It is highly dependent on power and transport. Some of the fundamental elements to be considered in cement production investment are discussed below.

a. Cost of Production

The cement industry is one of the highest energy-intensive industries in the world, with fuel and energy costs typically representing 30-40 % of total production costs. Raw material costs represent the second-largest percentage of cement manufacturers' cost structures. The abundance of these raw materials in most parts of the country is reliable.

The distribution of cement factories throughout the country justifies the availability of sample raw materials for the cement industry. However, variances across regions and companies depend on the operating efficiency of each producer relative to each other.

b. Raw Materials

The primary raw materials used for cement production are limestone, clay, chalk, marl, and others, significant quantities of which are continuously quarried to service the demand for cement.

Alternative materials have been sourced to substitute for traditional natural raw materials. The industry currently uses large quantities of blast furnace slag, power station fly ash, silica fume, and natural pozzolana and limestone fines, mainly to substitute for natural raw materials in the production process of blended cement such as GGBS and PFA. The use of these alternative materials has significant positive environmental and economic benefits. The needs to quarry primary raw materials are reduced, energy consumption in cement production is cut, and over all reductions in emission of dust, CO_2 and acid gases are attained. In some applications, the performance of concrete can be enhanced when these alternative materials complement Portland cement clinker.

c. Energy/Power

Cement manufacturing is an energy-intensive process. The specific thermal energy consumption of a cement kiln varies between 3,000 and 7,500 million joules per ton of clinker, depending on the basic process design of the plant. The specific electrical energy consumption typically ranges between 90-130 kWh and 60-130 Kg of fuel oil per ton of cement.

According to MoFD (2010),”the cement industry was expected to produce 4.7 mln tons of cement per year in order to meet the demand in 2015, 27 mln tons per years. However, the industry achieved an output of only 11.17 mln tons of cement in the year 2009/2010”. This result suggests the need to increase the production and supply capacity of cement in order to meet the need of the fast growing construction industry.

Table 2.4 Cement Consumption in Ethiopia (in mln MT)

Year(GC)	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**2014/15**	**2015/16**	**2016/17**
Consumption estimate	2.7	9.34	13.6	13.6	17	27	29.2	31.2
Actual production	1.87	2.08	3.55	1.91	2.14	6.11	11.3	12.9

Sources (CSA, 2016; MOI, 2017)

The future demand of Ethiopia for cement, like many other construction materials is a function of a number of interrelated variables. Some variables that is essential in determining the magnitude and trend of demand for cement are-

- The overall economic development level and growth trend of the country,
- The pattern and growth trend of the construction industry,
- Expected technological changes that affect the structure of the construction industry,
- Government policies and regulations that have impact on the future level and trend of construction activities, and
- Size of population and its growth rate etc.

Generally, review of sources put forward that Ethiopia has greater cement demand driver’s potential for higher cement consumption to come mainly due to continued and robust GDP growth. Some of those demand driver’s factor are;- Political stability, increasing per capita income and emergence of middle class, increasing government capital budget expenditures, rapid urbanization (4.3 %), high rate of population growth (2.6 %), significant housing shortages, large infrastructural gap and development of industrial parks (29.37 million square meters) (CSA, 2016; Getaneh, 2010; MoFD, 2010). Besides, in order for the country to realize the dream to join middle-income countries by 2025, several other mega projects will be undertaken in years to come.

Table 2.5 Cement production in Ethiopia in 2017

No.	**Factories Name**	**Annual Production Capacity (in MT)**	**Location of the project**
1	Abyssinia Cement PLC	90 000	North Shoa, Chancho
2	National Cement	1 050 000	Dire Dawa
3	Jemma PLC	180 000	North Shoa, Muketuri
4	Red fox Cement	150,000	Modjo
5	Derba Midroc-Dejen	90,000	Eas Gojjam, Dejen
6.	Huang shan Cement PLC	600,000	Modjo
7	Toure Dire Dawa Cement PLC	600,000	Dire Dawa, Melka Jebdu
8	Zangeshan Cement PLC	250,000	Dukem
9	East Cement PLC	750,000	North Shoa, Fiche
10	Ethio Cement PLC	850,000	North Shoa, Chancho
11	Mugher cement	1,400,000	West Shoa, Mugher
12	Derba Midroc-Derba (main)	2,300,000	North Shoa, Derba
13	Messebo Cement	1,800,000	Mekelle
14	Habesha Cement	1,200,000	Holeta
15	Hua Yi Cement	150 ,000	Nazareth
16	Sunrise Industrial PLC	3,000,000	West Shoa, Minare
17	Star Business Group	1,200,000	North Shoa, Ijjare

18	Falath Petroleum Dire Dawa Cement	750,000	Dire Dawa, Melka Jebdu
19	Chamo PLC	500,000	North Shoa, Fiche
20	MYK PLC	0.3-0.4 mln	North Shoa, Bekuyu (prop)
21	Dangote Industries PLC	2,500,000	West Shoa, Mugher
22	B.M Cement Technology PLC	1,600,00	Dire Dawa,
23	C.H Manufacturing PLC	4.0 mln	North Shoa, Fiche
24	Pioneer cement	400,000	
25	Capital cement	300,000	
26	Inchini Bedrock	150,000	
Total		26,210,000	

Source: *(MOI, 2017)*

***N.B** from the table 2.5 the total estimated annual local production is 26.21 mln of MT. but according to (Gemechu, 2016) our country's production capacity is around 60 % of their annual estimated production capacity. As a result the country's' annual production is 15,726,000 MT.*

Generally, the general trend of cement production and consumption in Ethiopia has been increasing. Yet the prevalence of underutilized cement production capacity remains outstanding challenge for Ethiopian's cement industry. Currently, the average cement production capacity utilization rate in the country is about 50 %. The level of capacity utilization even compared to global average of 60 to 70 % or recommended acceptable optimum production capacity utilization rate that ranges between 80 to 85 % is sustainably low (Gemechu, 2016).

2.3.2 Pozzolanas

The modern concrete technology uses different types of admixtures in order to enhance the properties of the fresh and hardened concrete. Mineral admixtures are one of these admixtures used in concrete for a variety of purposes. They may be found naturally or artificially. These admixtures can be divided into three main categories, which are pozzolanic, cementitious and non-reactive materials. In this study, the researcher concerned with pozzolanic admixtures particularly CHA, which are described in section 2.3.3.

2.3.2.1 Pozzolanic materials

A pozzolan is a siliceous or aluminosiliceous material that, in finely divided form and in the presence of moisture, chemically reacts with the calcium hydroxide released by the hydration of Portland cement to form calcium silicate hydrate (CSH) and other cementitious compounds (H. Kosmatka, 2003). Clay and shale, opalinc chert, diatomaceous earth, and volcanic ash are an example of natural Pozzolanas while fly ash, blast furnace slag, silica fume, rice husk ash, coffee husk ash and metakaolin are example of artificial Pozzolanas. Most of the pozzolan in use today are mainly by-product materials that are widely available. Because of the diversity of pozzolan, their chemical composition also varies. Therefore classifying Pozzolanas only depending on their chemical composition would be difficult. For this reason, ASTM C 618 classifies Pozzolanas depending on performance basis.

Table 2.6 chemical requirement for Pozzolanic materials

Chemicals	**Pozzolan Class**	
	F	**C**
SiO2+Al2O3+Fe2O3 (min %)	70	50
MgO (max %)	…	5
SO_3 (max %)	5	5
Moisture content (max %)	3	3
Loss on ignition (max %)	12	10
Available alkalis as Na_2O (max %)	1.5	1.5

Sources (ASTMC-618, 1999)

The reason behind using Pozzolanas is the improvement found on both the fresh and hard concrete. Lowering of the heat of hydration and thermal shrinkage, increase in water tightness, reduction in the alkali aggregate reaction, resistance to sulfate attack, better workability, and cost efficiency are some of the improvements achieved by using Pozzolanas blended with Portland cement (Hailu, 2011).

Fly ash is a supplementary cementitious material in concrete and a byproduct of the combustion of pulverized coal in electric power generating plants. It is a fine-grained material consisting primarily silicate glass containing silica, alumina, iron, and calcium. Minor constituents are magnesium, sulfur, sodium, potassium, and carbon. Deferent scholars sagest 10-15 % of fly ash cement replacements are recommend (Marsh, 1997).

Blast-furnace slag is a byproduct of iron manufacture. It is non-metallic hydraulic cement consisting essentially of silicates and aluminosilicates of calcium developed in a molten condition simultaneously with iron in a blast furnace. The molten slag at a temperature of about 1500 °C is rapidly chilled by quenching in water to form a glassy sand like granulated material which is one of the recommended cement replacing materials. Due to this GGBFS in the presence of water and an activator NaOH or CaOH supplied by Portland cement, hydrates and sets in a manner similar to Portland cement (H. Kosmatka, 2003)

Silica fume is a byproduct material that is use as a pozzolan. This byproduct is a result of the reduction of high-purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume is use in amounts between 5 % and 10 % by mass of the total cementitious material. It is use in applications where a high degree of impermeability is need and in high strength concrete (H. Kosmatka, 2003).

Highly reactive metakaolin has recently become available as a very active pozzolanic material for use in concrete. Unlike fly ash, slag, or silica fume, this material is not a byproduct but is manufacture from high-purity kaolin clay by calcination at temperatures in the region of 700 to 800 °C. Unlike silica fume, which contains more than 85 % SiO_2, highly reactive metakaolin contains equal proportions of SiO_2 and Al_2O_3 by mass (H. Kosmatka, 2003).

Bagasse is a cellulose fiber remaining after the extraction of the sugar-bearing juice from sugarcane. The bagasse ash is about 8-10 % of the bagasse and contains unburned matter, silica and alumina. Sugarcane bagasse ash as described before contains silica, which is the most important component of cement replacing materials. It is also finding in large amount as a byproduct in sugar factories. Some studies show that replacement of OPC by bagasse ash from 5 to 10 % results in a better compressive strength than that of the control mortar (Hailu, 2011).

Rise husk ash which is an agricultural by-product, has been report to be a good pozzolan by numerous researchers. They investigated the use of RHA to reduce temperature in high strength mass concrete and got result showing that RHA is very effective in reducing the temperature of mass concrete compared to OPC concrete (Obilade, 2014).

2.3.3 Coffee husk

Coffee is one of the most consumed beverages in the world and is the second largest traded commodity after petroleum. Due to the great demand of this product, large amounts of residues are generated in the coffee industry, which are toxic and represent serious environmental problems. Coffee silverskin and spent coffee grounds are the main coffee industry residues, obtained during the beans roasting, and the process to prepare "instant coffee", respectively. Recently, some attempts have been made to use these residues for brick, ceramic and mortar or value-added compounds production, as strategies to reduce their toxicity levels, while adding value to them (Teixeira, 2011).

Coffee husk is the most abundantly available agro industrial waste produced during the pulping action of the coffee cherries to obtain coffee beans in many coffee-producing areas of the tropics including Ethiopia.

The use of different cement replacing materials has become a common practice in the construction industry. Most of these cement replacement materials are byproducts of different industries and agricultural wastes. Blast furnace slags, silica fume, fly ash, bagasse ash and rice husk can be sited as an example. Coffee husk ash has also been founded to have such pozzolanic property.

With the rise in environmental awareness and the consumption of natural resources, the issue of energy saving has been gradually emphasize by the public. Therefore, if the researcher finds out an appropriate alternative material, it will be able to relieve the energy problem. Owing to considerable use of cement and concrete material, the natural material resources related to the construction industry has been continuously reduces in recent years. However, for each country particularly for developing country like Ethiopia, concrete is the most important material for fundamental and public constructions. Thus, an innovative and alternative concrete material, which possesses feasibility and practicality, is critical and significant for mitigating environmental impact and promoting energy-saving performance.

Coffee is one of the most consumed beverages in the world. The coffee tree or scrub originates from Ethiopia and is cultivated in over 80 countries worldwide. The scrubs start blooming after three to four years and provide a full harvest after another six years. The maximum yield obtained after 10-15 years and it bears fruit for approximately 40 years. The coffee fruit, which is a stone fruit and also is called coffee berry or coffee cherry, is cherry-like and grows to 1.5 cm in diameter. The fruit has a green unripe skin which turns red-violet or deep red during ripening, which occurs eight to twelve month after flowering (Bondesson, 2015).

Coffee, a commodity ranking second only to petroleum in terms of currency traded worldwide, is quite relevant to the economy of its major producing countries such as Brazil, Vietnam, Indonesia, Colombia, Ethiopia, India, and Mexico (Franca, 2015). Coffee husk is usually regarded as a kind of agriculture waste; as its quantity increases the treatment of coffee husk will become an environmental problem (Hsu, 2016).

Coffee processing generates significant amounts of agricultural waste, ranging from 90 to 130 % of the weight of the total coffee produced, depending on the type of processing. Coffee husks (CH) and coffee pulp (CP) are the solid residues obtained after dehulling the coffee cherries during dry or wet processing, respectively. They are probably the major residues from the processing of coffee, for which there are no profitable uses, and their adequate disposal constitutes a major environmental problem. Furthermore, in compliance with the concept of sustainable development, innovative techniques and products for the valorization, reuse, and recycle of this type of residue should be required (W. Mbugua, 2014).

2.3.3.1 Coffee processing

A brief description of the types of coffee processing is necessary to understand the different proposals for adequate exploitation of CHs available in the literature. The cherry usually bears two coffee beans inside, with their flat sides facing each other, and each bean is covered with a tightly fitting tegument, termed silver skin. A second yellowish skin, the parchment, loosely covers each bean. The parchment-covered beans are encased in a mucilaginous pulp, the flesh of the cherry, which, in turn, is covered by the outer skin or peel. The green coffee bean constitutes only 50–55 % of the dry matter of the ripe cherry. The remaining material is diverted to various types of waste, depending on the processing technique used (W. Mbugua, 2014). Once the cherries are harvested, the beans have to be extracted by using either the dry or the wet method (Aster, 2011; Kumar, 2013; W. Mbugua, 2014)

2.3.3.1.1 Dry method

The dry method (also called the natural method) is the oldest, simplest and requires little machinery and the process is slow, ranging from three to four weeks. The method involves drying the whole cherry. There are variations on how the process can be carried out, depending on the size of the plantation, the facilities available and the final quality desired. The three basic steps of this method are cleaning, drying and hulling. This method is use for about 95 % of the Arabica coffee produced in Brazil; most of it is produce in Ethiopia, Haiti and Paraguay (Shimelis, 2011).

Coffee husks, which are produced through these methods, are the major solid residues from the handling and processing of coffee, since for every 1 kg of coffee beans produced, approximately 1 kg of husks are generated (Aster, 2011; Franca, 2015).

Figure 2.1 CH disposal at Yayu, Illubabor, source (Takele, 2014)

2.3.3.1.2 Wet Method

The wet method requires the use of specific equipment and substantial quantities of water. When properly done, the qualities of the coffee beans are better preserved, producing a green coffee that is homogeneous and has few defective beans. Hence, the coffee produced by this method is usually regarded as being of better quality and commands higher prices (Franca, 2015; Shimelis, 2011; Takele, 2014).

2.3.3.2 Pozzolanic property of coffee husk ash

As described in previous sections Pozzolanas are siliceous or siliceous and aluminous materials which alone possess little or no cementitious value but which will, in finely divided form in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties (H. Kosmatka, 2003). CHA was also tested to have such property. It acts as a pozzolanic material when added to cement because of its silica (SiO_2) and aluminate content, which reacts with free lime release during the hydration of the cement and forms additional CSH as a new hydration product (Gonzalez, 2010). The silica content of the ash depends on the type of soil and harvesting. It also found that silica content of the ash depends on the burning temperature of the coffee husk. High temperature helps eliminate impurities in CHA as well. A research conducted on the burning of coffee husk at 400, 500, 600, 700, and 800 ^{o}C identified the suitable burning and residence time to be 500-600 ^{o}C(Gonzalez, 2010; Hsu, 2016). The higher temperatures will give higher amount of silica content, but the resulting silica is in crystalline form that is not in active state.

Table 2.7: Major chemical composition of cements raw materials of Vs CHA

Component	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**K_2O**	**Na_2O**
Limestone	2.68	0.62	0.46	51.85	1.94	0.03	0.05	0.02
Sandy Cay	81.56	11.29	1.79	0.12	0.09	0.05	0.14	0.03
Clay	65.18	21.91	3.36	0.11	0.08	0.06	0.19	0.04
Iron ore	14.88	16.79	57.74	0.12	0.56	0.04	0.04	0.03
Shale	61.10	16.42	7.01	1.02	2.34	0.01	4.12	1.65
Sand	94.70	2.90	0.24	0.35	0.13	0.01	0.60	0.21
Bauxite	3.11	57.59	15.74	4.16	0.16	0.29	0.08	0.08
Gypsum	4.31	0.34	0.14	31.19	0.11	43.88	-	-
Fuel Ash	57.20	17.36	9.11	3.95	1.80	3.40	0.78	2.50
Bagasse Ash	65.58	5.87	4.32	1.78	1.23	0.18	6.41	1.02
CHA	16.55	17.18	3.98	5.68	1.12	1.9	19.3	1.84

Source (Adisu, 2014; Hailu, 2011) and CHA complete silicate analysis appendix E

2.3.3.3 Coffee husk ash as cement replacing material

These days sustainability plays the major role in every aspect of human activities. Many technologies ended because they were not in harmony with the idea of sustainable development. Sustainability is concerned about the world we will be leaving behind for future generations, that is, to our children and their children. It focuses on the social, environmental and economic issues of human activities.

Concrete being one of the most widely used materials worldwide next to water, is not free from some negative environmental impacts. Its popularity carries with it a great cost in terms of environmental aspects. According to Meyer (1999), Environmental problems associated with concrete can have varied origins:

1. Worldwide, over ten billion tons of concrete produced each year. Such volumes require vast amounts of natural resources for aggregate and cement production. In addition to this, it is estimate that one ton of Portland cement production releases about one ton of CO_2.
2. The production of Portland cement is also energy intensive by its nature for the extraction of raw materials, transportation, clinker preparation, grounding of clicker, etc.
3. The demolition and disposal of concrete structures, pavements, etc., constitutes another environmental burden. Construction debris contributes a large fraction of solid waste disposal problem.
4. Finally, the water requirements are enormous and particularly burdensome in those regions of the earth that are not blessed with an abundance of fresh water. The concrete industry uses over 1 trillion gallons of water each year worldwide, and this does not even include wash water and curing water.

These points show that concrete industry has become the victim of its own success. However, most of the environmental problems associated with concrete come from the cement in it. This means that the final product i.e. concrete is environmental friendly material by itself (Meyer, 1999). This guides us to play on the concrete constituents that cause the problem. One of the constituent, which causes the largest environmental impact, is Portland cement. Therefore, if we are able to minimize the amount of Portland cement in the concrete we will be able to minimize the environmental impact of the concrete industry as a whole. Many ways were suggested to increase the compliance of the industry to the demand of sustainable development. Increased use of supplementary cementitious materials, increased reliance on recycled materials, improved sustainability and mechanical property and reuse of wash water are some of the methods.

The reduction of Portland cement in concrete can be achieved by replacing it with different supplementary cementitious materials that are a by-product of another industry. Fly ash, silica fume, GGBFS, etc. have been use for this purpose successfully. Coffee husk ash as described before contains silica, which is the most important component of cement replacing materials. It also found in large amount as a byproduct of agriculture. Despite this abundance and silica content, relatively little was been done to examine the potential of this material for concrete production. Even though little, the conducted researches confirm the suitability of this material for concrete production by replacing cement in some percentage for mortar and concrete. When CHA used as cement replacing material, it results in some improvement on the properties of concrete. At 28 days, mortar containing coffee husk ash at 15 % replacement showed compressive strength higher than the control mortar (Franca, 2015; Gonzalez, 2010).

2.3.3.4 Availability of coffee husk in Ethiopia

Ethiopia endowed with a good production environment for growing coffee with a combination of appropriate altitude, temperature, rainfall, soil type, and pH. Ethiopia is the center of origin for Coffea Arabica (Takele, 2014). The country possesses a diverse genetic base for this Arabica coffee with considerable heterogeneity. Ethiopia produces a range of distinctive Arabica coffees and has considerable potential to sell a large number of specialty coffees. Coffee production in Ethiopia is almost exclusively situated in the two regions of Oromia and the SNNPR in the south and west of the country (Bart Minten, 2014). Jimma zone is one of the areas in Ethiopia where coffee producing plants are cultivated in large quantities. According to (ICO, 2016b) Ethiopia’s coffee production from 2012-2016 are 6 233, 6 527, 6 625 and 6 700 in thousand 60kg bags respectively.

Ethiopia is the seventh largest coffee producer worldwide and ranked ninth in coffee export. And also the largest coffee producer in Africa: Around 400,000 tons per annual – all of it Arabica which is processed in both method (Shimelis, 2011). According to the (ICO, 2016a), the fourth international coffee conference (ICC) which was held in March 2016 at Addis Ababa, report forecasted for Ethiopian coffee export quantity for 2016 was 230,000 tons.

Jimma zone is one of the areas in Ethiopia where coffee producing plants are cultivated in large quantities. Coffee is the main important cash crop of the zone. Based on (CSA, 2016) coffee were produced in this zone in the year ending in 2016 represents 23.2 % of the Region's output and 11.8 % of Ethiopia's total output, and makes Jimma one of the three top producers of this crop, along with the Sidama and Gedeo Zones. In fact, most kebeles found Jimma zone has potential of producing coffee crop. Among seventeen woredas found in Jimma zone, Gomma, Limmu Kosa, Manna, limmu saqa and Gera produces altogether around 68 percent of coffee produced in zone.

Beyond this the fifth international coffee conference (ICC) that was held in February 2017 at Addis Ababa, report shows that Ethiopia export only 40 % of its total production. As a result, the reaming 60 % of coffee is use by local market.

As above dissection Coffee husks, which are produce through dry method, since for every 1 kg of coffee beans produced, approximately 1 kg of husks be generated (1:1 ratio) (Franca, 2015; Gonzalez, 2010; Shimelis, 2011).

Table 2.8 Total coffee production and associated residue from 2009-2016

Production years	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**2014/15**	**2015/16**
Total production (tons)*10^3	341	405.7	482.89	579.468	695.362	831	945.3
Residue (dry base) (tons)*10^3	341	405.7	482.89	579.468	695.362	831	945.3
Equivalent ash productions (tons)*10^3	62.403	74.243	88.369	106.043	127.251	152.073	172.990

Source (CSA, 2016)

From the tables 2.8 it is possible to summarize that coffee processing and coffee bean production produce huge amounts of coffee husk that can be converted in to cementiouse materials in factory level.

2.3.4 Aggregates

Aggregate may be defined as relatively inert mineral filler used in the production of concrete. This aggregate consists of uncrushed or crushed gravel, crushed stone or rock, sand, or artificially produced inorganic materials.

The importance of using the right type and quality of aggregates cannot be overemphasized. The paste is composed of cementitious materials, water, and entrapped air or purposely-entrained air. The paste constitutes about 25 to 40 % of the total volume of concrete. From these the absolute volume of cement is usually between 7 % and 15 % and the water between 14 % and 21 %. Air contents in air-entrained concrete ranges from about 4 % to 8 % of the volume. Aggregates generally divided into two groups: fine and coarse aggregates. Fine aggregates consist of natural or manufactured sand with particle sizes ranging up to 9.5 mm (3⁄8 in.); coarse aggregates are particles retained on the 1.18 mm (No. 16) sieve and ranging up to 150 mm (6 in.) in size. The maximum size of coarse aggregate is typically 19 mm or 25 mm (3⁄4 in. or 1 in.). An intermediate-sized aggregate, around 9.5 mm (3⁄8 in.), is sometimes added to improve the overall aggregate gradation (Marsh, 1997).

The fine and coarse aggregates generally occupy 60 to 75 % of the concrete volume (70 to 85 % by mass) and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy (Neville, 2000).

They are granular materials derived for the most part from natural rock and sands. Moreover, synthetic materials such as slag and expanded clay or shale are used to some extent, mostly in lightweight concrete. In addition to their use as economical filler, aggregates generally provide concrete with better dimensional stability and wear resistance. Based on their size, aggregates divided into coarse and fine fractions. The coarse aggregate fraction is that retained on the 4.75 mm sieve while the fine aggregate fraction is that passing the same sieve. Based on their origin, aggregates can be classified as natural aggregates and non-natural aggregates (E. Abebe, 2005).

a. Natural Aggregates

Mineral aggregates consist of sand and gravel, stones and crushed stone. Construction aggregates make up more than 80 % of the total aggregates market, and are used mainly for road base, riprap, cement concrete, and asphalt. The sources of mineral aggregates are by directly extracting from the original sources like river basins or by manufacturing them into a desired shape from the parent rock in a crasher mill**.** It was also found out that manufactured sand offers a viable alternative to the natural sand by providing a higher compressive strength and delivering environmental benefits.

b. Non Natural Aggregates

This category consists of aggregates that are artificial in origin. The reasons for their advent in concrete construction are:

- Environmental considerations are increasingly affecting the supply of aggregate.
- There are strong objections to opening of pits as well as to quarrying.
- At the same time, there are problems with the disposal of construction demolition waste and with dumping of domestic waste.

However, these types of waste can be processed into aggregate for use in concrete and this is increasingly being done in a number of countries. Wide varieties of materials come under the general heading of solid wastes. These range from municipal and household garbage, or building rubble, such as brick and concrete, through unwanted industrial byproducts such as slag and fly ash or discarded or unused materials such as mine tailings.

The physical properties of aggregates such as size shape, texture, porosity, absorption, moisture content, bulking of fine materials, presence of deleterious substances etc. affects significantly the resulting concrete quality produced.

Aggregates must conform to certain standards for optimum engineering use: they must be clean, hard, strong, durable particles free of absorbed chemicals, coatings of clay, and other fine materials in amounts that could affect hydration and bond of the cement paste. Aggregate particles that are friable or capable of being split are undesirable. Aggregates containing any appreciable amounts of shale or other shall rocks, soft and porous materials should be avoided; certain types of chert should be especially avoided since they have low resistance to weathering and can cause surface defects such as popouts. The most commonly used aggregates, sand, gravel, crushed stone, and air-cooled blast-furnace slag, produce freshly mixed normal-weight concrete with a density (unit weight) of 2200 to 2400 kg/M^3 (H. Kosmatka, 2003).

2.3.5 Water

Water is a key ingredient in the manufacture of concrete. Attention should be given to the quality of water used in concrete. The time-honored rule of thumb for water quality is “If you can drink it, you can make concrete with it.” A large amount of concrete is made using municipal water supplies. However, good quality concrete can be made with water that would not pass normal standards for drinking water.

Mixing water can cause problems by introducing impurities that have a detrimental effect on concrete quality. Although satisfactory strength development is of primary concern, impurities contained in the mix water may also affect setting times, drying shrinkage, or durability or they may cause efflorescence. Water should be avoided if it contains large amounts of dissolved solids, or appreciable amounts of organic materials (Abrham, 2010).

2.4 The Use of Recycled Materials in Concrete Construction

Waste materials are common problems in modern living. Waste accumulates from a number of sources including domestic, industrial, commercial, construction and agricultural. These waste materials have to be eventually disposed of in ways that do not endanger human health and their environment. In light of this, waste minimization is increasingly seen as an ecologically sustainable strategy for alleviating the need for the disposal of waste materials, which is often costly, time and space consuming, and can also have significant detrimental impacts on the natural environment. Nowadays governments and organizations have been concerned with developing policies and programs to bring about successful outcomes to waste minimization. This is seen as being essential to reduce the total amount of waste materials going into landfill, especially in the urban areas where land is very scarce. The use of recycled materials is often cheaper for the consumers of the end product. Hence, there is also an economic justification for promoting its use.

2.5 Environmental and economic role of coffee husk ash as cement replacement

Construction industry is one of the leaders in deterioration of environment by depleting resources and consuming energy or creation of waste. In addition, a considerable amount of emissions of greenhouse and acidifying gasses has the origin in construction industry. Concrete is the most common construction material used in civil engineering construction. Cement is a basic component of concrete, it belongs to the most often-used construction materials, and its production is increasing over the world. However, the cement industry is an energy enormous intensive and products many emissions, odors and noise. The emissions from cement plants which cause greatest concern and which need to be dealt with are dust, carbon dioxide (CO_2), nitrogen oxides (NOx) and sulphur dioxide (SO_2) (Eštoková, 2012).

It has known that cement is one of the basic materials used in the production of concrete for construction industries. However the production of cement is both environmental unfriendly and uneconomical as compared to the other constituents of concrete, showing that the cement industry has sustainability problems. In order to alleviate these problems of the cement industry different methods were being implemented specially in the developed countries. One of these methods is the use of different cement replacing materials which have lower cost of production, lower emission of CO_2, and lower energy consumption implying a more environmental friendly and economical material (Hailu, 2011).

Therefore concrete (i.e. cement) is one of the World’s most significant manufactured materials. Because of its abundance in the world market, understanding the environmental implications of concrete and cement manufacturing are becoming increasingly important.

On the other hand, agriculture also generates large bio wastes. In most cases, improper disposal of these wastes causes serious environmental damages. For instance, thousand tons of agricultural remnants such as coffee husk are produced in Western zones of Oromia and South Western regions of Ethiopia (Takele, 2014). If these wastes are not properly handled and managed, they will continue to challenge the life and livelihood of millions of people by polluting receiving environments (air, water and soil). However, these wastes have a potential to be converted into resources. This calls for rethinking of integrated approach of waste management and to sustain agricultural productivity and reduce greenhouse gas emission.

As a result coffee husk ash was found to have a great potential to be used as a cement replacing material in some parts of the world particularly in Tiland. The use of this material as a cement replacement reduces the cost of cement, the CO_2 emission and energy consumptions.

2.5.1 Advantages of CHA as partial replacement of cement

Coffee husk which is the most abundant and nonedible agricultural waste has the following advantages while using as partial replacement of cement for concrete productions**.**

2.5.1.1 Environmental advantages

The cement industry is an energy intensive industry with energy typically accounting for about 40 % of operational costs, i.e. excluding capital costs but including electricity costs. The production of cement involves the consumption of large quantities of raw materials, energy, and heat. Cement production also results in the release of a significant amount of solid waste materials and gaseous emissions (Eštoková, 2012).

The cement manufacturing industry is under higher scrutiny these days because of the large volumes of CO_2 emitted. Actually, this industrial sector is thought to represent 5–7 % of the total CO_2 anthropogenic emissions. Concern over the impact of anthropogenic carbon emissions on the global climate has increased in recent years due to growth in global warming awareness. In addition to the generation of CO_2 the cement manufacturing process produces millions of tons of the waste product cement kiln dust each year contributing to respiratory and pollution health risks .To produce 1 tons of clinker, the typical average consumption of raw materials is 1.52 tones (Eštoková, 2012).

The same as, it is estimated that, for a single kilogram of coffee beans produced, about 1kg husks are generated as a wastes and are generally dumped in large open piles in gorges or near rivers and cause both water and soil pollution. The husk does not have much commercial or other industrial advantage other than, becoming the major polluting agent of environment (Takele, 2014).

The amount of clinker needed to produce a given amount of cement can be reduced by the use of supplementary cementitious materials such as coal fly ash, slag, and natural Pozzolanas (e.g., rice husk ash, coffee husk ash and volcanic ashes). The addition of these materials into concrete not only reduces the amount of material landfilled (in case of industrials byproducts), but also reduces the amount of clinker required per ton of cement produced.

The coffee production and processing generates waste amounts of solid residues, second by quantity only to traded petroleum industry, and similar to the amounts of another agro-industry, namely the residues of the olive oil extraction production and processing. For coffee, the vast amount of residues encompasses the yearly generation of environmental and agricultural problems. These should be faced and properly assessed, also in terms of Life Cycle Management options (Echeverria, 2016).

In the last years, coffee husk have attracted great attention since they are generated in large amounts every year and represent a great pollution hazard if discharged into the environment.

However, as these residues are derived from coffee beans, they are expected to have properties similar to these beans and could be therefore exploited for different industrial applications. In this sense, some alternatives have been proposed to reuse these coffee residues (Mussatto, 2014). Coffee husks contain some amount of caffeine and tannins, which can make it toxic and slow degradation in nature and result in the disposal problem.Additionally, untreated coffee husk has been used as potential bio sorbents for treatment of dye contaminated waters (Khanh, 2013). In some part of our country, coffee husk is normally burnt or covered on the coffee field, so, untreated coffee husk will spread diseases and pets to next crop.

Currently, the coffee pulp is discharged into local streams and rivers where it tends to clog, forming a putrescent mass and producing a highly acidic effluent which pollutes the water, destroying aquatic life and generating an offensive odour. Recovery of this pulp for partial cement replacement use would require collecting the residues as they are discharged from the pulping machine and processing them to greatly reduce the moisture content (Ayele, 2011).

Therefore, replacing the portion of Portland cement with coffee husk ash can substantially reduce the environmental impact of concrete associated with cement production like consumption of raw materials and energy use as well as emissions to air and avoiding environmental pollution due to coffee husk wastes.

A. Energy saving

The cement industry plays a significant role in global energy consumptions. Worldwide the cement industry is one of the most energy intensive sectors in which energy represents 40 % of the total production cost. The energy consumption in cement manufacturing is mainly related to the production methods that is wet methods consume more energy than dry methods. For instance in dry method 1450 ^{0}C of temperature is needed for the production of clinker which accounts 97.2 % of the total and the remaining is for finishing and raw materials grinding with the share of 0.9 % and 1.9 % respectively (MOI, 2015, 2016).

B. Reduction of CO_2 emission

Sustainable development of cement and construction industry in relation to environmental impact is one of the biggest challenges. The production of one ton of Portland cement release approximately one ton of CO_2 to the atmospheres in the manufacturing process. The cement industry contributes about 5 % of the total atmospheric CO_2 emissions globally (Yossef, 2016). As a matter, of fact we are now concerned by the environmental impact of civil engineering structures. Judicious use of CHA as a partial replacement of cement can result a significant result in reduction of CO_2 footprint of concrete structures. Most of the CO_2 emissions and energy use in the cement industry are related to production of the clinker; 63 % of the CO_2 emitted during cement production comes from the calcination process, while the rest (37 %) is produced during the combustion of fossil fuels to feed the calcination process (Mercier, 2010).

2.5.1.2 Economical advantages

The production of cement is energy intensive, depends on the availability of raw materials near to the cement manufacturing area and nature disturbances due to extraction of raw materials. The process is mainly classified into three, the raw material preparation process, the clinker burning process and the finish grinding process. Off all this processes, clinker burning is the most energy intensive process, accounting for about more than 97.3 % of the fuel consumed and about 30 % of the electric power consumption and the rest about 40% of the electric power is consumed by the finish grinding process and about 30

% by the raw material preparation (Hailu, 2011; MOI, 2015, 2016). Fuel costs are a large part of the manufacturing cost of the cement industry, making cement plants to have aggressive energy consumption.

CHAPTER THREE

METHODOLOGY AND MATERIALS

3.1 Introduction

All the laboratory investigations on the aggregates, fineness of cement and CHA, pastes and concretes were carried out in Addis Ababa University, Ethiopian Institution of Architectural Building Construction and City Development, Materials Research and Testing Centre (MRTC) laboratory. Whereas the chemical properties of the CHA were conducted in Geological Survey Centre of Ethiopia and the CH ash determination and preparation of CHA was carried out at Jimma University, College of Agriculture and Veterinary Medicine Research Centre and Post Harvesting Department laboratories.

3.2 Methodologies of the Study

3.2.1 Sources of Materials

To investigate the suitability of CHA as a partial replacement of cement, all the required materials were collected and delivered to the laboratory from their respective sources. These were, Coarse aggregate from Kality market, Soder's fine aggregates from Legehar market, Cement from Megenagna market and CHA from Jimma Zone.

3.2.2 Mix Design

Concrete mix design was prepared using the ACI 211.1 method. Six mixes for concrete grades of C-25 were produced. A control mix with null CHA replacement was casted to make a comparative analysis.

By keeping, the mix proportion constant for each replacement the workability, compressive Strength and unite weight for C-25 concrete, was investigated and the result was compared with the control mix, CHA0. One of the methods of checking its suitability for purpose is to carry out a concrete cube test which measures the compressive cube strength of the concrete and relates directly to the required design strength specified by the designer. According to ASTMC-192/C192M (2007) and BS.EN.12390-3: (2009), test ages often used are 7 and 28 days for compressive strength tests. Based on this and my observation from MRTC of EiABC's and JIT's construction laboratory historical data and from literature reviews and to observe strength development within curing age added 14 days cube compressive test. As a result, compressive strength and unit weight test were made at 7, 14 and 28 days. The 7th, 14th and 28th day strength was investigated with their respective days of control mix strength to determine how much percentage of strength can be gained or loosed at 7th, 14th and 28th days.

3.2.3 Concrete specimens and mixing procedures

Cement, CHA and aggregates were batched by weight while water was batched by volume and castings of all specimens were carried out under same ambient conditions of average room temperature. All the replacement for the cement by CHA was done on a weight basis. Adjustment was made for moisture content of the fine aggregate. After determining the relative amount of materials to be used for the specimens, the aggregates, the cement and CHA were mixed dry for one minute. After the addition of water, all the materials were mixed for another two minutes by using mixing machine, mixer. Immediately after mixing the concrete, the workability and fresh unit weight were measured by using a slump cone and weight balance respectively. The specimens were then placed on a firm and level surface of prepared molds (150 x 150 x 150 mm) for compressive cubes by compacting in three layers using 25 strokes of a 25 mm diameter steel rod and hammered in both side of the mold by using plastic hammer. Then hand vibrator for 30 seconds until full compaction without segregation was achieved. After compaction of the final layer, the top surface was finished using a trowel. Placing, compaction and finishing were completed within 15 minutes. After 24 hours, the specimens were demolded from the mold and were curried in a curing tank for 7, 14 and 28 days at room temperature of the laboratory. While preparing the concrete it was mixed, six batches (phases), nine cubes in a single phase for particular percentages of cement replacement by CHA. Finally, for all replacement percentages of harden concrete density and compressive strengths were checked at age of 7, 14 and 28 days.

3.2.4 Data collection

The data collection was mainly based on the tests conducted on the prepared specimens in the laboratories.

3.2.5 Data Analysis and Evaluation

The test results of the samples were compared with the respective control concrete properties and the results were discussed analysed and presented using relevant formulas, tables, pictures and graphs. Conclusions and recommendations were finally forwarded based on the findings and observations.

3.2.6 Study Variables

a. Independent Variables

This is the variable, which is the presumed cause in an experimental study. All other variables that may influence the dependent variable were controlled. The values of the independent variable were under experimenter control. Such are

- Properties of aggregates
- CHA percentages
- Curing ages

b. Dependent Variables

This variable is the supposed effect in an experimental study. The values of the dependent variable depend upon another variable. As a result this study's dependent variable is

- Fresh and harden properties of C-25 concrete

3.2.7 Plan for dissemination

The study was mainly concentrated for academic purposes that were enrolled by the Jimma University; the finding will be present publically and defend in the presence of examiners. In addition, the final report will disseminate to Jimma University, JIT'S PGRPD office and will publish in an international journal.

3.3 Materials for the research

3.3.1 Coffee husk ashes

The coffee husk for this research was collected from different coffee pulpier companies at Jimma, Ethiopia. Then the fresh coffee husk was exposed to sun to avoid surface moisture and after that, it was filled in sacks and transported to the research centre at JU, CAVM.

In this research, coffee husk burned in a carbonate furnace for two, three, and four hours at 500, 550 and 600 ^{o}C, to determine the appropriate temperature and duration of it to get the required quality of CH ash at JU, CAVM, Post Harvesting Department laboratory. After a general comparison, this study selected 550 ^{o}C temperatures with three hours durations.

3.3.1.1 Determination of Ash Content of CH

Ash content is the non-combustible residue left after coffee husk was burnt. It represents the bulk mineral matter after carbon, oxygen, sulphur, water and other gases have been driven off during combustion. The ash content was calculated by using equation 3.1 from the residue that remained after samples were heated in a furnace.

The silica content of the ash depends on the type of soil that the coffee tree grown and burning temperature of the coffee husk. High temperature helps eliminate impurities in coffee husk ash as well. Coffee husk was heated in a temperature-controlled furnace (Carbonate furnace). Known amount of husk (5 gm) was heated in a crucible for two, three, and four hours at temperatures of 500, 550 and 600 ^{o}C, and the ash obtained was weighed. Figure 3.1 gives a plot of ‘Ash produced (ash %)’ versus ‘ashing temperature’. Maximum ash yield of 18.3 % was obtained at ashing temperature of 550 ^{o}C for three hours. The ash obtained at lower temperatures was blackish in color, indicating incomplete combustion due to unburned carbon. At higher temperatures more and more of carbon is oxidized to carbon dioxide. With the rise in the furnace temperature beyond 550 ^{o}C, the amount of ash decreased as ashing became more and more complete. As the temperature rises beyond 550 ^{o}C, reduction in mass was also due to disintegration of solid compounds, alkali metal salts, into gaseous components. Therefore, this study identified the suitable burning temperature and residence time to be 550 ^{o}C for 3 hours.

$$\textbf{Percentage of CHA} = \frac{(\mathrm{W3} - \mathrm{W1})}{(\mathrm{W2} - \mathrm{W1})} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ \ldots\ldots\ldots\ldots\ldots \text{Equation 3.1}$$

Where W1 is weight of crucible, W2 is summation of Weight of crucible (W1) and weight of sample of CH before burn and W3= W1+ weight of sample of CHA after burn.

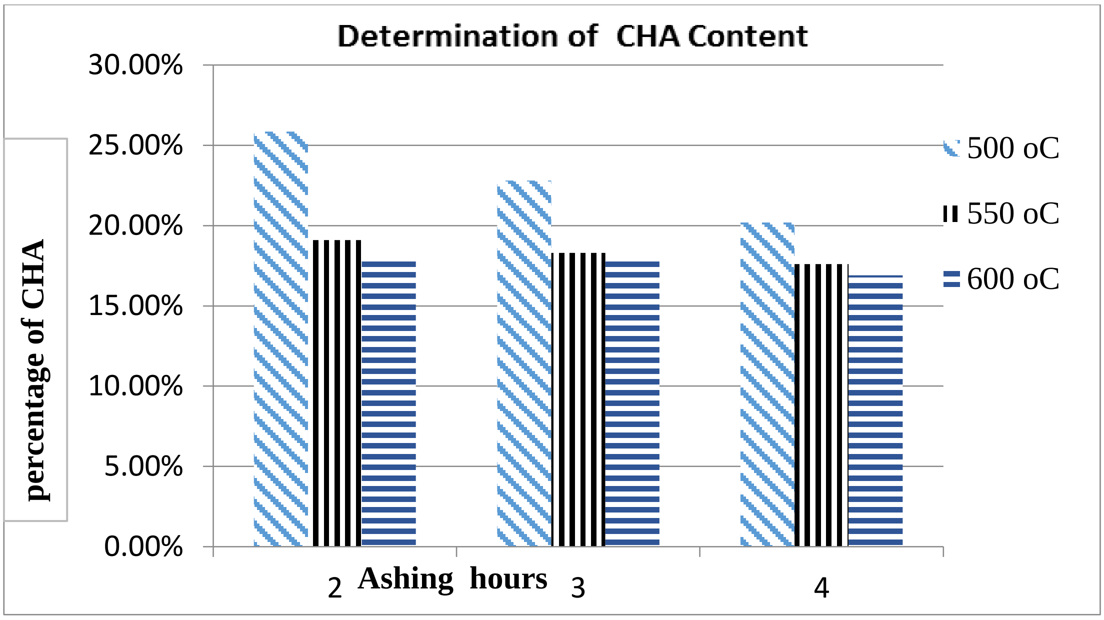

Figure 3.1 CHA ashing temperatures vs. ashing hours

As discussed ash determination in section 3.3.1.1, coffee husk was calciund in charcoals burners in JU, CAVM, research centre laboratory with the temperature of 550 ^{o}C for 3 hr. The grinding of the ash was done in JU, CAVM Post Harvesting Department laboratory using a small mill having a capacity of carrying about 400 gm of CH ash at a time, then packed in sacks, and transported to Addis Ababa, EiABC. By so doing, the CH ash fineness was reduced to fineness similar to that of Portland cement. The grain size distribution is as shown in the Figure 3.3.

Figure 3.2 CHA after grinding (Source photo taking on April 21/2017)

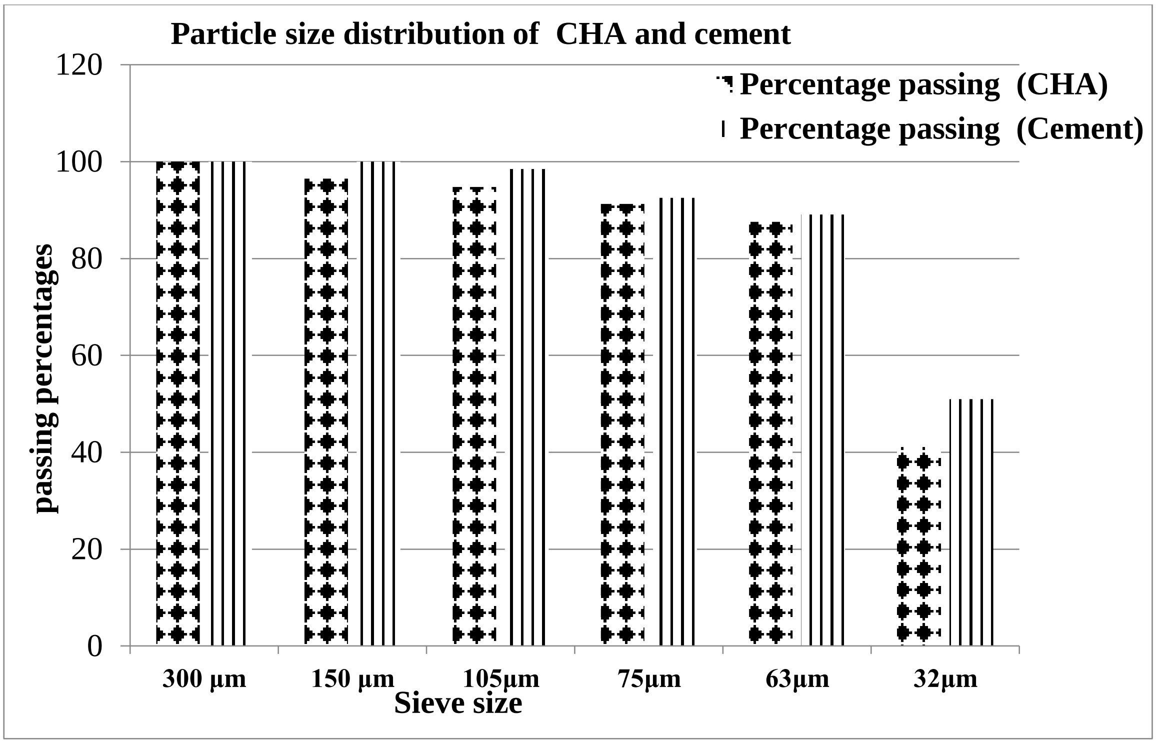

Figure 3.3 Graph for the particle size distribution of the CHA and cement

The ash was then taken to the Geological Survey center of Ethiopia for the complete silicate analysis, specific gravity and other related tests the result of which are given in Table 3.1. CH ash was analysed by Atomic Absorption Spectrophotometer (AAS) methods. The specific gravity of coffee husk ash was found from the laboratory investigation was 2.72.

Table 3.1 Chemical composition of cement, BA and CH ash

Chemical Composition (%)	**Messebo OPC Cement (Hailu, 2011)**	**Bagasse Ash (Hailu, 2011)**	**CHA (Appendix E)**	**Ethiopian standards (ESA, 2013)**
SiO_2	20.50	65.58	16.55	17-25
AlO_3	4.75	5.87	17.18	3-8
Fe_2O_3	3.70	4.32	3.98	0.5-6
CaO	63.94	1.78	5.68	60-67
MgO	1.31	1.23	1.12	0.1-4
Na_2O	-	1.02	1.84	0.3-1.3
K_2O	-	6.41	19.3	
MnO	-	0.05	<0.01	-
P_2O_5	-	1.35	1.72	-
TiO_2	-	0.25	0.04	-
H_2O	-	0.2	2.55	-
SO_3	2.41	0.18	1.9	1-3
SiO2+ Al2O3+ Fe2O3	-	75.77	37.71	

3.3.2 Cement

Commercially available Dangote Ordinary Portland Cement Grade- 42.5R was used that found in Addis Ababa around Megenagna. This cement complies with the requirements of Ethiopian Standards, ES C.D5 201 and ES 1177-ICEM 1/42.5R (ESA, 2013). The specific gravity of the Dangote OPC was known to have 3.15.

Figure 3.4: Dangote OPC (Photo Taken on 18 - June - 2017))

3.3.3 Aggregates

The relevant tests to identify the properties of the aggregates that were intended to be used in study were carried out. After that, corrective measures were taken in advance before proceeding to the mix proportioning particularly for the natural sand due to its higher silt content and organic impurity the researcher changed its sources. In general, aggregates should be hard and strong, free of undesirable impurities, and chemically stable. Soft, porous rock can limit strength and wear resistance; it may also break down during mixing and adversely affect workability by increasing the amount of fines. Aggregates should also be free from impurities: silt, clay, dirt or organic matter. If these materials coat the surfaces of the aggregate, they will isolate the aggregate particles from the surrounding concrete, causing a reduction in strength. Silt, clay, and other fine materials will also increase the water requirements of the concrete, and organic matter may interfere with cement hydration. To proportion suitable concrete mixes, certain properties of the aggregate must be known. These are; shape and texture, size gradation, moisture content, specific gravity and bulk unit weight.

Generally for this research the fine aggregates was purchased from Kality market that came from Sodery and the course aggregates (crashed) was purchased from Legehar market ,Addis Ababa, and both fine and course aggregates properties were examined as discussed in section 3.2.5 1 and 3.5.2.2 respectively.

3.3.3.1 Properties of fine aggregate

The fine aggregate used in this study was natural sand that sourced from Soder. In order to investigate its properties for the required application different tests were carried out that includes sieve analysis and fineness modules, specific gravity and absorption capacity, moisture content, silt content and unit weight.

3.3.3.1.1 Silt content

The material in fine aggregate, which is finer than 75µm, is generally regarded as silt. The presence of silt in sand that used to make concrete has severe impact on the quality of the resulting product. Mainly, it affects the workability and therefore, water-cement ratio of the mix and it is also responsible for reduction of strength and eventual concrete cracking (Birhanu, 2007).

From the silt content test performed on the sand, it was found that the original silt content was 25 % and the organic content was found no. 4. The Ethiopian standard restricts the silt content to a maximum of 6 % and the organic impurity limit is 1-3. If it exceeds this maximum values, the standard recommends washing or rejecting the sand. Since 25 % silt content was high, as a result, the sand was rejected and other sand was purchased and its final silt content becomes 5.26 % and the organic impurity laid on no. 1.

3.3.3.1.2 Sieve Analysis and fineness modules

Sieve analysis is a technique for the determination of the particle size distribution of aggregates using a series of square or round meshes starting with the largest. It used to determine the grading, fineness modulus, an index to the fineness, coarseness and uniformity of aggregates.

These properties of the aggregate greatly affect the property of the concrete. For this research, approximately 2 kg of fine aggregate was taken. The sample was then quartered using riffle box and two samples for each 500 gm of sample was taken for sieve analysis. The results obtained are shown in Table 3.4 and Figure 3.5.

Using the sieve analysis results, a numerical index called the fineness modulus (FM) is often computed. The FM is the sum of the total percentages coarser than each of a specified series of sieves, divided by 100. The specified sieves are 75.0, 37.5, 19.0, and 9.5 mm and 4.75 mm, 2.36 mm, 1.18 mm, 600µm, 300 µm, and 150 µm (No. 4, 8, 16, 30, 50, and 100) for course and fine aggregates respectively. The FM generally ranges from 2.3 to 3.1 as called for in ASTM C33/C33M (ASTMC33/C33M, 2011).

Table 3.2 Sieve analysis format and standard for fine aggregate

Sieve size	**Mass retained [g]**			**Percent retained**	**Cumulative percent retained**	**Cumulative percent passing**	**Specification % passing (ESC.D3.20)**
	Sample I	**Sample II**	**Average**				
9.5mm	0	0	0	0	0	100.00	100
4.25mm	11.8	16.4	14.1	2.82	2.82	97.18	95-100
2.36mm	39.1	46	42.56	8.52	11.35	88.65	80-100
1.18mm	84.9	98.5	91.7	18.37	29.71	70.29	50-85
600µm	133.6	140.7	137.15	27.47	57.19	42.81	25-60
300µm	151.7	135.4	143.55	28.75	85.94	14.06	5-30
150µm	58.3	45.3	52	10.42	96.35	3.65	0-10
0.75	14.9	10.6	12.75	2.55	98.91	1.09	
Pan	5.6	5.3	5.45	1.09	100	0.00	-
Total	**499.9**	**498.6**	**499.25**		**283.37**	**416.63**	

$$\mathbf{FM} = \frac{\boldsymbol{\Sigma}\mathbf{cumulative\ coarser}\ (\%)}{\mathbf{100}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.2}$$

$$\text{FM} = \frac{283.37}{100}$$

FM=2.83

According to ASTMC33/C33M (2011) fine aggregates should have fineness modules between 2.3 and 3.1; the sand used has fineness modules of 2.83, this means it is within the ASTM limits. This gradation of the fine aggregate is shown in Figure 3.3 along with the grading requirements for fine aggregate prescribed by Ethiopian standard and ASTM C33.

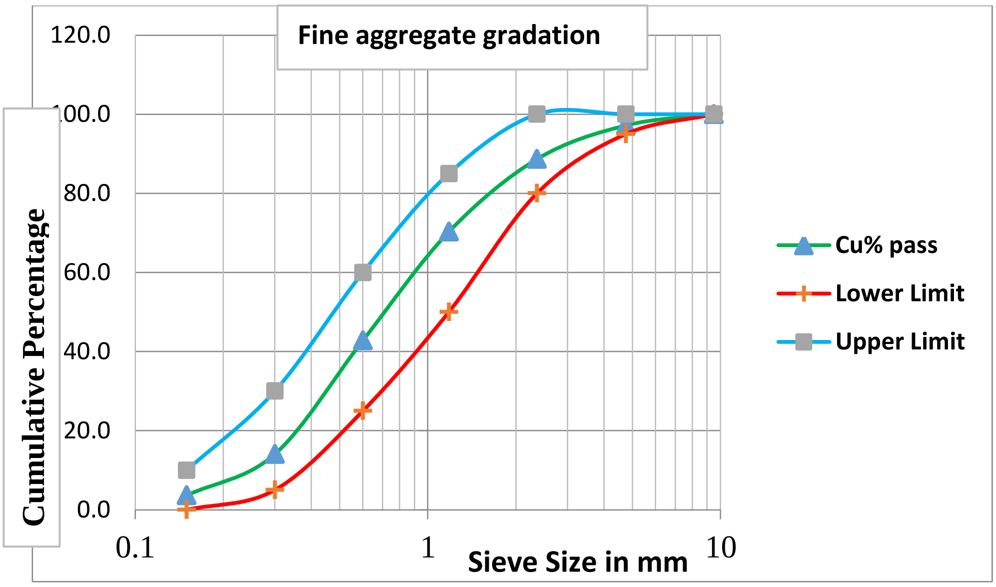

Figure 3.5 Graph for gradation of fine aggregate

Figure 3.5 and table 3.2 indicates that the gradation of fine aggregate satisfy the Ethiopian and (ASTMC33/C33M, 2011) standards requirement. The grading of aggregate is very important because it affects the paste requirement of concrete, workability of fresh concrete, packing density and determines the economy of concrete production.

3.3.3.1.3 Specific gravity and absorption capacity

The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. In addition, it is an expression of the density of an aggregate. It is the ratio between the weight of the substance and that of the same volume of water. This definition assumes that the substance is solid throughout. Aggregates, however, have pores that are both permeable and impermeable. The structure of the aggregate (size, number, and continuity pattern) affects water absorption, permeability, and specific gravity. Apparent specific gravity of an aggregate refers to the solid materials excluding the pores and bulk specific gravity refers to total volume i.e. including pores of the aggregate (Abrham, 2010).

The specific gravity of the fine aggregate was determined using two different pycnometers so that the average can be taken. For each test, 500 gm of oven dried fine aggregate was used. The result presented in the appendix A.4.

The following results were found for the fine aggregate:

Bulk specific gravity = 2.13

Bulk specific gravity (SSD basis) = 2.135

Apparent specific gravity =2.13

Absorption capacity = 1.92 %

According to ASTMC33/C33M (2011), the limitation for absorption capacity ranges from 0.2 to 2 % for fine aggregates. As a result, the aggregate is within ASTM limitations.

3.3.3.1.4 Moisture content

A design water-cement ratio is usually specified based on the assumption that aggregates are inert (neither absorb nor give water to the mixture). But, in most cases aggregates from different sources do not comply with this i.e. wet aggregates give water to the mix and drier aggregates take water from the mix affecting in both cases, the design water cement ratio, workability and strength of the mix. In order to correct for these discrepancies, the moisture content of aggregates has to be determined.

The moisture content of fine aggregates was determined by oven drying two samples of fine aggregate (500 gm each) in an oven at a temperature of 110 ^{o}C for 24 hours and dividing the weight difference by the oven dry weight. The moisture content of the average of the two samples found was 18.89 %.

In making quality concrete, it is very essential that corrective measures should be taken both for absorption and free moisture so that the water/cement ratio is kept as exactly as per the mix design as shown in mix design computation in appendix A.1.

3.3.3.1.5 Unit weight of fine aggregates

Unit weight can be defined as the weight of a given volume of graded aggregate. It is thus a density measurement and also known as bulk density. However, this alternative term is similar to bulk specific gravity, which is quite a different quantity, and perhaps is not a good choice. The unit weight effectively measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate particles and the voids between them. The unit weight is simply measured by filling a container of known volume and weighing it. Clearly, however, the degree of compaction will change the amount of void space, and hence the value of the unit weight. Since the weight of the aggregate is dependent on the moisture content of the aggregate, constant moisture content is required. Oven dried aggregate sample is used in this test (D. Abebe, 2002; ASTMC-128, 1997).

The bulk density is used to convert quantities by weight to quantities by volume for batching concrete. The rodded bulk density of aggregates used for normal weight concrete generally ranges from 1200 to 1760 kg/m3 (ACI318M, 2011). The average unit weight of the fine aggregate samples of loss and compacted used was found to be 1011 and 1122 kg/m3 respectively that is nearly in the range. The above test results of fine aggregate are summarized in Table 3.3:

Table 3.3 Summary of test results for fine aggregate

No.	**Test Description**		**Test Result**
1	Silt content (%)		5.26
2	Moisture Content (%)		18,87
3	Unit weight (kg/m3)	Loss	1011
		Compacted	1122
4	Absorption capacity (%)		1.92
5	Fineness Modulus		2.83
6	Specific gravity	Bulk	2.25
		Bulk(SSD)	2.123
		Apparent	2.13

3.3.3.2 Properties of the coarse aggregate

Coarse aggregate for concrete shall consist of natural gravel or crushed rock or a mixture of natural gravel and crushed rock. Coarse aggregate used in this research was crashed aggregates, which purchased from Legehar market.

In a similar manner like the fine aggregate, laboratory tests were carried out to identify the physical properties of the coarse aggregate such as gradation, specific gravity and absorption capacity, moisture content and unit weight.

3.3.3.2.1 Sieve analysis

Approximately 10 kg of crashed course aggregate was taken for quartered using riffle box and two samples with a weight of 2 kg was taken for sieve analysis.

Table 3.4 Sieve analysis of coarse aggregate

Sieve Size [mm]	**Weight Retained[kg]**			**% retainer**	**Cumulative % retained**	**Cumulative % passing**	**Specification % passing (ES C. D3.201) &ASTM C-33**
	Sample I	**Sample II**	**Average**				
37.5	-	-	-			100	100
25	325.8	550.4	438.1	5.48	5.48	94.52	90-100
19	1580.0	1502.0	1541.0	19.26	24.74	75.26	40-85
12.5	3151.5	3067.9	3109.7	38.87	63.62	36.38	10-40
9.5	2711.3	2614.3	2662.8	33.29	96.9	3.10	0-15
4.75	49.5	55.5	52.4	0.66	97.56	2.44	0-5
Pan	181.5	209.1	195.3	2.44	100.00	0.00	
Sum	7999.6	7999.0	7999.3				

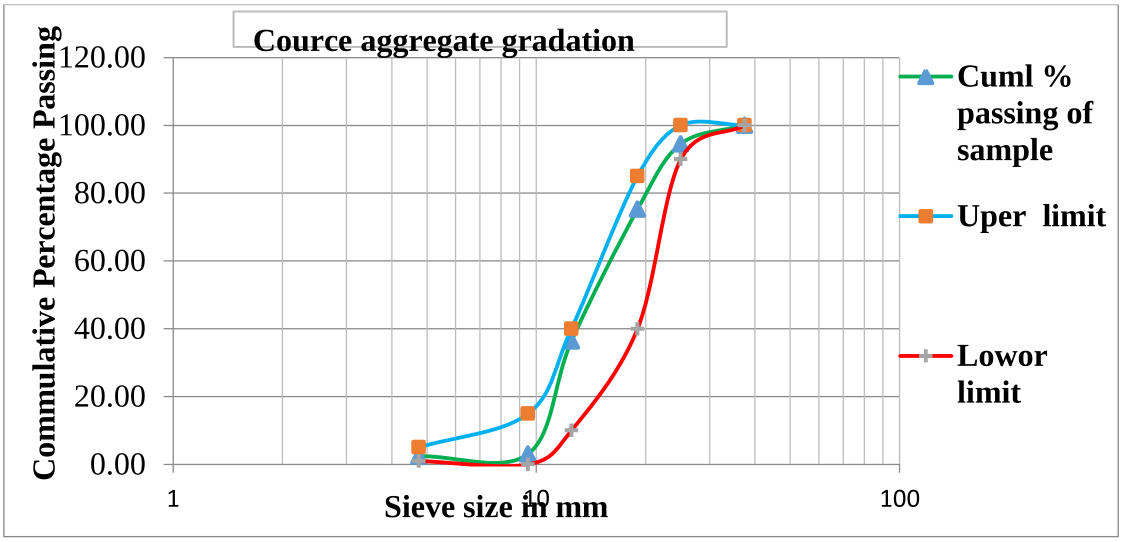

Figure 3.6 Graph for gradation of course aggregate

3.3.3.2.2 Specific gravity

The specific gravity of the coarse aggregates was determined using displacement method. First, approximately 2 kg of two samples of coarse aggregate sample was taken and submerged in water for 24 hours. The aggregates were then taken out and their surface was dried using a towel to remove the excess moisture. After determining their masses, the aggregates were carefully immersed into a beaker filled with water, after which volume of the displaced water was measured. The mean result was 2.45 and the overall results obtained are shown in the appendix A.5. Generally, all other test of course aggregates are summarizing in table 3.5.

Table 3.5 Summary of test results for coarse aggregate

No.	Test Description		Test Result
1	Maximum size (in mm)		25
2	Moisture Content (%)		1.83
3	Unit weight (in Kg/m^3)	Loss	1428
		Compacted	1589
4	Absorption capacity (%)		2.6
5	Specific gravity	Bulk	2.64
		Bulk(SSD)	2.63
		Apparent	2.75

Generally, according to ASTMC33/C33M (2011) the limitation for bulk specific gravity (SSD) is from 2.4 to 3.0 and absorption capacity ranges from 0.2 % to 4 %, for coarse aggregates. Accordingly, the aggregates are within ASTM limitations.

3.3.4 Water

The quality of the water plays a significant role in concrete production. Impurities in water may interfere with the setting of the cement, may adversely affect the strength of the concrete or cause staining of its surface, and may also lead to corrosion of the reinforcement. For these reasons, the suitability of water for mixing and curing purposes should be considered.

In this research, tap water supplied by Addis Ababa water and sewerage authority at room temperature was used in all mixes.

3.4 Test of blended materials (CHA and Cement)

The key objective of the test program was to study the suitability of coffee husk ash as a cement replacing material. These include studying properties of paste and concrete works by replacing part of the cement with coffee husk ash in six different percentages.

Two major tests were conducted in order to achieve these objectives. The first experiment done on blended powders and pastes in which part of the cement was replaced by coffee husk ash in order to determine the fineness of the blended powder, the water requirement or normal consistency and setting time of the blended paste.

The second experiment was made on concrete in which part of the cement was replaced by coffee husk ash that discussed and analysed in chapter four. These tests were used to investigate the pozzolanic property of coffee husk ash, its effect on the performance of the concrete such as workability, density and strengths. All the experiments were made at MRTC Laboratory of EiABC of AAU.

3.4.1 Fineness test

The fineness of the coffee husk ash, the cement and the blended powders at different percentage were determined by the ASTM standard sieve no.200 (75-μm). The different mixes are as shown in Table 3.6. The sieve method is based on the relationship between weight of residue (after sieving) and weight of the cement (before sieving) in gram. The replacements were done within 0, 2, 3, 5, 10 and 15 %.

Table 3.6 Proportion of blending of coffee husk ash and cement

S. No	**Code**	**Proportion by weight W1 (gm)**		**Weight of cement retained on no.200 sieve (gm) W2**	**Fineness, F, (%)** $F=\frac{W2}{W1}*100$
		Cement (%)	**CHA (%)**		
1	CHA 0	100	0	1.2	1.2
2	CHA 2	98	2	1.9	1.9
3	CHA 3	97	3	2.7	2.7
4	CHA 5	95	5	4.3	4.3
5	CHA 10	90	10	9.2	9.6
6	CHA 15	85	15	11.3	11.3

According to ASTM C11, the residue by weight on sieve is not to exceed 10 % of original weight for OPC. Therefor the cement CHA blends where found within limit of the standards as shown in table 3.6.

Where:

CHA0 indicate control Dangote OPC with 0% CHA

CHA2-blended powder with 98% Dangote OPC and 2% CHA

CHA3 -blended powder with 97% Dangote OPC and 3% CHA

CHA5-blended powder with 95% Dangote OPC and 5% CHA

CHA10-blended powder with 90% Dangote OPC and 10% CHA

CHA15-blended powder with 85% Dangote OPC and 15% CHA

***N.B-** In all the blended mixes in this study weight measurements were used. However, the ratio of replacement is not 1:1 rather 1:0.86, i.e. 1 kg of cement is replaced by 0.86 kg of CHA since the replacement by volume to account for the lower density of CHA (2.72 g/cm3) and to keep the paste volume constant*.

3.4.2 Normal consistency test

ASTM C 595 recommends the normal consistency test of blended cements to be measured by the ASTM C 187 method, which is the method for that of hydraulic cement.

Therefore, the normal consistency was measured by a Vicat apparatus. This measure the resistance of the paste to the penetration of a plunger or needle of 300 gm released at the surface of the paste. The procedure used for this test is as described in ASTM C 187.

Different pastes for both control i.e. without CHA and blended were prepared by replacing part of the Ordinary Portland cement with CHA. The water content was varied for each of the pastes produced until a normal consistent paste is obtained within the range of 10±1 mm.

3.4.3 Setting time test

ASTM C 595 recommends the use of ASTM C 191 method of measuring setting time, which is used for that of hydraulic cements. The initial setting time of the paste was determined by the duration of 25 mm penetration of Vicat needle into the paste in 30 seconds after it has been released while the final setting time was determined by measuring the time related to zero penetration of the needle into the paste the result is discussed in chapter 4.

3.5 Mix design and trial mix preparation

Mix design is the process of determining the required and specified characteristics of a concrete mixture. The required or specified concrete characteristics can be fresh concrete properties, mechanical properties of the hardened concrete such as strength and density. Mix proportioning on the other hand is the process of determining the quantities of concrete ingredients using local materials to achieve the specified characteristics of the concrete. The aim of mix design is to get acceptable workability of the freshly mixed concrete and to check economic feasibility of the concrete.

It is intended to prepare concrete grades C-25 which is the most commonly used grade of concrete throughout the country and the ACI 211.1 method was used to determine the mix proportions. Details of the mix proportions and the essential calculations and procedures for the mix can be found on appendix B. The proportions needed to produced 9 cube specimens for each mixes were calculated from the proportions of a 1 m^3 concrete as per the ACI 211.1 mix design procedures and is tabulated in table 3.7.

Before proceeding to the preparation of the main mix design of the research, trial mixes were prepared for the control mixes. A particular mix design method determines a set of mix proportions for producing a concrete that has approximately the required properties of strength and workability. The method however is based on simplified classification for type and quality of the materials and it remains to check whether the particular aggregates and cement selected for use in a given case will behave as expected or not. This is the object of making the trial mix, and the subsequent feedback of information from the trial mix is an essential part of the mix design process. For this research, the trial mix was prepared for C-25 MPa characteristic strength that is equivalent with 33.3 MPa target strength with water to cement ratio of 0.5 and a cement content of 360 kg/m^3. Dangote cement (OPC) was used for all mixes and admixtures were not used.

Table 3.7 Material constituents and results of the trial mix.

Ingredient	**Quantities for**			**Results**	
	1m^3 concrete		**3 cubes for trial mix (0.014m^3)**	**Slump (mm)**	**3rd day strength**
	Before adjustment	**After adjustment**			
Cement (kg)	360	360	5.32	35	18.53Mpa
Water (kg or lt)	180	86.98	1.22		
Fine aggregate (kg)	770.37	894.17	10.91		
Coarse aggregate (kg)	1064.63	1084.98	15.18		
Water-cement ratio	0.5	-	-		

Once the trial mixes were prepared as shown in table 3.7, mixing was carried out and the trial mix was resulted in a slump of 35 mm which was in range of 30-50 mm by ACI 211.1 table 3.8 and 3rd day compressive strength tests was conducted. Accordingly, the results obtained, that was above the required limit that was 40 % of target strength, 13.32 MPa, as shown in Table 3.7. As a result, if these trial mix proportions are adopted, the required strengths will be satisfied. Based on this, the total quantities needed for all 54 cubes specimens are tabulated in appendix C.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results and discussions on CHA and cement blend pastes

4.1.1 Physical and Chemical properties of CH Ash

As shown in appendix E, CHA has low density, (2.72 g/cm^3, as compared to OPC that has density 3.15 g/cm^3). The combined chemical composition; $SiO_2 + Al_2O_3 + Fe_2O_3 = 37.1 < 50$ % which is nearly (74.2 %) testified the pozzolanic nature of coffee husk ash as per ASTM C- 618 specifications. The loss on ignition (LOI) value for the CHA was found to be 27.98 %, which was higher than that specified by the same standard (6

Table 4.1 Major oxides of CHA with temperature

Temperature in °C	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**K_2O**	**LOI**
550	16.55	17.18	3.98	5.68	19.3	27.98
600	14.18	10.44	1.48	2.88	2.45	47.98

From table 4.1 as the temperature increased the major chemical compounds of CHA decreases. It is due to disintegration of the ash to their respective chemicals elements. As a result this study was performed based on 550 °C.

As shown in Table 3.1, CHA has found that SiO_2, Al_2O_3, Fe_2O_3, and MgO with in the range as described in Ethiopian standards (ESA, 2013) and it resulted for the formation of compounds like C3S and C3A which are mainly responsible for early strength of concrete. Moreover, the CHA was found to have high alkali content like K_2O (19.5 %) implying high potential for alkali-silica reaction when used in concrete with silica reach aggregates.

Addition to that from table 2.7 it was found that, CHA has higher values from some common raw materials of cement. Such as SiO2 of CHA was greater than gypsum, bauxite, iron ore and lime stone. Al2O3 of CHA was greater than limestone, bagasse ash sand, shale, iron ore and sandy clay. Fe_2O_3 of CHA in similar manner was found higher than gypsum, sandy clay, clay and limestone. The same as CaO of CHA was greater than bagasse ash, fuel ash, bauxite, sand, shale, iron ore, clay and sandy. This shows that CHA has the required chemical requirement of raw materials for cement productions.

4.1.2 Consistency of blended pastes

Normal consistencies of pastes containing coffee husk ashes are shown in Table 4.2. The control paste or the paste without coffee husk ash had normal consistency of 26 %. All of the pastes containing coffee husk ash showed normal consistency equal and higher than the control paste, CHA0. Up to 2 % replacement, the normal consistency was constant, at 3 %, replacement the normal consistency had shown a slight increment to 31 %, and it increases continuously to 38 % at 15 % replacement.

Table 4.2 Normal consistency of blended pastes containing CHA

S. No	**Code**	**Consistency (%) (ASTM C 187)**
1	CHAO	26
2	CHA2	26
3	CHA3	31
4	CHA5	33
5	CHA10	35
6	CHA15	38

The usual range of water to cement ratio for normal consistency is between 26 to 33 % (ASTMC-138, 2000). The pastes with replacement up to 5 % showed a consistency with in this range, however, after 10 % replacement the results showed slightly higher values. This was due to the fineness of CHA and its porosity.

4.1.3 Setting time of blended pastes

The Ethiopian standard limits the initial setting time of cement not to be less than 45 minutes and the final setting time not to exceed 10 hrs. The results for the setting time in Table 4.3 indicated that addition of coffee husk ash retarded the setting; however, this retardation was within limits as specified by the Ethiopian standard. As the coffee husk ash content increases, the setting time has also showed a trend of increment.

The reason for the increasing in setting time could be the adsorption of water on coffee husk ash surface. The higher the proportion of the coffee husk ash, the higher was the adsorption of water increasing the normal consistency that in turn retreaded the setting time of paste.

Table 4.3 Setting time of pastes containing CHA

S. No	Code	Initial setting time (minutes)	Final setting time (minutes)
1	CHAO	63	365
2	CHA2	69	392
3	CHA3	77	415
4	CHA5	89	431
5	CHA10	105	465
6	CHA15	112	475

4.2 Results and discussion on fresh and harden CHA concrete properties

In this part of the thesis, the fresh and hardened coffee husk ash concrete properties such as workability, unit weight and compressive strength tests are presented and analysed respected to control specimens and relevant standards.

4.2.1 Fresh concrete properties

4.2.1.1 Workability Test

During concrete mixing, the mix might vary without the change very noticeable at first. For instance, a load of aggregate may be wetter or drier than what is expected or there may be variations in the amount of water added to the mix. These all necessitate a check on the workability and strength of concrete after producing (Abrham, 2010).

Workability embodies certain characteristics of fresh concrete, such as consistency and cohesiveness. Slump test is the simplest test for workability and are most widely used on construction sites. In the slump test, the distance that a cone full of concrete slumps down is measured when the cone is lifted from around the concrete. The slump can vary from nil on dry mixes to complete collapse on very wet ones. The slump test carried out for all six mixes were done using the apparatus shown in Figure 4.1.

Figure 4.1 Slump Test

The mold for the slump test is in the form of a frustum of a cone, which was placed on top of a rigid and flatten surface. The mold was filled in three equal layers and each layer was tamped 25 times with a tamping rod. Surplus concrete above the top edge of the mold was stroked off with the tamping rod. The cone immediately lifted vertically and the amount by which the concrete sample slumps were measured. The value of the slump obtained from by taking the mean of the distance between the underside of the round tamping bar and the highest, the lowest and medium points on the surface of the slumped concrete sample. The types of slump i.e. zero, true, shear or collapsed are then recorded. Table 4.4 shows the results of the slump test for the control concretes and the coffee husk ash concretes.

Table 4.4 Slump test results for CHA concrete

Code	**Replaced OPC (%)**	**W/B**	**Observed Slump (mm)**
CHA0	0	0,5	38
CHA2	2	0.5	36
CHA3	3	0.52	33
CHA5	5	0.54	33
CHA10	10	0.60	32
CHA15	15	0.68	30

As observed from Table 4.4 the slumps of the concrete containing coffee husk ash have shown a reduction as the coffee husk ash content increases. Table 4.2 (normal consistency), shows that the normal consistency of the blended pastes increased with increase of the coffee husk ash, this can also be an indication that in order to get a certain slump, OPC-CHA blended concretes needs a higher water content than a concrete with no coffee husk ash. The possible reason for this was CHA’s lower density giving it a higher porosity, resulting in higher water request. In order to get similar slump for the control and OPC-CHA concrete, the water content be increased as the coffee husk ash content increases. According to ASTMC143/C143M (2011) concretes having slumps less than 15 mm may not be adequately plastic and concretes having slumps greater than about 230 mm may not be adequately cohesive for this test to have significance. As a result, since the slump of the study found in the range of 30-38 mm, CHA concrete is good in plastic and cohesive properties. As a result it was found that CHA concrete will be good to minimize segregation of fresh concrete during placing and consolidating of concrete.

4.2.1.2 Fresh concrete unite weight

Density or unit weight properties of the fresh CHA concrete was investigated by using mold with constant weight and volume of 5.4 kg and 9 litter or 0.009 m^3 respectively. And according to ACI318M (2011), fresh concrete properties can be determined by their respective maximum size of aggregates as a result for the 25 mm size of course aggregates the corresponding unit weight was found 2375 kg/m^3.in this research the fresh concrete unit weight was calculated as follow in equation 4.1 and presented in table 4.4.

$$\mathbf{Density} = \frac{W2 - W1}{V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \text{equation 4.1}$$

Where W1 is weight of mold that is constant 5.4 Kg, W2 is weight of mold plus weight of fresh concrete in Kg and V is volume of mold in M^3.

As shown in Table 4.5 the fresh CHA concrete density decreases as percentage of coffee husk ash increases. It was observed that there was reduction of fresh density up to 6.06 % relative to control mixes, CHA0, and from over all CHA concrete is good to produce lightweight concrete structures.

Table 4.5 Fresh concrete density

Mix code	**Weight of fresh concrete plus mold (Kg)**	**Density of fresh concrete (Kg/M^3)**	**Reduction of density in %**
CHA0	27.8	2489	0
CHA2	27.5	2456	1.34
CHA3	27	2400	2.26
CHA5	26.4	2333	2.78
CHA10	25.2	2200	5.71
CHA15	24	2066	6.06

4.2.2 Hardened CHA concrete properties

4.2.2.1 Unit weight (Density) determination

The weights and the dimension of the concrete cubes for this research were measured just before testing them for the compressive strength. The results for the weight and dimension are given in the appendix C. Unit weights of the concrete were calculated by using the 28 days average unit weight and the results are as shown in Table 4.6.

The unit weight values used for the analysis of this section were measured from the concrete cubes sample after 28 days of cured in curing tank. From the results, it was found out that there were a significant reduction of unit weight while, coffee husk ash replacement percentages increases. As shown in Table 4.5 when 2 % of CHA added the density of control concrete resulted reduction of density within 6.27 % and the reduction continued up to 12.14 % was observed when 15 % of the cement was replaced by coffee husk ash in sample CHA15 replacement were undergone. Whereas 9.66, 9.87 and 10.30 % reductions were observed for 3, 5, and 10 % coffee husk ash replacement respectively.

Table 4.6 Unit weights of control and CHA concretes

Mix Code	Replaced OPC (%)	Density (kg/m3)	Density Reduction (%)
CHA0	0	2306.2	00
CHA 2	2	2243.5	6.27
CHA 3	3	2209.6	9.66
CHA 5	5	2207.5	9.87
CHA 10	10	2203.3	10.30
CHA 15	15	2184.9	12.14

The low specific gravity of the CHA, 2.72, as compared to the cement, 3.15, produced a decrease in the unit weight of the coffee husk ash concrete, as shown in Table 4.6. Since CHA was nearly 16 % lighter than cement, it was expected that the mass density of the mix would be significantly reduced. In addition to that it could be attributed to the increase in voids in the concrete cubes as the percentage CHA increases. However, the densities increase as the number of days of curing increase as the concrete cubes become denser. The results for the unit weight are presented in Table 4.6 and Figure 4.2 demonstrates the comparative decrease in unit weight of the CHA concrete in contrast with the respective control concrete, CHA0 at the 28th age of curing.

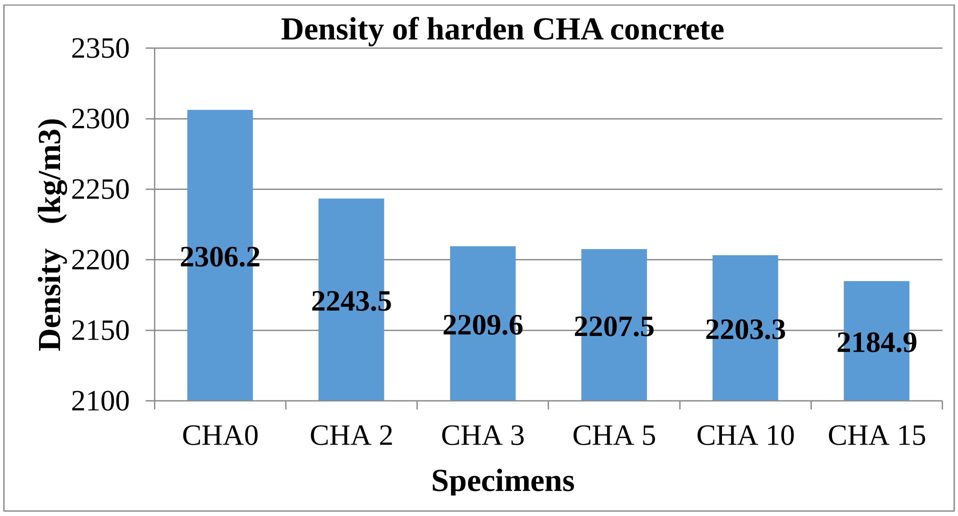

Figure 4.2 Graphical comparison for unit weight values of coffee husk ash

Using concrete with a lower density can result in significant benefits in terms of load bearing elements of smaller cross-section and a corresponding reduction in the size of foundations. Occasionally, the use of concrete with a lower density permits construction on ground with a low load-bearing capacity. Furthermore, with lighter concrete, the formwork need withstand a lower pressure than would be in case with normal weight concrete, and also the total mass of materials to be handled is reduced with a consequent increase in productivity (Abrham, 2010). Therefore, the reduced density of concrete containing CHA as cement partial replacement can provide with all the benefits mentioned which are associated with a lower density.

This research was conducted for production of normal weight concrete, and the density of the specimens ranges from 2203.3 Kg/m^3 to 2306.2 Kg/m^3 (table 4.5) for CHA0 to CHA10 and 2184.9 Kg/m^3 for CHA15 replacement. This showed that 2, 3, 5 and 10 % replacements lies within the range of 2200 Kg/m^3 to 2600 Kg/m^3 and 15 % replacements was out of the range specified as the density of normal weight concrete by Neville (2000).

4.2.2.2 Compressive strength Test

The compressive strength test of concrete is the most common test type for the hardened concrete. The reasons for these are; many codes and design manuals are based on this property, many other properties of concrete depend on the compressive strength and when compared to other tests this is an easy one. The compressive strengths of concrete specimens were determined after 7, 14 and 28 days of curing by testing the cubes in a calibrated compression machine with a rate of loading of 5 N/mm^2 per second. For each of the mixes the mean values of three cubes were taken as their compressive strength. The strength reductions due to in an increment of coffee husk ash were calculated by using equation 4.2 Table 4.6 shows this compressive strength values:

$$\textbf{Decrement } \% = \frac{\mathbf{Foj-Fij}}{\mathbf{Foj}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{equation } 4.2$$

Where F0j is the compressive strength of control, CHA0, at j curing days, and Fij is the compressive strength of i % replacement at j curing days.

Table 4.7.Average compressive strength values of concrete summery

No	**Mix Code**	**Average compressive strength in N/mm2**			**Loss of strength in % due to increasing CHA**			**Increments of strength due to aging of cubs from 7 to 28 days (%)**
		7 day	**14 day**	**28 Day**	**7 day**	**14 day**	**28 day**	**7 to 28 days**
1	CHA0	24.89	29.63	32.89	0.0	0.0	0.0	24,32
2	CHA2	22.81	26.37	30.07	8.33	11	8.56	24.14
3	CHA3	20.44	24.59	28.15	17.86	17	14.41	27.39
4	CHA5	19.70	22.96	26.67	20.83	22.5	18.92	26.13
5	CHA10	17.33	22.52	25.78	30.36	24	21.62	32.78
6	CHA15	15.70	21.19	23.56	36.90	28.5	28.38	33.36
Min. strength requirements (BS.EN.12390-3:, 2009)		65 %	90 %	99 %	Requirement in Percentage			
		16.25	22.5	24.75	Requirement in N/mm^2			

For CHA concrete, the results show that addition of coffee husk ash resulted in reduction in concrete compressive strength compared with the control mix, CHA0. This reduction increased with increasing percentage of coffee husk ash. Losses in compressive strength of 8.56, 14.41, 18.42, 21.82 and 28.38 % were observed when 2, 3, 5, 10 and 15 % of the cement was replaced by an equivalent volume of coffee husk ash respectively. However, the compressive strengths increased as the number of days of curing increased for each percentage CHA replacement.

As shown in Table 4.7 cube compressive strengths increased from the 7th day to 28th day by average of 28.02 of strength.

The probable reason for decreasing of CHA concrete compressive strength is due to the high replacement of cement by coffee husk ash, thus reducing cement content of the mixture, which in turn causes a reduction in the hydration reaction. In addition to this, the high content of coffee husk ash resulted in a higher water requirement, making the water unavailable for the hydration of the cement. Figure 4.3 shows the trend in compressive strength of the concrete.

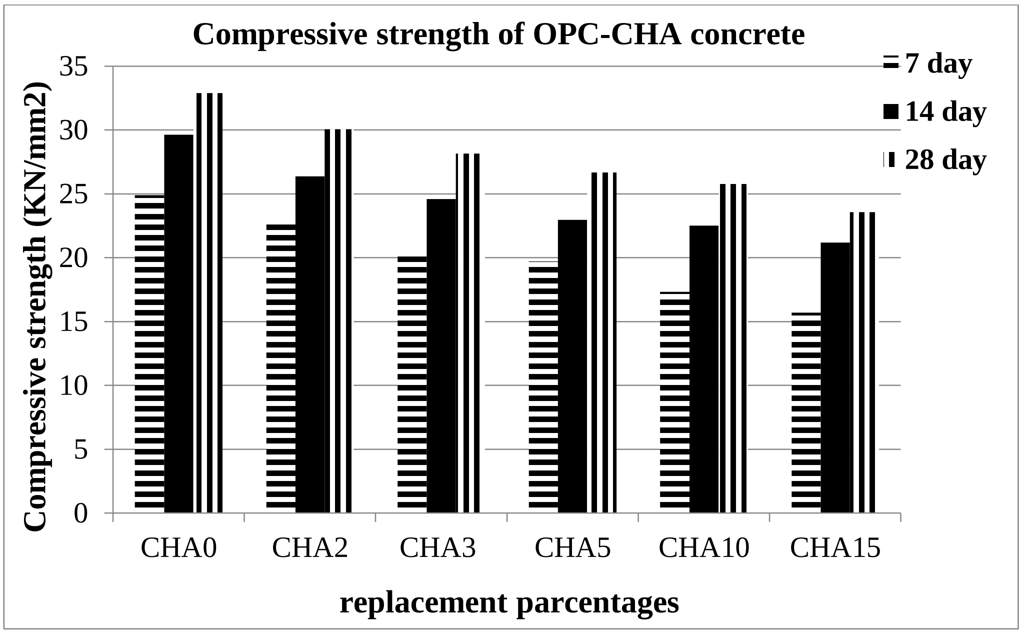

Figure 4.3 Compressive strength of OPC-CHA concrete

Although the compressive strength values have considerably decreased with the addition of CHA as seen in Table 4.7 and Figure 4.3 their values are still in a reasonable range up to 10 % and for 15 % replacement is slightly out of range for targeted grade of concrete ,C-25, but it good for lower grades of concrete like C-20.

4.3 Environmental and economic benefit of CHA concrete

The Ethiopian government has been continuously promoting the concept of Green Building, which is conducted on the basis of ecology, energy saving, health and waste reducing as the final objectives to realize the condition of low energy consumption and environmental damage.

One of the sustainability targets set by some governments for the construction industry is replacing cement with recycled cementiouse materials as alternatives while also reducing waste disposal. However, for use of alternative CHA to be sustainable, there must be an economic supply of sufficient quantity. There must also be methods of quality assurance plus specification and a market appropriate to the costs of the processed wastes, as well as good technical performance

The accumulation of CH at landfill sites presents the threat of uncontrolled fires, producing a complex mixture of chemicals harming the environment and contaminating soil and vegetation. On the other hand, solid waste that is not recycled or reused needs to be disposed in landfills, with direct costs in the form of tipping fees and indirect costs in the form of environmental impact and depletion of suitable landfill capacities. Hence, the successful use of waste of coffee processing, CH, in concrete could provide one of the environmentally responsible and economically viable ways of converting this waste into a valuable resource.

Construction is the largest consumer of natural resources. In addition to being a major consumer of natural resources, the construction industry is also one of the largest generators of waste. The replacement of Portland cement by coffee husk ash reduces the volume of cement utilized that is a major benefit since cement manufacturing is a significant source of carbon dioxide emissions worldwide. It was also emphasized that the possibility of using solid wastes of coffee husk ash as cement replacement in concrete serves as one promising solution to the escalating solid waste problem.

4.3.1 Reduction in materials usages

Using coffee husk ash, which is a recycled material, will save a great deal of materials used for concrete production. This is because when inventorying the materials that are used to manufacture concrete, only the concrete ingredients are included in the comparative calculations not recovered materials (i.e. coffee husk ash), because recovered materials already exist and would be disposed if not productively utilized. Table 4.7 shows the comparative calculation of concrete ingredients.

The assumptions were made in order to get the concrete material saving which are to manufacture 1 tons of Portland cement, 1.52 tons of raw materials is required (Eštoková, 2012) and CHA is a recycled (recovered) material.

Table 4.8 Raw material input for cement per cubic meter of concrete

Mix Code	**CHA0**	**CHA2**	**CHA3**	**CHA5**	**CHA10**	**CHA15**
OPC (kg/m3)	547	536	530	519	492	465
CHA (kg/m3)	0	11	17	28	55	82
Saving of materials (%)	0	2.01	3.10	5.12	10.05	15.00

As can be seen from Table 4.8, using coffee husk ash as a cement replacement has resulted in saving of raw materials for production of cement. For example, the 10 % replacement saved about 10.05 % of raw material required to produce 360 kg of cement it means 38 kg of cement per a meter cube of concrete when compared to the control concrete, which is about 38 kg/m3 that is nearly one bag of cement per one-meter cubic of concrete. If we see only 2016-production year (table 2.8), coffee production and associated residue were 172,990 MT of coffee hush ash which equivalent with the annual total production of cement from Abyssinia cement PLC and Durban Dejen cement factories.

Based on assumption made on above, for 1 ton of cement production consumed 1.52 ton of raw materials which is equivalent to 10 % of CHA will reduce the raw materials for cement production by the amount of 172,900 MT (Table 2.4) of CHA, will save 262,808 (172900*1.52) MT of raw materials per each year.

4.3.2 Energy saving

As discussed in section 3.3.1, in determination of ash of coffee husk, it needs only 550 ^{o}C that is reduction of 900 ^{o}C, 62.1 %, of temperature required for formation of clinker. This plays a great role in reduction of global warming.

According to MOI (2016) report, to produce one tone of clinker it needs to burn 0.164 tone of coals and usage of 43,223.8 KJ of energy per one kilogram of clinker. If we substitute it by CHA10, it will reduce the energy consumption by 0.1018 (i.e. 0.164 x 62.1 %) tons of coal per ton of clinkers and 26,841(i.e. 43223 x 62.1 %) KJ of energy per 1 kg of clinker productions.

The energy resources such as heavy fuel oil, coal and others are imported through state owned Ethiopia Petroleum Supply Enterprise. Cement price in Ethiopia has sharply declined compared to the price few years ago. However, cement price is still perceived to be higher compared to global price level. Several factors have contributed to relatively higher cement price in Ethiopia: high production cost mainly due to relatively higher energy cost.

Therefore, in this industry the energy cost are significant and cement manufacturers attempt to utilize the lowest energy required raw materials to meet the high temperature required. As a result, CHA is important for the energy cost reduction of cement productions that finally reduced the cost of cement as cement partial replacement.

4.3.3 Reduction in CO_2 emission

Most of the CO_2 emissions and energy use in the cement industry are related to production of clinker; 63 % of the CO_2 emitted during cement production comes from the calcination process, while the rest (37 %) is produced during the combustion of fossil fuels to feed the calcination process (Mercier, 2010).

According to Mercier (2010) the range of CO_2 emissions amounts is 0.65 to 0.92 kg of CO_2 per kg cement, based on a cement plant with modern technology and equipment, at worldwide level, the weighted average is approximately 0.79 kg of CO_2 per kg of cement.

Based on the finding in this research 10 % CHA replacement was found an optimum replacement percentage within acceptable level of concrete strength. As a result, to calculate the amount of CO_2 reduction in concrete particularly in cement productions it is selected. In addition, the facts for calculation is 10 % CHA replacement of cement was used, since this study did not cover CO_2 emissions during production of CHA, it was focused only combustion of fossil fuels to feed the calcination process. For this, from total CO_2 emissions, 37 % is generated from fuel consumptions during production of cement.and CHA productions needed only 550 ^oC as a result it can be produced by using low amount of electric energy relative to cement that is around 1500 ^oC (MOI, 2016).

One kg cement production emits around 0.79 kg CO_2 from this 37 %, 0.37*0.79 kg=0.2923 Kg, CO_2 come from fuel consumptions as a result for 10 % CHA replacement 0.02923 kg of CO_2 will be saves. Based on 2016 annual coffee productions there were equivalent coffee husk production (Table 2.8) and for this there was around 172, 900 MT of coffee husk ash productions. As a result, if we use it as a partial replacement of cement within 10 % as a limit, it will reduce the emission of CO_2 by the quantities of 0.02923*172900 MT=5,053.867 MT of CO_2 per year only from fuel consumption, since

CHA can be produced by suing lower amount of electric power instead of fuel energy. Addition to that it also play grate role in saving of foreign currency due to importing of fuel.

4.3.4 Economic advantages

Fuel costs are a large part of the manufacturing cost of the cement industry, making cement plants to have aggressive energy consumption. Moreover, the clinker burning process as shown above take more than 97 % of the fuel consumption, implying that it is the most expensive part of the cement production.

From this study, it was found that about 10 % replacement of cement by coffee husk ash results in a comparable concrete characteristics in strength and workability

The production cost of coffee husk ash is much lower than that of Portland cement due to less energy consumption and very cheap cost of the waste from coffee processing center to the cement plant. This is because the cost of coffee husk requires only transportation and grinding. Addition to that using CHA as cement partial replacement also make coffee producers more profitable by avoiding cost due to disposal of CH and generate income from sailing of it.

This implies that, using coffee husk ash to the minimum totally reduces the cost of clinker production (the most expensive one) by 10 % (since 10 % replacement was chosen because of it has resulted with in the required strength of C-25 Concrete), not mentioning the raw material preparations and other costs associated with cement production. Therefore, from the above stated evidences an economical advantage can be exploited by using coffee husk ash as a cement replacing material in countries like Ethiopia with a plan to boost cement and coffee production.

Generally using of coffee husk ash as partial replacement of cement for normal concrete production have a great role in terms of saving environment by reducing natural resources degradation (262 808 MT of raw materials per each year) and CO_2 emissions (5,053.867 MT). In addition, it reduces cost of cement due to reduction in energy usage by 62.1 % for production of cement clinkers.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The use of coffee husk ash as a cement replacing material in concrete production was studied and after the research work is done, the following conclusions were made:

The chemical composition test reveals that the coffee husk ash from Jimma has significant values of Al_2O_3 and SiO_2 which are major components of cement.

Higher replacements of cement by coffee husk ash resulted in higher normal consistency (implying higher water demand for workability) and longer setting time. The introduction of coffee husk ash in concrete significantly decreased the slump and workability. It was noted that the slump has decreased as the percentage of coffee husk ash was increased in all samples. A reduction in unit weight of up to 12.14 % was observed when 15 % by weight of the cement was replaced by CHA in sample CHA15. A much similar trend of reduction in unit weight of the CHA concrete was observed in all the other samples containing CHA with the reduction percentages of 6.27, 9.66, 9.67 and 10.30 % for CHA2, CHA3, CHA5 and CHA10 respectively. The low specific gravity of the CHA as compared to cement produced a decrease in the unit weight of the CHA concrete.

The compressive strength increased with curing period and decreases with increased amount of CHA. For this CHA concrete, the test results show that the addition of CHA resulted in a significant reduction in concrete compressive strength compared with the control concrete. This reduction increased with increasing percentage of CHA. Losses in compressive strength ranging from 8.56 to 28.38 % were observed at 28th day of curing for 2 and 15 % replacements respectively but strength development of CHA concrete increased with age. As a result compression test tell that more replacement ratio caused less strength degree for the same specimen age. In contrast, longer specimen age produced better strength for the same replacement ratio.

Therefore, the investigation of this study has found out that replacement of ordinary Portland cement by coffee husk ash from 2 to 10 % results in a better compressive strength and unit weight. Therefore, 10 % of CHA replacement is the optimum ratio for C-25 concrete production.as the same manner 15 % of CHA concrete is good for lower grade of concrete like C-20. Based on these preliminary results, it can be concluded that coffee hush ash can be used as an alternative cement replacing cementiouse materials for the production of normal weight concrete with acceptable physical, chemical and mechanical performance.

Finally, Since CHA is an agricultural by-product material, its use as a cement replacing material to reduces the levels of CO_2 emission by 5,053.867 MT only from fuel consumption from the cement industry and also saves a great deal of virgin materials by the amount of 262 808 MT of raw materials per each year and as a way of reducing the use of non-renewable natural materials. In addition, this research has demonstrated that concrete produced from coffee husk ash has high potential as a source of environmentally friendly cementiouse materials, which is that, reduces pollution as well as provides a sound coffee waste management option.

5.2 Recommendations

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

- The coffee husk ash as investigated in this study can be used as a cement replacing material with economic and environmental benefits. Therefore concerned bodies like coffee pulpler, cement industries, Ethiopian construction and chemicals institution and government entities should be made aware about this potential cement replacing material and promote its standardized production and usage.
- The coffee pulpler and Ethiopian cement industries associations in collaboration with Ethiopian construction and chemicals institution should work together and establish a research team to further study for the use of coffee husk ash as a cement replacing material.
- Most of the time, it is observed that designers and contractors go to a high strength and expensive concrete to get few improved properties such as light weight structures for particular applications. Nevertheless, these properties can be achieved through the application of CHA concrete by first conducting laboratory tests regarding the desired properties. Therefore, the use of CHA concrete as an alternative concrete making material needs an attention.
- This research studied some of the basic physical and chemical properties of coffee husk ash of Jimma zone coffee as a cement replacing material. Future studies should be continued in the following areas as part of the extension of this research work:

- The coffee husk ash from different major sources of coffee producing areas throughout the country should be studied.
- Studies should be made to check the chemical compositions and pozzolanic reaction of the coffee husk ash using more advanced methods like X-ray Diffraction (XRD) Analysis, Thermal Analysis (TGA) and Scanning Electron Microscopy (SEM).
- Since the use of coffee husk ash in concrete construction is not a common trend in our country, more studies and research works need to be done in this area and academic institutions should play a great role.
- The test results in this study were based on results taken after 7th, 14th and 28th days of standard curing of the test samples. The long-term effects of CHA concrete needs to be studied to find out the relevant properties associated with the age of the concrete.
- The estimative value of combustion cost and carbon emissions of coffee husk ash could be accurately calculated using more scientific research methods in the future.

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APPENDIX A

CONCRETE INGREDIENT PROPERTIES

1954 - 2014

EiABC
Ethiopian Institute of Architecture,
Building Construction and City Development
የኢትዮጵያ አርክቴክቸር፣ ህንፃ ግንባታ እና ከተማ ልማት ተቋም
Addis Ababa University
አዲስ አበባ ዩኒቨርሲቲ

Materials Research and Testing Centre (MRTC)
Certificate No.
Sample No.

Client : Abebe Demissew
Test Object : 4 bags of cement, 15 kg of CHA, 12 bags of sand and
5 18 bags of coarse aggregate

Sampled by : Client
Test Specified by : Abebe Demissew
Working Site : Jimma University, JIT
Kind of Test : Mix design for C-25 concrete and Materials quality test (sieve analysis, unit weights, specific gravity, water absorptions, moistur contents, silt content, organic impurity, consistence, setting time, Fresh and harden state CHA concrete properties).

A.1 MOISTURE CONTENT OF FINE AGGREGATE

Description		**Samples**	
		I	**II**
Weight of Wet (original) aggregate sample	W_1 (gm)	500	500
Weight of Oven dry aggregate sample	W_2 (gm)	421.6	419.5
Moisture Content = $\frac{(W1\ W2)\ x\ 100}{W_2}$	%	18.60	19.19
Average Moisture Content	%	**=18.89**	

A.2 MOISTURE CONTENT OF COURCE AGGREGATE

Descriptions		**Samples**	
		I	**II**
Weight of Wet(original) aggregate sample	W_1 (gm)	2000	2000
Weight of Oven dry aggregate sample	W_2 (gm)	1964.2	1964
Moisture Content = $\frac{(W1 - W2)}{W_2}$ x 100	%	1.82	1.83
Average Moisture Content	**%**	**1.83**	

A.3 UNITE WEIGHT OF FINE AND COURES AGGREGATES

Description	**Unite**	**Course aggregate**		**Fine Aggregate**	
		Sample 1	**Sample II**	**Sample 1**	**Sample 1I**
Weight of the mold	V (lit)	9	9	9	9
Weight of the mold only	W (Kg)	5.4	5.4	5.4	5.4
Weight of the mold loosely with aggregate	W1(Kg)	18.2	18.3	14.5	14.5
Weight of mold with aggregate fully Compacted	W_2 (Kg)	19.5	19.9	15.5	15.5
Loose Unit Weight = $\frac{(W1 - W)}{V}$ x 1000	(Kg/m3)	1422.2	1433.3	1011.1	1011.1
Compacted Unit Weight = $\frac{(W2 - W)}{V}$ x1000		1566.7	1611.1	1122.2	1122.2
Average Loose Unit Weight	(Kg/m3)	1427.78		1011.1	
Average Compacted Unit Weight		1588.89		1122.2	

A.4 SPECIFIC GRAVITY AND WATER ABSORPTION OF FINE AGGREGATES

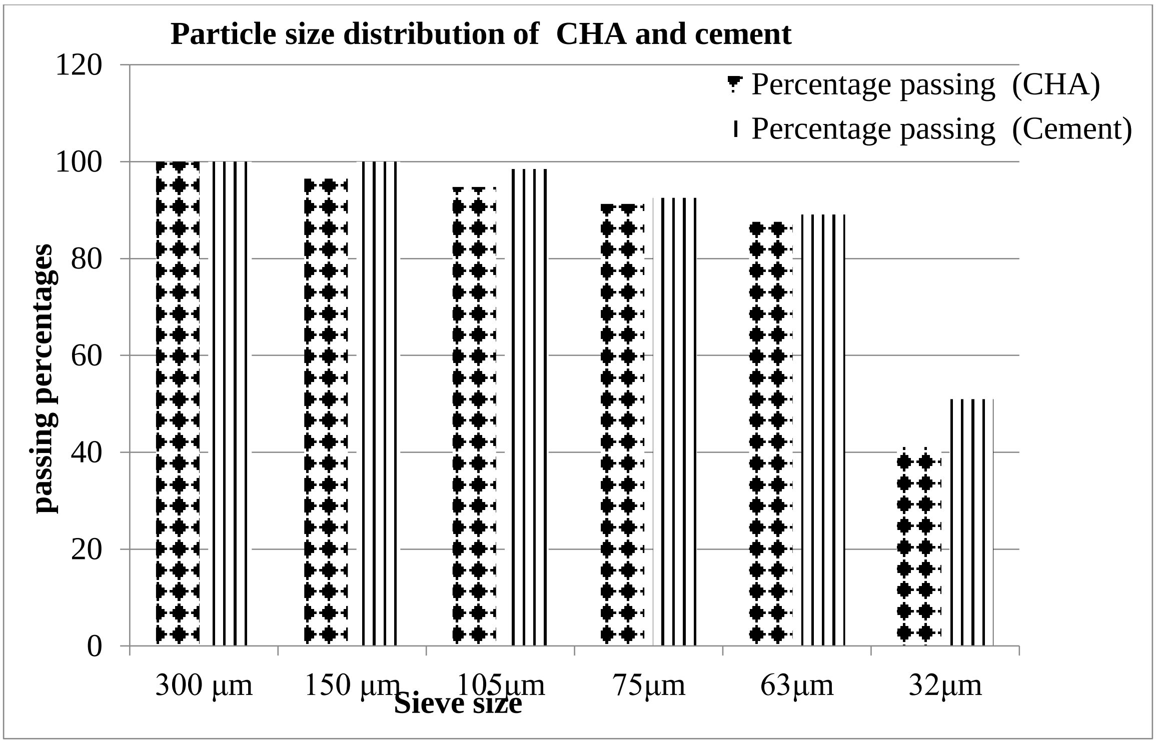
Description		**Units**	**Samples**	
			I	**II**
Weight of Sample taken		(gm)	500	500
Weight of Pycnometer + Sample + Water		W1(gm)	1561.8	1572.6
Weight of Pycnometer + Water		W2(gm)	1301.5	1307.9
Weight of SSD sample in air		W3(gm)	500	500
Weight of Oven dry sample		W4(gm)	490.5	490.7
$SG(SSD) = \frac{W3}{W_3 - (W_1 - W_2)}$			2.09	2.12
$WA(dry\ wt) = \frac{W3 - W_4}{W_4} \times 100$		%	1.87	1.82
$ASG = \frac{W4}{W4-(W1-W2)}$*100		%	1.94	1.90
Average values	SG		2.13	
	WA	%	1.92	
	ASG	%	1.87	

A.5 SPECIFIC GRAVITY AND WATER ABSORPTION OF COURSE AGGREGATES

Description			Samples	
			I	II
Weight of Sample taken		(gm)	4000	4000
Weight of Packet + Sample + Water		W1(g)	4337	4333
Weight of Packer + Water		W2(g)	1853	1855
Weight of SSD sample in air		W3(g)	4000	4000
Weight of Oven dry sample		W4(g)	3898.4	3899.2
$SG(SSD) = \frac{W3}{W_3 - (W_1 - W_2)}$			2.64	2.63
$WA(dry\ wt) = \frac{W3 - W_4}{W_4} \times 100$		%	2.61	2.59
$ASG = \frac{W4}{W4-(W1-W2)}*100$			2.76	2.74
Average values	SG		2.63	
	WA		2.6	
	ASG		2.75	

A.6 DETERMINATION OF ASH CONTENT OF CH

No.	Temperature duration (in hrs.)	Temperature (^oC)		
		500	550	600
1	2	25.85 %	19.10 %	18.10 %
2	3	22.80 %	18.30 %	17.80 %
3	4	20.20 %	17.60 %	16.90 %



Graph for the particle size distribution of the CHA and cement

A.7 GRAIN SIZE DISTRIBUTION FOR COFFEE HUSK ASH AND OPC CEMENT

Sieve size	Percentage passing of CHA	Percentage passing of Cement
300 µm	100	100
150 µm	96.5	100
105µm	94.75	98.5
75µm	91.3	92.5
63µm	87.6	89.1
32µm	41	51

APPENDIX B

MIX DESIGN PROCEDURES

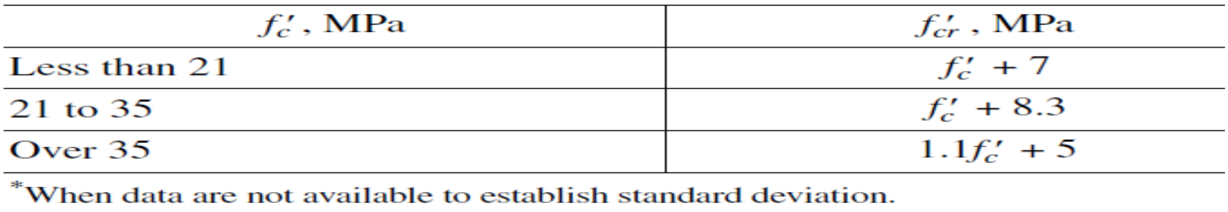
The mix design for C-25 non-air entrained normal strength concrete was done as per ACI 211.1. mix design procedure manual.

Step-1: Choice of slump: consistent to the method of placement the slump was set to be 25 - 50 mm (minimum slump possible) is selected

Step-2: **Maximum size of aggregate:** Maximum size was fixed to be 25 mm.

Step 3: Target mean strength calculation

From ACI 301 table 4.2.3.3C seen below for a 28-day compressive strength, when no test data is available, 8.5 MPa shall be added to get mean strength. As a result for 25 MPa characteristic strength, the target compressive strength will be = 25+8.5=33.3 MPa



f'_c, MPa	f'_{cr}, MPa
Less than 21	$f'_c + 7$
21 to 35	$f'_c + 8.3$
Over 35	$1.1f'_c + 5$

*When data are not available to establish standard deviation.

Step-4: Mixing water requirement: Based on the ACI table.3.8 seen below for the slump rang of 25-50 mm and a maximum size of 25 mm aggregates; the required mixing water is 180 kg. Therefore, for the first trial mix the mixing water required was 180 kg of water.

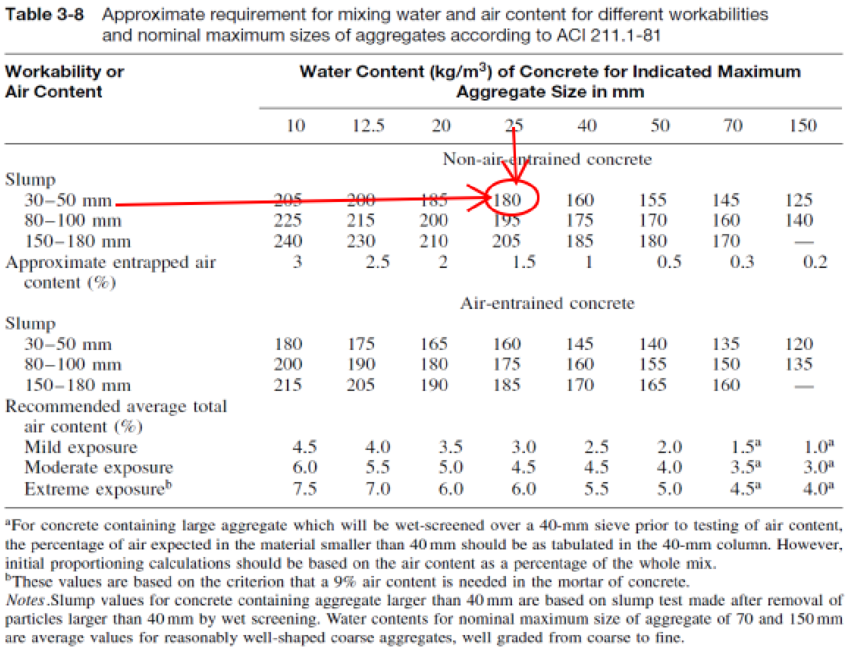


Table 3-8 Approximate requirement for mixing water and air content for different workabilities and nominal maximum sizes of aggregates according to ACI 211.1-81

Workability or Air Content	Water Content (kg/m^3) of Concrete for Indicated Maximum Aggregate Size in mm							
	10	12.5	20	25	40	50	70	150
	Non-air-entrained concrete							
Slump								
30–50 mm	205	200	185	180	160	155	145	125
80–100 mm	225	215	200	195	175	170	160	140
150–180 mm	240	230	210	205	185	180	170	—
Approximate entrapped air content (%)	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
Slump								
30–50 mm	180	175	165	160	145	140	135	120
80–100 mm	200	190	180	175	160	155	150	135
150–180 mm	215	205	190	185	170	165	160	—
Recommended average total air content (%)								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5[a]	1.0[a]
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5[a]	3.0[a]
Extreme exposure[b]	7.5	7.0	6.0	6.0	5.5	5.0	4.5[a]	4.0[a]

[a] For concrete containing large aggregate which will be wet-screened over a 40-mm sieve prior to testing of air content, the percentage of air expected in the material smaller than 40 mm should be as tabulated in the 40-mm column. However, initial proportioning calculations should be based on the air content as a percentage of the whole mix.

[b] These values are based on the criterion that a 9% air content is needed in the mortar of concrete.

Notes.Slump values for concrete containing aggregate larger than 40 mm are based on slump test made after removal of particles larger than 40 mm by wet screening. Water contents for nominal maximum size of aggregate of 70 and 150 mm are average values for reasonably well-shaped coarse aggregates, well graded from coarse to fine.

Step 5: water to cement (W/C) ratio

For 30 MPa W/C ratio is 0.55 and for 35 MPa W/C ratio is 0.48. The W/C ratio can be found by interpolation as follows from table 3.1 of ACI 211.1.81:

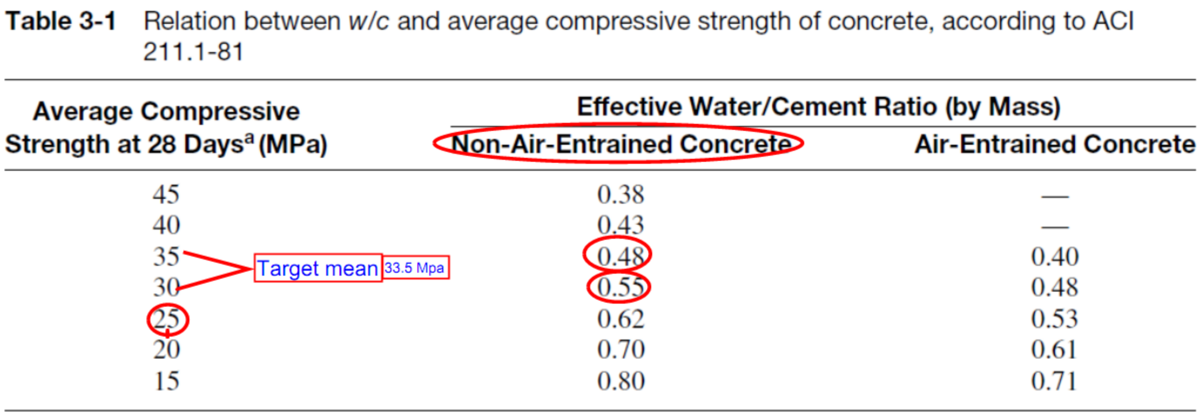


Table 3-1 Relation between *w/c* and average compressive strength of concrete, according to ACI 211.1-81

Average Compressive Strength at 28 Days[a] (MPa)	Effective Water/Cement Ratio (by Mass)	
	Non-Air-Entrained Concrete	Air-Entrained Concrete
45	0.38	—
40	0.43	—
35	0.48	0.40
30	0.55	0.48
25	0.62	0.53
20	0.70	0.61
15	0.80	0.71

$$\frac{w}{c} = \left[\frac{0.55 - 0.48}{30 - 35}\right](33.3 - 30) + 0.55 = 0.5$$

Step-6: Determining Cement content: From this ratio the amount of cement required will be about 360KGs (180/0.5).

Step-7: Estimation of Coarse aggregate content**:** The dry mass of coarse-aggregate required for a cubic meter of concrete is equal to the value from ACI 211-Table 3.11 multiplied by the dry-rodded unit mass of the aggregate in kilograms per cubic meter. In sieve analysis, it was found that the fines modulus of fine aggregate was 2.83.The unit weight of the dry rodded coarse aggregates is 1585KG/m^3. From the table the percentage by volume of coarse aggregate with a nominal maximum size of 25 mm is about 67%. This intern gives a mass of 1064.63 (0.67*1585) Kg of course aggregates.

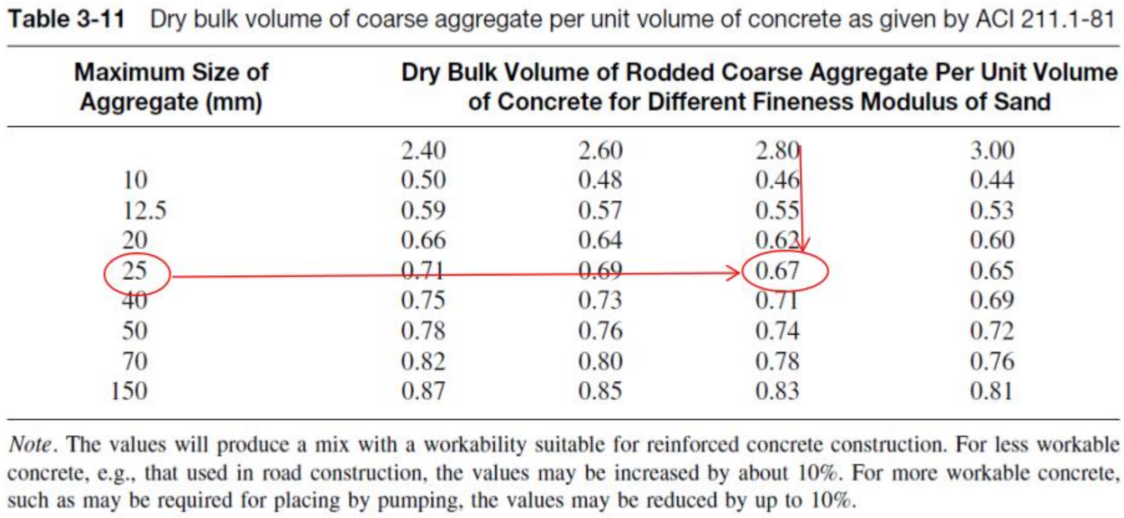


Table 3-11 Dry bulk volume of coarse aggregate per unit volume of concrete as given by ACI 211.1-81

Maximum Size of Aggregate (mm)	Dry Bulk Volume of Rodded Coarse Aggregate Per Unit Volume of Concrete for Different Fineness Modulus of Sand			
	2.40	2.60	2.80	3.00
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
40	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
70	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Note. The values will produce a mix with a workability suitable for reinforced concrete construction. For less workable concrete, e.g., that used in road construction, the values may be increased by about 10%. For more workable concrete, such as may be required for placing by pumping, the values may be reduced by up to 10%.

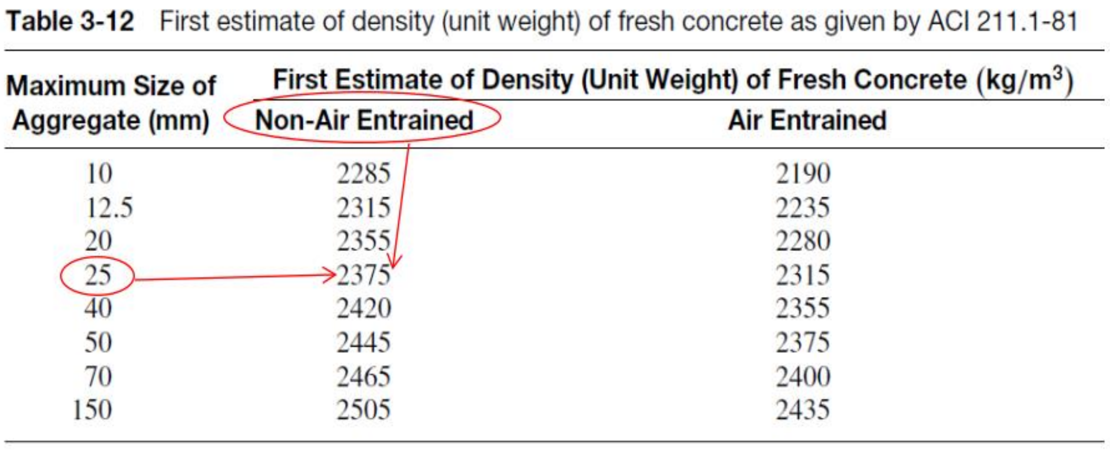


Table 3-12 First estimate of density (unit weight) of fresh concrete as given by ACI 211.1-81

Maximum Size of Aggregate (mm)	First Estimate of Density (Unit Weight) of Fresh Concrete (kg/m^3)	
	Non-Air Entrained	Air Entrained
10	2285	2190
12.5	2315	2235
20	2355	2280
25	2375	2315
40	2420	2355
50	2445	2375
70	2465	2400
150	2505	2435

Step-8: Fine aggregate content: it is clear that the estimated weight of the fresh Non air entrained concrete is 2375 KG. Deducting the weight of all the known ingredients gives the weight of the sand 770.37 Kg (2375-180-360-1064.63).

Step 9: Adjustments for moisture

	Cement Kg/M^3	**Water (Kg/M^{3}or Lit/M^3)**	**Fine Aggregate (Kg/M^3)**	**Coarse Aggregate (Kg/M^3)**	**Total Kg/M^3**
Materials Per M^3	360	180	770.37	1064.63	2375
Free moisture %	-	-	18.89	1.83	
Absorption capacity	-	+	1.92	2.60	
Adjustment	-	111.21-8.20	+123.8	+19,48	0
Adjusted per M^3	360	86.98	779.17	1084.11	2330.09
Adjusted per 0.014 M^3	5.32	1.22	10.91	15.18	32.63

APPENDIX C

MATERIALS AND FRESH CONCRETE POPERITIES FOR CUBES

MATERIALS PER NINE CUPES WITH 11% WASTAGE WITH RESULT OF FRESH CONCRETE

Mix code	% of replacement	Cement (Kg)	CHA (Kg)	Water (Kg)	Fine aggregate (Kg)	Course aggregate (Kg)	Mean value of Slump (mm)	Fresh concrete weight (Kg/ M^3)
CHA0	0	13.3	0	5.4	27.27	37.54	38	2780
CHA2	2	13.034	0.266	5.9	27.27	37.54	36	2750
CHA3	3	12.905	0.399	6.2	27.27	37.54	33	2700
CHA5	5	12.635	0.665	7.2	27.27	37.54	33	2640
CHA10	10	11.970	1.330	8	27.27	37.54	32	2520
CHA15	15	11.305	1.995	9	27.27	37.54	30	2400

APPENDIX D

COMPRESSIVE STRENGTH OF OPC-CHA CONCRETE

D-1 Seven Days Compressive strength of OPC-CHA concrete

No.	Code of mix	Date Poured	Date of Test	Age In Day	Dimensions (cm)			Vol. (dm^3)	Weight in Kg	Density (kg/dm^3)	Press area in cm^2	Failure load in tons	Com. Strength (Kg/cm^2)
					L	B	H						
1	CHA0	13/07/17	20/07/17	7	15	15	15	3.345	7.882	2.339	225	59	262.2
2		‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.787	2.311	225	53	235.6
3		‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.901	2.344	225	56	248.9
								Average	**2.311**		**248.9**		
1	CHA2	13/07/17	20/07/17	7	15	15	15	3.345	7.647	2.269	225	54	240
2	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.605	2.257	225	49	217.8
3	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.683	2.280	225	51	256.7
								Average	**2.269**		**228.1**		
1	CHA3	13/07/17	20/07/17	7	15	15	15	3.345	7.588	2.252	225	46	204.4
2	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.593	2.253	225	45	200.0
3	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.558	2.244	225	47	208.9
								Average	**2.249**		**204.4**		
1	CHA5	17/007/17	24/07/17	7	15	15	15	3.345	7.443	2.209	225	43	191.1
2	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.412	2.199	225	45	200
3	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.465	2.215	225	45	200
								Average	**2.208**				**197.1**
1	CHA10	17/07/17	24/07/17	7	15	15	15	3.345	7.424	2.203	225	39	173.3
2	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.413	2.200	225	40	177.8
3	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.435	2.206	225	38	168.9
								Average	**2.202**		**173.3**		
1	CHA15	17/07/17	24/07/17	7	15	15	15	3.345	7.292	2.164	225	35	155.6
2	‘’	‘’	‘’	’	‘’	‘’	‘’	3.345	7.289	2.163	225	37	164.4
3	‘’	‘’	‘’	’	‘’	‘’	‘’	3.345	7.290	2.163	225	34	151.1
								Average	**2.163**		**157.0**		

D-2 Fourteen Days Compressive strength of OPC-CHA concrete

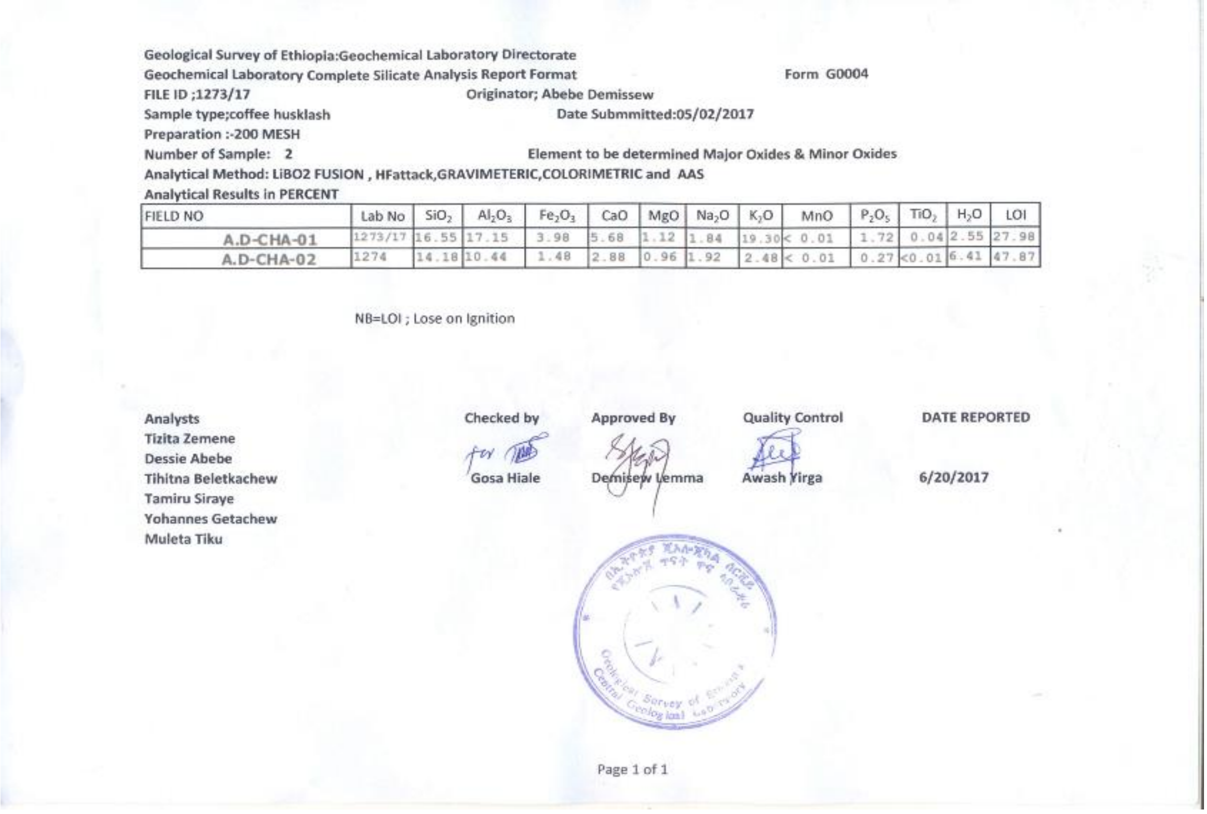
No.	**Code of mix**	**Date Poured**	**Date of Test**	**Age In Day**	**Dimensions (cm)**			**Vol. (dm^3)**	**Weight in Kg**	**Density (kg/dm^3)**	**Press area in cm^2**	**Failure load in tons**	**Com. Strength (Kg/cm^2)**
					L	**B**	**H**						
1	CHA 0	13/07/17	27/07/17	14	15	15	15	3.345	7.845	2.328	225	67	297.8
2		‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.856	2.331	225	65	288.9
3		‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.719	2.290	225	68	302.2
								Average		**2.316**			**296.3**
1	CHA 2	13/07/17	27/07/17	14	15	15	15	3.345	7.611	2.258	225	59	262.2
2	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.587	2.251	225	62	275.6
3	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.532	2.235	225	57	253.3
								Average		**2.248**			**263.7**
1	CHA 3	13/07/17	27/07/17	14	15	15	15	3.345	7.502	2.226	225	55	244.4
2	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.499	2.225	225	59	262.2
3	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.513	2.229	225	52	231.1
								Average		**2.227**			**245.9**
1	CHA 5	17/007/17	31/07/17	14	15	15	15	3.345	7.482	2.222	225	52	231.1
2	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.424	2.203	225	50	222.2
3	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.473	2.218	225	53	235.6
								Average		**2.214**			**229.6**
1	CHA 10	17/07/17	31/07/17	14	15	15	15	3.345	7.436	2.206	225	51	226.7
2	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.351	2.181	225	52	231.1
3	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.456	2.212	225	49	217.8
								Average		**2.200**			**225.2**
1	CHA 15	17/07/17	31/07/17	14	15	15	15	3.345	7.298	2.166	225	49	217.8
2	‘’	‘’	‘’	’	‘’	‘’	‘’	3.345	7.302	2.167	225	50	222.2
3	‘’	‘’	‘’	’	‘’	‘’	‘’	3.345	7.406	2.198	225	44	195.6
								Average		**2.177**			**211.8**

D.3 Twenty Eight Days Compressive strength of OPC-CHA concrete

No.	**Code of mix**	**Date Poured**	**Date of Test**	**Age In Day**	**Dimensions (cm)**			**Vol. (dm^3)**	**Weight in Kg**	**Density (kg/dm^3)**	**Press area in cm^2**	**Failure load in tons**	**Com. Strength (Kg/cm^2)**
					L	**B**	**H**						
1	CHA0	13/07/17	10/08/17	28	15	15	15	3.345	7.786	2.310	225	75	333.3
2		‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.723	2.292	225	73	324.4
3		‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.807	2.317	225	74	328.9
									Average	**2.306**			**328.9**
1	CHA2	13/07/17	10/08/17	28	15	15	15	3.345	7.589	2.252	225	68	302.2
2	CHA2	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.532	2.235	225	71	315.6
3	CHA2	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.561	2.244	225	64	284.4
									Average	**2.244**			**300.7**
1	CHA3	13/07/17	10/08/17	28	15	15	15	3.345	7.435	2.206	225	61	271.1
2	CHA3	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.468	2.216	225	66	293.3
3	CHA3	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.436	2.206	225	63	280.0
									Average	**2.210**			**281.5**
1	CHA5	17/007/17	14/08/17	28	15	15	15	3.345	7.385	2.191	225	61	271.1
2	CHA5	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.419	2.201	225	59	262.2
3	CHA5	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.514	2.230	225	60	266.7
								Average	**2.208**				**266.7**
1	CHA10	17/07/17	14/08/17	28	15	15	15	3.345	7.447	2.210	225	57	253.3
2	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.351	2.195	225	58	257.8
3	‘’	‘’	‘’	‘’	‘’	‘’	‘’	3.345	7.429	2.204	225	59	262.2
									Average	**2.203**			**257.8**
1	CHA15	17/07/17	14/08/17	28	15	15	15	3.345	7.384	2.191	225	53	235.6
2	‘’	‘’	‘’	’	‘’	‘’	‘’	3.345	7.403	2.197	225	51	226.7
3	‘’	‘’	‘’	’	‘’	‘’	‘’	3.345	7.302	2.167	225	55	244.4
									Average	**2.185**			**235.6**

APPENDIX E

CHEMICHAL PROPERITIES OF CHA



Geological Survey of Ethiopia:Geochemical Laboratory Directorate
Geochemical Laboratory Complete Silicate Analysis Report Format
Form G0004
FILE ID ;1273/17
Originator; Abebe Demissew
Sample type;coffee husklash
Date Submmitted:05/02/2017
Preparation :-200 MESH
Number of Sample: 2
Element to be determined Major Oxides & Minor Oxides
Analytical Method: LiBO2 FUSION , HFattack,GRAVIMETERIC,COLORIMETRIC and AAS
Analytical Results in PERCENT

FIELD NO	Lab No	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
A.D-CHA-01	1273/17	16.55	17.15	3.98	5.68	1.12	1.84	19.30	< 0.01	1.72	0.04	2.55	27.98
A.D-CHA-02	1274	14.18	10.44	1.48	2.88	0.96	1.92	2.48	< 0.01	0.27	<0.01	6.41	47.87

NB=LOI ; Lose on Ignition

Analysts	Checked by	Approved By	Quality Control	DATE REPORTED
Tizita Zemene Dessie Abebe Tihitna Beletkachew Tamiru Siraye Yohannes Getachew Muleta Tiku	Gosa Hiale	Demisew Lemma	Awash Yirga	6/20/2017

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Geological Survey of Ethiopia
Geochemical Laboratory Directorate
Hydrocarbon Laboratory analysis report format:Form GD0006
File ID 1276/17pvt
Originator.Abebe Demissew.
Sample type:Coffe husklash
Number of Samples:2
Preparation required :60mesh
Element to be determined: sulfur Specific gravity .
Method of analysis: Gravimetric method and Physical method.

customer type:pvt
Date submitted 24/09/2009(06/02/2017)
Date completed 07/10/2009(06/14/2017)

Field No.	*Lab No.*	*SO_3*	*Specific gravity gm/cm^3*
A.D-CHA-01	1276/17	1.00	2.57
A.D-CHA-02	1277/17	1.25	2.79
A.D-CHA-03	1277/17Dup	1.23	2.81

ANALYSTS:	CHECKED BY:	QUALITY CONTROL:	DATE REPORTED
Alemnesh Haimanot Bayeh	Alemnesh Abate	Awash Yerga	08/10/2009(06/15/2017)

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APPENDEX F

SAMPLE PHOTOS TAKEN DURING THE STUDIES

Photo 1 CH sample collected for test and preparation of CHA

Photo 2 Determination of coffee husk ash by Furness at PH laboratory

Photo 3 CH burning machine at JUCAVM

Photo 4 Grinding of CHA by grinding machine at PH laboratory

Photo 5 Silt content determinations of fine aggregate

Photo 6 Sieve analysis of coarse aggregates (left) and fine aggregates (right)

Photo 7 Fine and Coarse aggregate under specific gravity test

Photo 8 Unite weights determination of fine and coarse aggregates

Photo 9 Determinations of consistence and setting time of past (CHA + Cement)

Photo 10 Mixing procedures for trial mix

Photo 11 Prepared molds cube (left) and mixer (right)

Photo 12 Concrete ingredients to be mixed (left), being mixed (centre) and after mixed (right)

Photo 13 Fresh concrete properties Slump Test

Photo 14 Fresh concrete properties of fresh unit weight test

Photo 15 Concrete specimens’ preparations being trawled and finished

Photo 16 concrete spacemen transported to curing pond after Demolding

Photo 17 Concrete specimens ready to be cured

Photo 18 Concrete specimens in curing ponds

Photo 19 concrete specimen’s weight measurement (left), before and during compressive strength test (center and right respectively)

Photo 20 Calibrated compressive strength test machine