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Study on Effect of Partial Replacement of Cement by Cattle Bone Ash in Concrete Property

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FACULTY OF CIVIL AND WATER RESOURCES ENGINEERING

STUDY ON EFFECT OF PARTIAL REPLACEMENT OF CEMENT BY CATTLE BONE ASH IN CONCRETE PROPERTY

By

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February, 2020

Bahir Dar, Ethiopia

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BY

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A Thesis submitted to the school of Research and Graduate Studies of Bahir Dar Institute of Technology, Bahir Dar University

In partial fulfillment of the requirements for the degree of Masters of Science in Construction Technology and Management

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February, 2020

DECLARATION

I, the undersigned, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have acknowledged and refereed all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the University and can also evoke penal action from the sources which have not been properly cited or acknowledged.

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Date of submission: 30/04/2012 E.C

Place: Bahir Dar

This thesis has been submitted for examination with my approval as a university advisor.

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Bahir Dar University

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Thesis Approval Sheet

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To my family

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ABSTRACT

The growth of the Ethiopian economy stimulates the expansion of private and public construction industry. Construction materials demand increases with the growth of infrastructures and private building construction. Cement is one of the most commonly used construction materials to produce concrete. The environmental degradation because of the exploration of cement forming clinker materials highly affects the sustainability of ecology. Utilization of the locally available waste material is one of the most important way to reduce the environmental degradation due to cement production and affording cheap and sustainable cementitious material.

The study was aiming to investigate the effect of partial replacement of cement by cattle bone ash in concrete property. Complete silicate analysis of cattle bone ash shows that the material has high calcium oxide content (43.26%) which is the major oxide compound of cement.

This study was conducted by using locally available concrete making materials in Bahir Dar city. A C-25 concrete grade was selected for this study. The Normal consistency, setting time, soundness of cement paste, slump, compressive strength and density of concrete tests are done with (0%), 5%, 10%, 15% and 20% cement replacement with cattle bone ash. The compressive strength of concrete was done by curing 15cmx15cmx15cm cube concrete specimens underwater for 3, 7, 28 and 56 days.

The normal consistency of the cement paste increases as the percentage of the cattle bone ash increases in the paste attributed to high water absorption of CBA than OPC. The initial and final setting time of cement paste increase as the percentage of replacement of cement with bone ash, because of the presence of P_2O_5 in CBA which exhibits retarding setting time. The slump of concrete decreases at 0% to 10% CBA mix and increases in 15% to 20% CBA mix. From the results, the partial replacement of Ordinary Portland Cement with bone ash shows a gradual decrease of the compressive strength of concrete due to low formation of C_3S in CBA blended cement. The concrete density decreases as the percentage of bone ash increases due to low unit weight of bone ash compared to Ordinary Portland Cement. The use of cattle bone waste as an additive or supplementary cementing material production has vital importance to produce low-cost concrete and helps to conserve materials needed for cement production.

Key words: Cement, Compressive strength, Density, Cattle Bone Ash, Setting time, Slump

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation officials
ACI	American Concrete Institute
ASTM	American Society of Testing Materials
AWCB	Agricultural Wastes Co-products and By-products
CAB	Cattle Bone Ash
CC	Cubic Centimeter
ETB	Ethiopian Birr
FTIR	Fourier Transform Infrared Spectroscopy
g	gram
HAP	Hydroxyapatite
IS	Indian Standard
Kwh	Kilowatt hour
MPa	Mega Pascal
Mt	Million Ton
OPC	Ordinary Portland Cement
PCC	Portland Cement Concrete
PSD	Particle Size Distribution
SEM	Scanning Electron Microscope
SPSS	Statistical Package for the Social Sciences
W/C	Water Cement Ratio

1. INTRODUCTION

1.1 Background

The construction industry has become the main ingredient of the national economy. It is growing alarmingly in the world as well as in Ethiopia. This economic growth correspondingly increases the demand for construction materials. There is a high demand for low-cost building materials in providing adequate housing for low-income people. The cost of conventional building materials continues to increase as the majority of the population continues under poverty. The exploitation of raw construction material becomes a major environmental burden. Thus, there is a need to search low cost locally available materials as alternatives for the building construction industry.

Cement is one of the most widely used binding material which comprises about 11% of the concrete volume, is the most expensive concrete component and encompasses 45% of the total concrete cost (Quezon, Busier, & Hawaz, 2018). Ethiopia is one of the world countries having low cement per capita consumption. According to Armstrong's (2018) report, the world average cement per capita consumption is 563kg; but the Ethiopian cement consumption is 62kg per capita in 2015, which is even less than African countries average of 165kg per capita (Olana, 2015).

Several researches have been undertaken to replace cement by a partial addition of new materials. These materials are mainly pozzolanic materials (Fly ash, Rice husk ash) and other additive cementitious materials like animal bone powder and corn cob ash. Addition of these additive materials in concrete provides alternative ways to replace cement by low cost locally available materials.

Ethiopia is one of the famous countries in its cattle population of the world. Meat is highly consumed as a major recipe in Ethiopian at all cultural occasions, ceremonies and regular meals. High consumptions of meat correspondingly produce a high amount of bone waste that contaminates the environment, causes health problems and needs four thousands of years to decay in radiocarbon dating (Snoeck & Schulting, 2013). Proper utilization of these bone waste is necessary to create a clean environment and provide an option for recycling of bone waste as partial cement replacement.

The study examines the physical property of CBA blended cement paste, compressive strength, and slump difference between 0% Cattle bone ash (CBA) concrete and partial cement replacement in concrete. Partial replacement of cement with bone ash has dual advantages; reducing the problem of waste accumulation and simultaneously helps the preservation of natural resources needed for cement production.

1.2 Statement of the Problem

Nowadays, the development of infrastructures and private sector construction in Ethiopia has raised the demand for construction materials. There is a high gap between demand and supply of cement. In 2010, total cement demand has been 4.19 million ton and supply was 3.5 million ton, which indicates that there had been 0.69-million-ton shortage of cement (Aregaw, 2010). Cement demand in Ethiopia has been increasing in the last three years 2015 to 2018 by an average of 10.1 % per year (Olana, 2015). The production of cement consumes a high amount of energy and materials. For every one ton of cement produced, one ton of carbon dioxide is emitted to the atmosphere that causes depletion of the ozone layer (J.O. Akinyele, 2016).

The cement manufacturing process is a high-volume in nature, which demands a high amount of natural resources. Limestone, shells, and chalk or marl combined with shale, clay, slate, blast furnace slag, silica sand, and iron ore are common materials used in cement production. But the exploration of these materials highly degrades the natural environment. The use of wastes as raw materials in the clinker burning process can replace a relatively large amount of raw materials. The quantities of wastes while using raw materials in clinker production have more than doubled since 2001. In 2004, waste raw materials use in clinker production allowed the cement industry to make a direct saving of almost 14 million tons of conventional raw materials, which is equivalent to about 6.5 % of the natural raw materials needed. However, these waste raw materials have to have and meet characteristic, chemical elements and components which are necessary for the clinker burning process. These waste materials may have an impact on the emissions content of the which can have a direct and indirect effect on the emissions (Stajanča M., 2012).

Sustainable development of construction materials involves recycling of waste materials to compensate future scarcity of natural resources and conservation of the environment. Since the current construction industry needs to look for alternative low-cost materials, reuse of waste materials is an important option to provide cheaper materials. These enforces researchers to find alternative cementitious materials.

Ethiopia takes the first place in Africa and the fifth in the world by its cattle population. The waste products of animal bone in Ethiopia accounted for the 10% population of its cattle which are slaughtered per year, and the average weight of cow and oxen is 300kg plus. Out of this mass from 20% to 30% are the weight of the bone, we can get an average of 400.5 million Kilograms animal bone generated annually as waste (Quezon et al., 2018).

The total cattle population of Ethiopia in 2017 is estimated to be about 59.5 million that covers 44.93% of Ethiopian Livestock population. Over the next 15 years, the consumption of red meat (beef, sheep, goat and camel meat) in Ethiopia is projected to grow by about 276% from 775,000 tons in 2013 to 2.9 million tons in 2028 (Shapiro et al., 2017).

Environmental pollution by wastes from slaughtering houses and households as well as the waste disposal land requirement is one of the issues for large cities like Bahir Dar. Bone is one of the wastes removed from slaughtered animals (oxen and cows) which has high calcium content. On the other hand, 60% to 67% of Portland cement is comprised of calcium oxide. This indicates that the bone waste potential for partial replacement of cement. Despite its high calcium oxide content, it causes environmental pollution due to the harmful gases released from burning in the disposal site. Waste disposal for large towns is one source of expense to waste transportation and management. Natural landscape changes due to waste disposal, loss of beauty of city scenery and disease related to respirational causes due to bad smelling are among the major negative impacts on the environment and human well being. Proper utilization of this bone waste has a dual advantage by creating a sustainable environment and provides low-cost cementing material.

1.3 Objective of the Study

General objective

- ✓ Investigation of effect of partial replacement of cement with Cattle bone ash (CBA) in fresh and hardened properties of concrete.

Specific objectives

- ✓ Investigating the potential of cattle bone mineralogical composition as a supplementary cementitious material.

- ✓ Studying the effect of partial cement replacement with CBA in normal consistency and soundness of cement paste.
- ✓ Analyzing the effect of cement replacement with CBA in initial and final setting time of cement paste.
- ✓ Investigating the effect of partial replacement of cement with CBA in compressive strength, workability and density of standard concrete mix within CBA in varied proportions.
- ✓ Determining the optimum percentage of partial cement replacement with CBA in concrete.

1.4 Scope

The study is focused on partial replacement of ordinary Portland cement by bone ash which is a waste disposed from slaughtering houses. Dangote OPC and PPC cement is used for mixes. Locally available sand, crushed coarse aggregate, and tap water is used for mix. Bone is crushed by using manual hammering to remove bone marrow, furnace is used to burn clean dried bone and the disk mill machine is used for size reduction. Physical property of the cement paste with varied CBA proportion is one part of the study. Workability(slump) and compressive strength tests were under taken to monitor fresh and hardened concrete properties respectively. One grade of concrete(C-25) is selected for the study with four types of concrete mixes (5%, 10%, 15% and 20% CBA) of partial cement replacement. Compressive strength test on 15cmx15cmx15cm cubes of concrete at 3, 7, 28 and 56 days was conducted.

1.5 Significance

This study has vital importance by providing low cost cement for the construction stakeholders. It is helpful in providing an option for environmental protection and a sustainable environment for the human habitat by creating a clean environment. Additionally, it provides information for academicians and researchers to initiate further studies.

1.6 Limitations of the Study

The effect CBA replacement in durability of concrete test was not conducted due to lack of testing device in Bahir Dar Institute of Technology Construction Material Laboratory.

2. LITERATURE REVIEW

2.1 Cement

Portland cements are hydraulic cements composed primarily of hydraulic calcium silicates. Hydraulic cements include Portland cement and blended cements. Other types of hydraulic cements include natural cement and slag cement. They are used in all aspects of concrete construction. 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. Hydration begins as soon as cement comes in contact with water. Each cement particle forms a fibrous growth on its surface that gradually spreads until it links up with the growth from other cement particles or adheres to adjacent substances. This fibrous build up results in progressive stiffening, hardening, and strength development (Kosmatka Steven etal., 2011).

The stiffening of concrete can be recognized by a loss of workability that usually occurs within three hours of mixing, but is dependent upon the composition and fineness of the cement, any admixtures used, mixture proportions, and temperature conditions. Subsequently, the concrete sets and becomes hard. Hydration continues as long as favorable moisture and temperature conditions exist (curing) and space for hydration products is available. As hydration continues, concrete becomes harder and stronger. Most of the hydration and strength development take place within the first month, but then continues, though more slowly, for a long time with adequate moisture and temperature. Different types of Portland cement are manufactured to meet various normal physical and chemical requirements for specific purposes. Portland cements are manufactured to meet the specifications of ASTM C 150 and ASTM C 1157 (Kosmatka Steven etal., 2011).

The sum of the proportions of reactive calcium oxide (CaO) and reactive silicon dioxide (SiO_2) in cement shall be at least 50 % by mass ("ES 1177 - 1:2005," 2005).

2.2 Chemical Compounds and Hydration of Portland Cement

During the burning operation in the manufacture of Portland cement clinker, calcium combines with the other components of the raw mix to form four principal compounds that make up 90%

of cement by mass. Gypsum (4% to 6%), or other calcium sulfate source, and grinding aids are also added during grinding. Cement chemists use the following chemical shorthand (abbreviations) to describe compounds. A= Al_2O_3, C= CaO, F= Fe_2O_3, H=H_2O, M=MgO, S= SiO_2, and $\overline{s}$ = SO_3.

Al_2O_3, CaO, Fe_2O_3, H_2O, MgO, SiO_2, SO_3 are abbreviations representing; Aluminum oxide, Calcium oxide, Iron oxide, Water, Magnesium oxide, Silicon oxide and Sulphur trioxide respectively. The term "phase" rather than "compounds" can also be used to describe the components of clinker (Kosmatka Steven etal., 2011).

Table 2-1: Portland Cement Chemical Composition (Sandor Popovics,1992)

Four primary compounds in Portland cement	**Approximate chemical formulas**	**Abbreviations**
Tricalcium silicate	$3CaO\cdot SiO_2$	C_3S
Dicalcium silicate	$2CaO\cdot SiO_2$	C_2S
Tricalcium aluminate	$3CaO\cdot Al_2O_3$	C_3A
Tetracalcium aluminoferrite	$4CaO\cdot Al_2O_3\cdot Fe_2O_3$	C_4AF
Forms of calcium sulfate		
Anhydrous calcium sulfate	$CaSO_4 = CaO\cdot SO_3$	$C\overline{s}$
Calcium sulfate, dihydrate (gypsum)	$CaSO_4 \cdot 2H_2O = CaO\cdot SO_3\cdot 2H_2O$	$C\overline{s}H_2$
Calcium sulfate hemihydrate	$CaSO_4 \cdot \frac{1}{2} H_2O = CaO\cdot SO_3 \cdot \frac{1}{2} H_2O$	$C\overline{s}H_{1/2}$

Gypsum, calcium sulfate dihydrate, is the predominant source of sulfate used in cement. C_3S and C_2S in clinker are also referred to as alite and belite, respectively. Alite constitutes 50% to 70% of the clinker, whereas belite accounts for only 15% to 30%. Aluminate compounds constitute about 5% to 10% of the clinker and ferrite compounds 5% to 15% (Taylor 1997).

According to Kosmatka Steven etal. (2011), Portland Cement compound hydration reactions;

$$2(3CaO \bullet SiO_2) + 11\ H_2O = 3CaO \bullet 2SiO_2 \bullet 8H_2O + 3(CaO \bullet H_2O) \ldots\ldots Equation\ 1$$

$$2(2CaO \bullet SiO_2) + 9\ H_2O = 3CaO \bullet 2SiO_2 \bullet 8H_2O + CaO \bullet H_2O \ldots\ldots\ldots\ldots Equation\ 2$$

$$3CaO \bullet Al_2O_3 + 3(CaO \bullet SO_3 \bullet 2H_2O) + 26\ H_2O = 6CaO \bullet Al_2O_3 \bullet 3SO_3.32H_2O \ldots\ldots\ldots\ldots\ldots Equation\ 3$$

$$2(3CaO \bullet Al_2O_3) + 6CaO \bullet Al_2O_3 \bullet 3SO_3 \bullet 32H_2O + 4H_2O = 3(4CaO \bullet Al_2O_3 \bullet SO_3 \bullet 12H_2O) \ldots\ldots\ldots\ldots\ldots Equation\ 4$$

$$3CaO \bullet Al_2O_3 + CaO \bullet H_2O + 12H_2O = 4CaO \bullet Al_2O_3 \bullet 13H_2O \ldots\ldots Equation\ 5$$

$$4CaO \bullet Al_2O_3 \bullet Fe_2O_3 + 10\ H_2O + 2(CaO \bullet H_2O) = 6CaO \bullet Al_2O_3 \bullet Fe_2O_3 \bullet 12H_2O \ldots\ldots\ldots\ldots\ldots Equation\ 6$$

Tricalcium Silicate, C_3S, hydrates and hardens rapidly and is largely responsible for initial set and early strength. In general, the early strength of Portland cement concrete is higher with increased percentages of C_3S.

Dicalcium Silicate, C_2S, also known as belite accounts about 15% to 30% of the clinker, hydrates and hardens slowly and contributes largely to strength increase at ages beyond one week of mixing.

Tricalcium Aluminate, C_3A, liberates a large amount of heat during the first few days of hydration and hardening. It also contributes slightly to early strength development. Cements with low percentages of C_3A are more resistant to soils and waters containing sulfates.

Tetracalcium Aluminoferrite, C_4AF, is the product resulting from the use of iron and aluminum raw materials. Its contribution to strength is little but most color effects that make cement gray are due to C_4AF and its hydrates.

Calcium Sulfate, as anhydrite (anhydrous calcium sulfate), gypsum (calcium sulfate dihydrate), or hemihydrate, often called Plaster of Paris or bassanite (calcium sulfate hemihydrate) is added to cement during final grinding to provide sulfate to react with C_3A to form ettringite (calcium tri sulfoaluminate). This controls the hydration of C_3A without sulfate, a cement would set rapidly. In addition to controlling setting and early strength gain, the sulfate also helps control drying shrinkage and can influence strength through 28 days.

2.3 Supplementary Cementitious Materials

Supplementary cementitious materials are materials that, when used in conjunction with Portland or blended cement, contribute to the properties of the hardened concrete through hydraulic or pozzolanic activity or both. Supplementary cementitious materials are added to concrete as part of the total cementitious system. They may be used in addition to or as a partial replacement of Portland cement or blended cement in concrete, depending on the properties of the materials and the desired effect on concrete (Kosmatka Steven etal., 2011).

Supplementary cementitious materials are used to improve a particular concrete property, such as resistance to alkali-aggregate reactivity. The optimum amount to use should be established by testing to determine (1) whether the material is indeed improving the property, and (2) the correct dosage rate, as an overdose or underdose can be harmful or not achieve the desired effect. Supplementary cementitious materials also react differently with different cements.

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 and other cementitious compounds. Pozzolans and slags are generally categorized as supplementary cementitious materials or mineral admixtures Kosmatka Steven etal.(2011). As ASTM C618, pozzolanic materials contain the summation of silicon dioxide, aluminum oxide and iron oxide are greater than 50%. According to Sandor Popovics (1992), commonly used supplementary cementitious materials are;

A. Fly Ash

Fly ash, the most widely used supplementary cementitious material in concrete, is a byproduct of the combustion of pulverized coal in electric power generating plants. Upon ignition in the furnace, most of the volatile matter and carbon in the coal are burned off. During combustion, the coal's mineral impurities (such as clay, feldspar, quartz, and shale) fuse in suspension and are carried away from the combustion chamber by the exhaust gases. Fly ash is primarily silicate glass containing silica, alumina, iron, and calcium.

B. Slag

Ground granulated blast-furnace slag also called slag cement, is made from iron blast-furnace slag; it is a nonmetallic hydraulic cement consisting essentially of silicates and aluminosilicates of calcium developed in a molten condition simultaneously with iron in a blast furnace. It contains 40% calcium oxide and 35% silicon oxide by mass.

C. Silica Fume

Silica fume, also referred to as micro-silica or condensed silica fume, is a byproduct material that is used 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. It contains 90% of silicon oxide by mass.

D. Natural Pozzolans

Natural pozzolans have been used for centuries. The term “pozzolan” comes from a volcanic ash mined at Pozzuoli, a village near Naples, Italy, following the 79 AD eruption of Mount Vesuvius. However, the use of volcanic ash and calcined clay dates back to 2000 BC and earlier in other cultures. The North American experience with natural pozzolans dates back to early 20^{th} century public works projects, such as dams, where they were used to control temperature rise in mass concrete and provide cementitious material. In addition to controlling heat rise, natural pozzolans were used to improve resistance to sulfate attack and were among the first materials to be found to mitigate alkali-silica reaction. The most common natural pozzolans used are processed materials, which are heat treated in a kiln and then ground to a fine powder. They include calcined clay, calcined shale, and metakaolin (Kosmatka Steven , Kerkhoff Beatrix, & William, 2011).

2.4 Physical Properties of Cement

Setting time to determine;

(1) the time that elapses from the moment water is added until the paste ceases to be fluid and plastic (called initial set) and

(2) the time required for the paste to acquire a certain degree of hardness (called final set).

Particle Size and Fineness Portland cement consists of individual angular particles with a range of sizes, the result of pulverizing clinker in the grinding mill. Approximately 95% of cement particles are smaller than 45 micrometers, with the average particle around 15 micrometers.

Soundness refers to the ability of a hardened paste to retain its volume. Lack of soundness or delayed destructive expansion can be caused by excessive amounts of hard burned free lime or magnesia.

Consistency refers to the relative mobility of a freshly mixed cement paste or mortar or to its ability to flow. During cement testing, pastes are mixed to normal consistency as defined by a penetration of 10 ±1 mm of the Vicat plunger.

Early Stiffening (False Set and Flash Set) Early stiffening is the early development of stiffness in the working characteristics or plasticity of cement paste, mortar, or concrete. This includes both false set and flash set.

Compressive Strength Compressive strength as specified by ASTM cement standards is that obtained from tests of 50-mm (2-in.) mortar cubes tested in accordance with ASTM C 109.

Heat of Hydration Heat of hydration is the heat generated when cement and water react. The amount of heat generated is dependent chiefly upon the chemical composition of the cement, with C_3A and C_3S being the compounds primarily responsible for high heat evolution.

Loss on Ignition loss on ignition (LOI) of Portland cement is determined by heating a cement sample of known weight to between 900°C and 1000°C until a constant weight is obtained.

Density and Relative Density (Specific Gravity) The density of cement is defined as the mass of a unit volume of the solids or particles, excluding air between particles.

2.5 Quality of Concrete

Quality concrete possesses well defined and accepted principal requirements. According to (Kosmatka Steven et al., 2011), fresh and hardened concrete properties are given as follows;

Table 2-2: Freshly Mixed Concrete Quality

Properties	Description
Consistency	The ability to flow
Stability	The resistance to segregation
Uniformity	Homogeneous mixture, with evenly dispersed constituents
Workability	Ease of placing, consolidating, and finishing
Finish ability	Ease of performing finishing operations to achieve specified surface characteristics

Table 2-3: Hardened Concrete Quality

Properties	Description
Strength	Resists strain or rupture induced by external forces (compressive, flexural, tensile, torsion and shear)
Durability	Resists weathering, chemical attack, abrasion, and other service conditions
Appearance	Meets the desired aesthetic characteristics
Economy	Performs as intended within a given budget.

Note: adapted from "Design and Control of Concrete Mixtures" by the (Kosmatka Steven etal., 2011).

2.6 Animal Bone

Bone is a strong, hard, fibrous material in the mammalian body (endo- skeleton) which gives shape and supports to the body. It is rigid tissue consisting of cells embedded in abundant hard intercellular material that provides structural support for soft tissues and regulates calcium phosphate level in the body. Bone mineral is a complex chemical made from calcium, phosphate and hydroxyl ions, but which may also contain a small amount of cationic, magnesium and strontium replacing calcium and bicarbonate and fluoride, replacing the hydroxyl anions (Gaurav Vispute etal., 2018).

Bone is a mineralized connective tissue that exhibits four types of cells: osteoblasts, bone lining cells, osteocytes, and osteoclasts. Bone exerts important functions in the body, such as locomotion, support and protection of soft tissues, calcium and phosphate storage, and harboring of bone marrow. Despite its inert appearance, bone is a highly dynamic organ that is continuously resorbed by osteoclasts and neoformed by osteoblasts (Gaurav Vispute, Shubham Suryawad, Akshay Adhore, & Tupsoundare, 2018). Regarding to the difference between ox and cow, (Ylva Telldahl, 2011) study shows that the gender difference has no significant effect on the physiological characteristics of bone and both belongs to cattle group.

Bone cells

1. **Osteoblasts:** Osteoblasts are cuboidal cells that are located along the bone surface comprising 4–6% of the total resident bone cells and are largely known for their bone forming-function.

2. **Bone Lining Cells:** Bone lining cells are quiescent flat shaped osteoblasts that cover the bone surfaces, where neither bone resorption nor bone formation occurs.
3. **Osteocytes:** Osteocytes, which comprise 90–95% of the total bone cells, are the most abundant and long-lived cells, with a lifespan of up to 25 years
4. **Osteoclasts:** Osteoclasts are terminally differentiated multinucleated cells, which originate from mononuclear cells of the hematopoietic stem cell lineage (Florencio-Silva et al., 2015).

The major minerals of the intercellular composite are calcium and phosphate. When first deposited, mineral is crystallographically amorphous, but with maturation, it becomes typical of the apatite minerals, the major being hydroxyapatite. the crystal minerals are responsible for hardness, rigidity, and the great compressive strength of bone, but they share with other crystalline materials weak in tension, arising from the tendency for stress to concentrate about defects and for these defects to propagate. Collagen fibers of bone possess high elasticity, little compressive strength of and considerable intrinsic compressive strength.

Bones from slaughtered animals have several uses. In ancient times, they have been used for making bone tools. They have further been used in bone carving, already important in prehistoric art, and also in modern time as crafting materials for, beads, handles, buttons, bobbins, calculation aids, head nuts, dice, poker chips, pick-up sticks, ornaments, etc. (Anatomy, 2019)

Bone powder is an inorganic material derived from animal bones, dried and heated in a furnace at a very high temperature or burning in the air and grounded to fine powder using milling machine. The bones were dried in open air after they have been separated from all the muscles, flesh tissues and fats. Dried bone is burnt at moderate fire to remove organic fats and other tissues. after cooling burned bone, it was hammered to make small pieces (Okoye & Odumodu, 2016).

Bone consists of both organic and inorganic components. The major inorganic component is calcium phosphate, $Ca_3(PO_4)_2$, accounting for two-thirds of the weight of bone. Calcium phosphate interacts with calcium hydroxide, $Ca(OH)_2$, to form hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$. As the crystals of hydroxyapatite form, they also incorporate other inorganic materials including calcium carbonate, sodium, magnesium and fluoride. The remaining organic portion of the bone is made up of cells (osteoblasts, osteocytes, and osteoclasts) and osteoid, which includes collagen fibers and ground substance (proteoglycans and glycoproteins). The osteoid is secreted by osteoblasts ("Anatomy and Physiology of Domestic Animals," 2019).

Bone inorganic minerals such as calcium ions are obtained by heating at higher temperature (calcination) usually greater than 900 ºC (Figueiredo et al., 2010).

Although marked alterations in structure and mineralogy of the bone samples on heating were detected, these alterations were similar for each specimen. At 600 ºC the organic component was removed and a carbonate apatite was obtained. At 900 ºC, carbonate was no longer detected and traces of Calcium oxide (CaO) were found at 1200 ºC. Crystallinity degree and crystallite size progressively increased with the calcination temperature, contrary to porosity that strongly decreased at elevated temperatures. Relatively to the control samples, a significant increase in porosity was found in samples calcined at 600 ºC (reaching values around 50%). At higher temperatures, a dramatic decrease was observed, reaching, at 1200 ºC, values comparable to those of the non-calcined bone (Figueiredo et al., 2010).

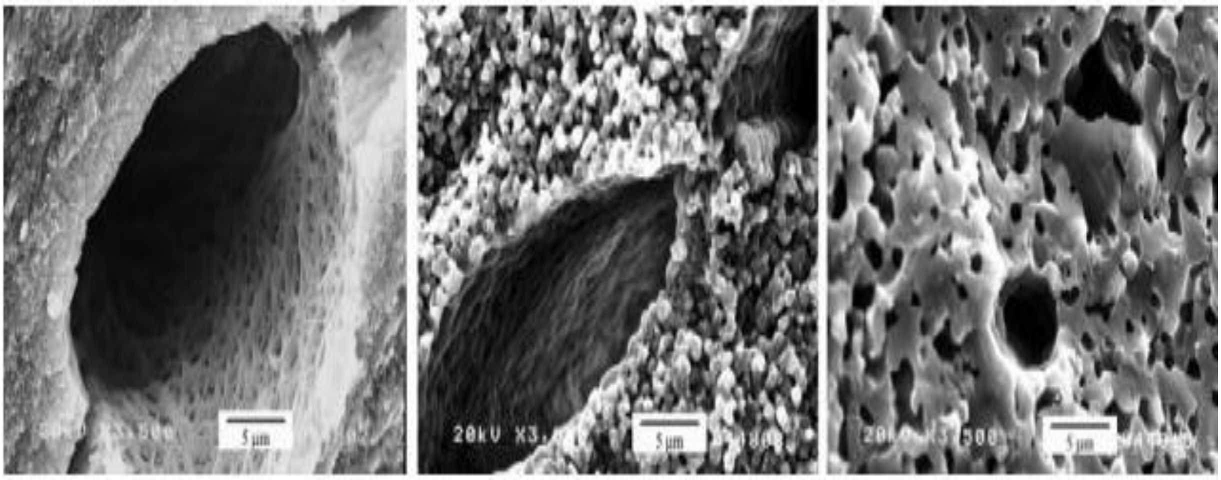

Figure 2-1: SEM Images of Bovine Bone at 600, 900 and 1200 ˚C (from left to right)

Note: adapted from "Effect of the calcination temperature on the composition and microstructure of hydroxyapatite derived from human and animal bone" by the (Figueiredo et al., 2010).

In the calcination process, bone particles were placed in an open alumina crucible and then heated in a furnace (Carbolite, UK) to eliminate organic constituents contained in the bovine bones, leaving only Hydroxyapatite. All samples were heated at various temperatures, i.e., 700°C, 900°C, and 1100°C for 3 hours at heating rate 10°C/min and afterward were cooled slowly to room temperature (Khoo, Nor, Ardhyananta, & Kurniawan, 2015).

2.7 Physical and Mechanical Properties of Cow Bone Ash

Different researches were done on identifying the physical and mechanical properties of animal bone. Bulk density, specific gravity, moisture content, tensile strength and compressive strength are the most important physical characteristics of bone.

Table 2-4: Physical Properties of Cow Bone Ash

Properties	(Okeyinka, Olutoge, & Okunlola, 2018)	(Otunyo, Umueyo, & Kingsley, 2014)
Bulk density	1.13g/cm³	1.02 g/cm³
Specific gravity	1.29	1.42
Moisture content	-	6.8%
Particle size range	75µm-1.18mm	-

Table 2-5: Overview (Average) Properties of Cow Cortical Bone

Property	Cow (Bovine) value
Elastic Modulus transverse	20.4 GPa
Elastic modulus long	11.7 GPa
Shear modulus	4.1 GPa
Tensile yield stress long	141 MPa
Tensile ultimate stress long	145 MPa
Tensile ultimate stress transverse	50 MPa
Compressive yield stress long	196 MPa
Compressive yield stress transverse	150 MPa
Compressive ultimate stress long	137 MPa
Compressive ultimate stress transverse	178 MPa

Note: adapted from "Machine Crushed Cow Bones as a Partial Replacement of Fine Aggregates in Lightweight Concrete" by the (Otunyo et al., 2014).

2.8 Factors Affecting Bone Characteristics

2.8.1 Temperature

Temperature is the main factor that changes the physical and chemical properties of animal bones. Distinct structural changes were detected on firing cattle bone at 600˚C, indicating the formation of α-$Ca_3(PO_4)_2$ together with hydroxyapatite at temperature below 600˚C.

Approximate sintering temperature for synthetic calcium hydroxyapatite ranges from 900 ˚C to 1400 ˚C. Morphology changes at the surface as calcination temperature increases. Unlike the highly dense micro surface observed in raw bovine bone particles, calcinated bones contain multiple pores created by decomposition of organic substances. Calcination temperature brings a direct impact on changes in grain growth where higher calcination temperature yields an increase in grain size. This grain growth may associate with the absorption of heat energy by the particles (Khoo et al., 2015).

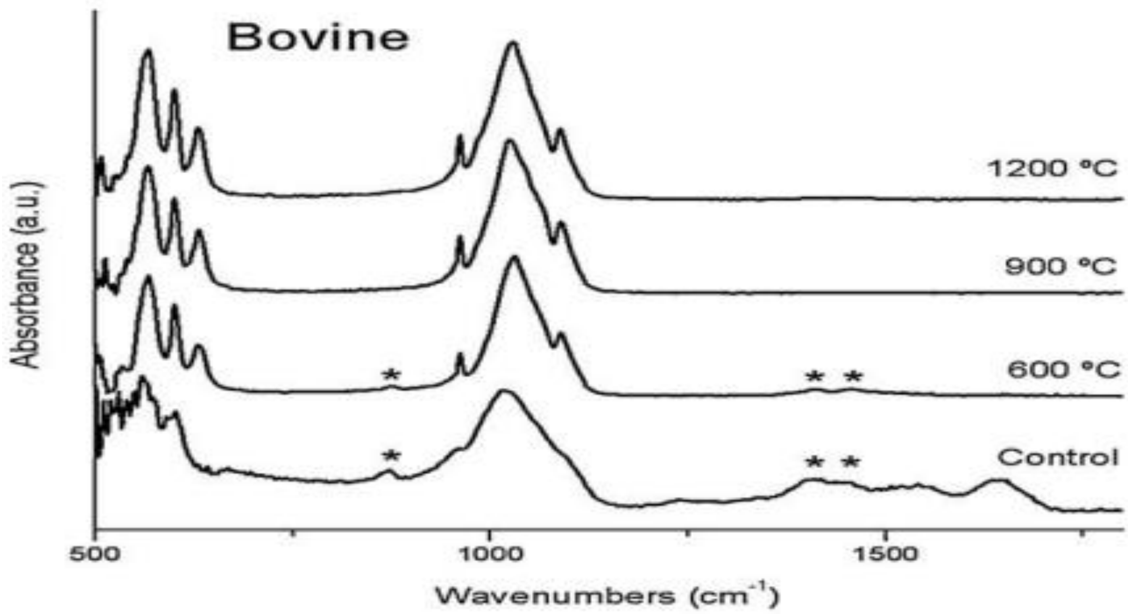

Figure 2-2: FTIR spectra of bovine(cow) bone samples before and after calcination at 600, 900 and 1200 ºC. *Bands attributed to lattice carbonate vibrations.

Note: adapted from "Effect of the calcination temperature on the composition and microstructure of hydroxyapatite derived from human and animal bone" by the (Figueiredo et al., 2010).

The fabrication of bone ash mineral is done through burning by high temperature in furnace and final powder is obtained by milling using milling disk. The high temperature phases of cow bones deduced (Lorprayoon, 1986).

$$Ca_{10}(PO_4)_6(OH)_2 \xrightarrow{900-1300°c} Ca_{10}(PO_4)_6(OH)_{2(1-x)}O_x + xH_2O \quad (x = 0 \text{ to } 1)$$ ….. Equation 7

Note: adapted from "Phases of cattle bones at elevated temperatures" by the Lorprayoon, page 9.

Bone ash produced by different temperature has been used for the production of hydroxyapatite. As the temperature increases the weight of bone decreases. The muffle furnace was near room temperature at the start of each run and ramped up to the set temperature from 400^0C to 1000^0C. Each sample was combusted for 3 hours at the designated temperature and then immediately removed to allow for quicker cooling as soon as the crucible was cool enough to handle, it was weighed again (to minimize absorbing ambient moisture) to determine post-combustion (ash) weight. Before re-use after a sample run, crucibles were cleaned by combustion of the residue in the muffle furnace, at 1000^0C. After a complete set of samples were burned, duplicates were run at each temperature (Richardson, 2017).

Calcium oxide (CaO) is the main ingredient for the process of cement production. It provides cement soundness and strength. Phosphate is usually considered as an excellent retarder in cement-based materials. It is often thought that the mechanism behind this excellent retarding effect is attributed to the precipitation of calcium-based phosphate or the formation of a complex on the surface of the cement particles. Thus, phosphates delay the hydration of the cement paste and increases the initial and final setting time of the cement paste (Tan et al., 2017).

2.8.2 Age Related Changes in Healthy Bone Composition

Bone is a dynamic as well as a heterogeneous tissue; therefore, it is not surprising to see changes in composition as a function of age. These are distinct from the changes that are associated with bone disease, fragility fractures or treatments to prevent such fractures. Important is the observation that some age-dependent changes in composition are due to alterations in cell activity and protein expression as well as changes in the concentration and post-translational modification of those non collagen proteins that regulate matrix composition and mineralization (Boskey, 2013). Detail the types of compositional changes of animal bone with age is shown in Table 2-6.

Table 2-6: The Types of Compositional Changes of Animal Bone with Age

Bone characteristics	**Age effect**
Bone Mineral Density and Tissue Mineral Density	Increase with Age
Mineral to Organic Matrix Ratio	Increase with Age
Calcium to phosphate ratio	Increase with Age
Carbonate to Phosphate Ratio	Increase with Age
Crystal Size and Perfection (Crystallinity)	Increase with Age
Acid Phosphate Substitution	Decrease with Age
Matrix Heterogeneity	Decrease with Age
Total Collagen Crosslinks (Collagen Maturity)	Increase with Age
Collagen Enzymatic Crosslinks	Increase with Age

Note: adapted from "Animal age, physiological maturity, and associated effects on beef tenderness" by the Tatum,2011.

2.8.3 Color Changes of Bone by Heating

Carbonization and calcination cause color changes in the residual bone. Bones go through a transition from the natural color of bone to black when carbonized and to white when completely calcined with several different shades between the stages (Shipman, Foster, & Schoeninger, 1984). Some studies have focused on determining the temperature of the fire from the color of the bones, but there is not an agreement (Shipman et al., 1984; Mays, 1988 and he found five stages of color change, using a muffle furnace to burn cleaned mandibles and vertebrae of goats and sheep. The muffle furnace was set at temperatures between 185^{0}C and 940^{0}C. They found the colors overlapped and were not sufficient to determine the temperature of the heating. (Mays, Lees, & Stevenson, 1998) heated animal bones in a muffle furnace to temperatures between 185^{0}C and 1200^{0}C, following the methods outlined in (Shipman et al., 1984). They found six stages of color change, including no further change after 645^{0}C. There were inconsistencies between his observations and the observations by (Shipman et al., 1984). This suggests that using color to infer temperature is subjective and not as accurate as investigators would require.

2.9 Chemical Composition of Bone Ash

Different researches show that bone ash has comparable calcium oxide content with cement. It has also high phosphate content. The chemical composition of bone ash is shown in Table 2-7.

Table 2-7: Chemical Composition of Cow Bone Ash and Portland cement

Chemical oxides	**Chemical composition by weight percentage**			
	Bone ash			**Portland cement**
	(Okeyinka et al., 2018)	**(J.O. Akinyele, 2016)**	**(Quezon et al., 2018)**	**ES 1176-2-2005 ("Methods of testing cement," 2005)**
Calcium Oxide (CaO)	63.86	76.31	48.40	61-69
Silica Oxide (SiO_2)	19.02	2.28	0.01	18-24
Aluminum Oxide (Al_2O_3)	13.21	2.97	0.01	2.6-8
Iron Oxide (Fe_2O_3)	0.025	0.43	0.01	1.5-7
Sodium Oxide (Na_2O)	0.86	0.37	0.60	0-5
Magnesium Oxide (MgO)	1.01	1.21	0.36	0.5-4
Potassium Oxide(K_2O)	0.05	0.24	0.01	0.2-1
Manganese Oxide (MnO)	0.015	0.086	-	-
Phosphate (P_2O_5)	-	5.57	33.85	-
Sulfur trioxide (SO_3)	-	-	-	0.2-4
Loss on Ignition (LOI)	0.90	0.37	5.89	-

Bogue's equations for the percentages chemical content in Bone powder ash. Bogue's equations for the percentages of the main compounds in binders are given below. The terms in brackets represent the percentage of the given oxide in the total mass of binder.

$$C_3S = 4.07(\mathrm{CaO}) - 7.60(\mathrm{SiO_2}) - 6.72(Al_2O_3) - 1.43(Fe_2O_3) - 2.85(SO_3) - 5.19(CO_2) \ldots\ldots\ldots \textit{Equation } 8$$

$$C_2S = 2.87(SiO_2) - 0.754\,(C_3S) \ldots\ldots\ldots \textit{Equation } 9$$

$$C_3A = 2.65(Al_2O_3) - 1.69(Fe_2O_3) \ldots\ldots\ldots \textit{Equation } 10$$

$$C_4AF = 3.04(Fe_2O_3) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Equation\ 11$$

Note: adapted from ("ASTM C150, Standard Specification for Portland Cement," 2011).

Using the above equations 8 to 11, on the components of the various binder materials as tabulated in elemental oxide Table 2-8, indicating the percentage components of the main compounds.

Table 2-8: Calculations of Cattle Bone Ash Powder Chemical Component

Elemental oxides	**100%C 0%BPA**	**95%C 5%BPA**	**90%C 10%BPA**	**85%C 15%BPA**	**80%C 20%BPA**	**75%C 25%BPA**
SiO_2	20.7	19.78	18.86	17.94	17.02	16.1
Al_2O_3	4.48	4.4	4.33	4.25	4.18	4.1
Fe_2O_3	2.5	2.2	2.29	2.19	2.09	1.98
CaO	64	64.62	65.23	65.85	66.46	67.08
SO_3	2.75	2.61	2.48	2.34	2.2	2.06
Compound composition						
C_3S	50.7	72.57	82.71	93.3	103.79	114.39
C_2S	22.5	2.05	-8.24	-18.86	-29.41	-40.04
C_3A	8.6	7.6	7.6	7.56	7.54	7.52
C_4AF	9.4	7.3	6.96	6.66	6.35	6.02

Note: adapted from" The Effect of Partial Replacement of Cement with Bone Ash and Wood Ash in Concrete" by the (J.O. Akinyele, etal.,2016).

The abbreviations of chemical compounds represent;

- ✓ C_3S – Tri-Calcium Silicate
- ✓ C_2S – Di-Calcium Silicate
- ✓ C_3A –Tri -Calcium Aluminate
- ✓ C_4AF – Calcium Ferro Aluminate

C_3S and C_2S are the most important components of a binder material because they are the strength indicator of the binder material in concrete and other allied cement products. Their hydration reaction gives the same products but only differ in the quantity produced. The approximate equations showing their reactions in water is as shown below.

$$2(3CaO.SiO_2) + 6H_2O \rightarrow 3\ CaO.2SiO_2.3H_2O + 3Ca\ (OH)_2 \ldots\ldots\ldots\ldots. Equation\ 12$$

$$2(2CaO.SiO_2) + 4H_2O \rightarrow 3CaO.2SiO_2.3H_2O + Ca\ (OH)_2 \ldots\ldots\ldots\ldots\ldots\ldots... Equation\ 13$$

It has been observed that C_3S produces a comparatively lesser quantity of calcium silicate hydrates and more of $Ca(OH)_2$ than that formed in the hydration of C_2S. $Ca(OH)_2$ is not a desirable product in the concrete mass because it is porous and gets leached out making the concrete porous. C_3S is responsible for the early strength of cement/binder paste.

The greatest 28 days compressive strength of 10% bone powder ash should owe its reason to the fact that it has a great amount of C_3S content which is responsible for the early strength of cement products (J.O. Akinyele, 2016).

2.10 Bone Ash Effect on Concrete Properties

2.10.1 Setting Time of cement paste

The objective of setting time is to determine the time that elapses from the moment water is added until the paste ceases to be fluid and plastic (initial set) the time required for the paste to acquire a certain degree of hardness (final set) (Steven H. Kosmatka, 2002).

The use of pulverized bone increased the setting times (initial and final) of cement paste as proportion of pulverized bone content increased up to 30% where the highest retardation of approximately 2 hours and 2.5 hours for initial and final setting times respectively occurred. Although the increase dropped beyond 30%, it can still be said to have a retarding influence up to 80% replacement when compared with the control. At 80% replacement, the paste did not set a requirement for strength development. The fact that pulverized bone sets only in the presence of cement, to release calcium hydroxide (CH) during hydrolysis, is an indication of its pozzolanic traits (Falade, 2012).

2.10.2 Slump (Consistency)

The slump test is a measure of the consistency of fresh concrete and a means of identifying discrepancies in the uniformity of concrete mixes fluidity. The slump test was thus carried out in accordance to determine the effect of cattle bone ash blended cement on the workability of the concrete mixes.

Animal bone powder requires more water than the cement in equal quantity. However, at varying dosage of replacement of cement, there is a strong indication that bone powder absorbed more water content which reduces the slump (Quezon et al., 2018).

The slump value of the concrete mixes increases with increasing cow bone ash content, the PCC mix which contained 0% cow bone ash content displayed 30mm slump value while the cow bone ash mixes containing 10%, 20% and 30% cow bone ash content displayed 33mm, 37mm and 40mm slump value respectively. The slump value of a freshly mixed concrete is an indication of its flow and overall workability. Thus, the increasing slump value with increasing cow bone ash content implies that the mixes became wetter and more workable as the cow bone ash content increases. This may be attributed to the higher fineness and low specific gravity of cow bone ash compared to the specific gravity of cement.

Workability of concrete was found to increase steadily with the incremental addition of cow bone ash. For all the mixes prepared in this study, the slump values range from 30mm to 40mm which can be classified as a slump (Okeyinka et al., 2018).

2.10.3 Compressive Strength

Compressive strength is the measured maximum resistance of a concrete specimen to axial loading. Studies show that the compressive strength of concrete decreases as the partial replacement of bone ash amount increases in concrete.

The strengths for 0%, 5%, 10%, 15%, and 20% cement replacement with pulverized bone developed lower strengths when compared with the control specimens at all the curing ages for both water and air cured specimens. It is noted that the strength reduction is insignificant up to 10% replacement of cement with pulverized bone. However, the strength development up to 20% pulverized bone content levels still qualified the foamed aerated concrete used for this investigation to be classified as structural lightweight concrete (Falade, 2012).

According to (J.O. Akinyele, 2016), the compressive strength of concrete cubes determined after 7, 14, 21 and 28 days of normal curing the strength of control cubes mixes is generally higher than Partial replacement of bone ash, but the compressive strength of 10% partial replacement using cattle bone powder ash is higher than that of the control for all the test days, the reason for these properties can be linked to the percentage proportion of the oxides of carbon, aluminum, magnesium and silicon present in each sample. Calcium is the main constituents of bones hence its abundance in the bone ash, and this gave it the required advantage as a pozzolana. The gradual reduction in strength after the 10% replacement can be attributed to the excessive presence of the oxide of calcium in the mixture, while other constituent elements of pozzolanas was reducing as more replacement was carried out.

A similar study done by (Okeyinka et al., 2018), the compressive strength increases as the cow bone ash content increases from 0% to 10% and thereafter the strength reduced gradually until the cow bone ash content reaches 30%. In all the mixes produced, 10% cow bone ash replacement level appears to be the optimum replacement level of cow bone ash in concrete, as 10% mix displayed 5%, 17% and 21% higher average compressive strength compared to the 0%, 20% and 30% cow bone mixes respectively.

2.10.4 Density

Conventional concrete, normally used in pavements, buildings, and other structures, has a density (unit weight) in the range of 2200 kg/m^3 to 2400 kg/m^3. The density of concrete varies depending on the amount and density of the aggregate, the amount of air that is entrapped or purposely entrained and the water and cement contents, which in turn are influenced by the maximum size of the aggregate.

Density of concrete decreases with increasing content of pulverized bone. In relation to the control specimens, the decreased in wet density are 2.5%, 4.0%, 4.8%, and 6.3% respectively for 5%, 10%, 15%, and 20% cement replacement with pulverized bone. This trend can be attributed to the fact that the specific gravity of cement is 2.92 and that of pulverized bone is 2.22. Specific gravity of bone ash is lower than the cement (Falade, 2012).

2.10.5 Flexural Strength

In this test, the plain (unreinforced) concrete beam is subjected to flexure strength test using two-point loading test. As the percentage of partial replacement of bone powder increases the flexural strength of concrete declines (Quezon et al., 2018).

2.10.6 Split Tensile Strength

According to (Falade, 2012) study, the split tensile strengths with animal bone powder varying percent dosage showed a decline from the strength of the control specimen.

2.10.7 Cow Bone Ash Effect on Durability of Concrete

Cow bone ash blended cement containing 10% replacement of CBA content has the optimum potential for application in an aggressive environment and especially in hydrochloric acid prone environment (Okeyinka et al., 2018).

2.11 Environmental Impact of Animal Bone Waste

Solid waste management is the most important issue to create clean and comfortable cities to inhabitants. Improper solid waste disposal is a major public health and environmental concern in the urban areas of many developing countries like Ethiopia.

The cattle meat processing in slaughterhouses passes through several stages to get edible portions from the meat processing cycle for human consumption. But, significant quantities of secondary waste materials including organic and inorganic solids not suitable for further consumption are generated. However, these wastes are removed by informal slaughters to the environment unsafely. Animal bone waste is one of the solid wastes that aggravates global warming due to the coverage of natural green area and waste removing activities, waste burning and transportation to the waste disposing site. Landfill affects the sustainability of the environment towards living things and increases high land demand of towns.

Bone waste causes bad odor, chronic health problems in people living around waste disposing site. This waste also causes the pollution of rivers and lakes and consequently it is the cause of transmitted diseases for downstream people and animals.

2.12 Availability of Cattle Bone

Overall world meat production increased by 1.25% to 323 Mt in 2017, with moderate increases in the production of bovine and poultry meats and more modest gains in pig and sheep meat. Much of the world meat production expansion originated in the United States but other main contributors were Argentina, India, Mexico, the Russian Federation and Turkey (FAO report, 2018). In Ethiopia Over the next 15 years, the consumption of red meat (beef, sheep, goat and camel meat) is projected to grow by about 276% from 775,000 tons in 2013 to 2.9 million tons in 2028 (Shapiro et al., 2017). The high consumption of cattle meat causes the corresponding increase of the animal bone waste that endanger the natural environment.

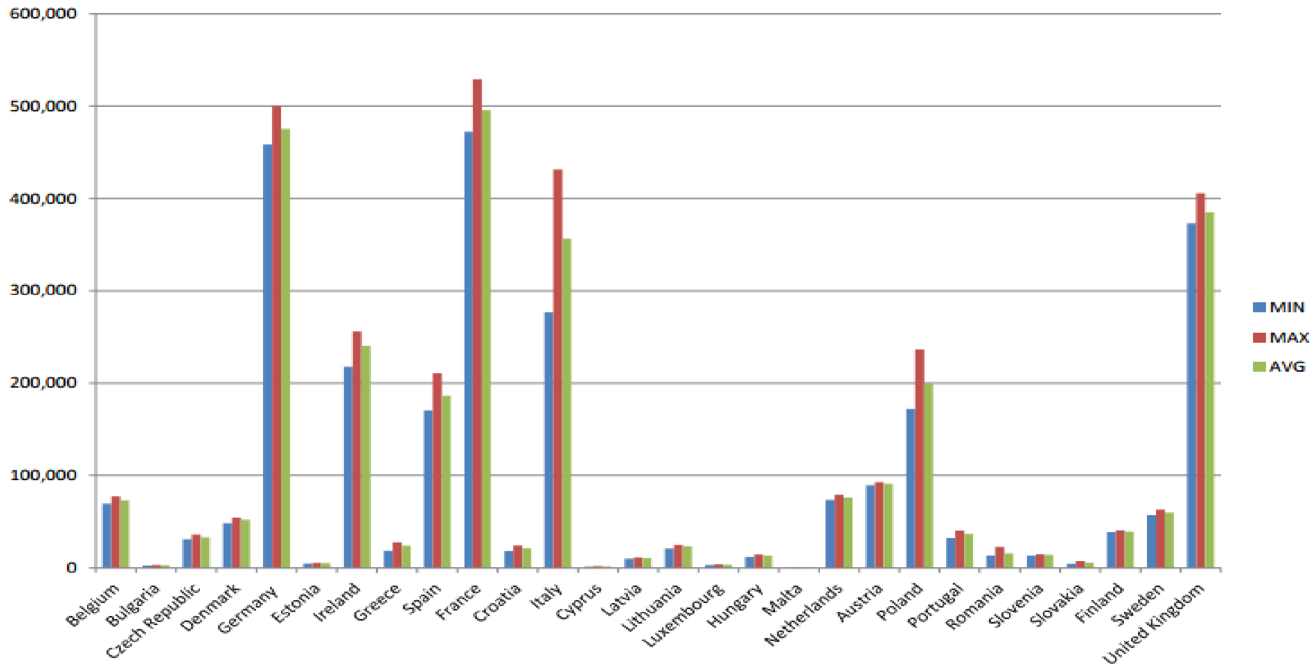

Figure 2-3: Cattle Bone Waste in European Countries (Tons)

Note: adapted from "Database/Inventory of the ANIMALS AWCB value chain-Agro Cycle Deliverable D. 1.1" by the (Ćosić, 2016).

From Figure 2-3; France, Germany, Italy and the United Kingdom are the top European countries who produced more than 400,000-ton cattle bone waste from the year 2010 to 2015 G.C. This data shows that each country had produced average of approximately 100,000-ton cattle bone waste per year.

2.13 Gap Identification

Different researches have been conducted to analyze the effect of bone ash in concrete property, but its effect on the soundness of cement paste has not been studied. The effect of bone ash in longtime (56th day curing) concrete compressive strength has not been done in previous researches. In previous researches, the color change and loss in weight during burning process at different temperature and burning condition has not been considered as part of their study. The energy saving and economic benefits of using CBA in concrete production has not been studied quantitatively. The stated gaps ignited the initiation of this research.

3. MATERIALS AND METHODS

3.1 Introduction

The study investigates the effect of partial replacement of cement with cattle bone ash in concrete property. This chapter briefly describes the methods(procedures), materials used, material properties, design standards, equipment used for tests and mix proportions of the specimen. Two sacks of cattle bones that were collected from Bahir Dar Institute of Technology waste disposal site were used for the study after selecting dry samples containing less flesh tissues and muscles. It was crushed with a maximum size of 25 mm and dried in the sun. The maximum size is selected to make suitable for inserting in to furnace and for milling purposes. Cortical and vertebral bone parts are selected for the test, since it has low organic compounds and muscle tissues. The prepared bone sample was burned in muffle furnace at different temperatures and milled using a disk mill machine. Chemical analysis of CBA was done in the Ethiopian Geological Survey Laboratory.

Locally available aggregates were selected and collected based on the quality requirement confirmation as in standards (ASTM and ACI). Coarse and fine aggregates are collected and stockpiled in proper place with enough ventilation. Aggregates were washed until organic and other deleterious materials are detached from the aggregate surface. The prepared aggregates were kept in prepared open surface to keep it in its' saturated surface dry condition (SSD). The gradation, density, moisture content, absorption and specific gravity are main physical tests were conducted to verify the quality of aggregates. Normal consistency, setting time and soundness tests are conducted to examine the physical property of Cement and to investigate the effect of partial replacement of cement with varied CBA proportion (0% to 20%) in cement paste. The mix design was done based on the physical test results of aggregates as in the ACI 211.1 mix design procedure for normal concrete.

Slump and compressive strength tests were taken from fresh and hardened concrete properties respectively. Compressive strength test was done by taking standard casted in concrete molds of 15cmx15cmx15cm cube moist cured for 3,7, 28 and 56 days. All Standard Practices for Making and Curing Concrete Test Specimens tests were followed according to ASTM C192 for the Laboratory procedures. But the 56th day compressive strength test was taken to verify the effect of CBA replaced hardened concrete and to examine its pozzolanic effect (later strength gain) compared to control (100%OPC and 100%PPC) mixes.

3.2 Research Procedures

To achieve the objective of the study the following experimental sequence is used as shown in the below diagram.

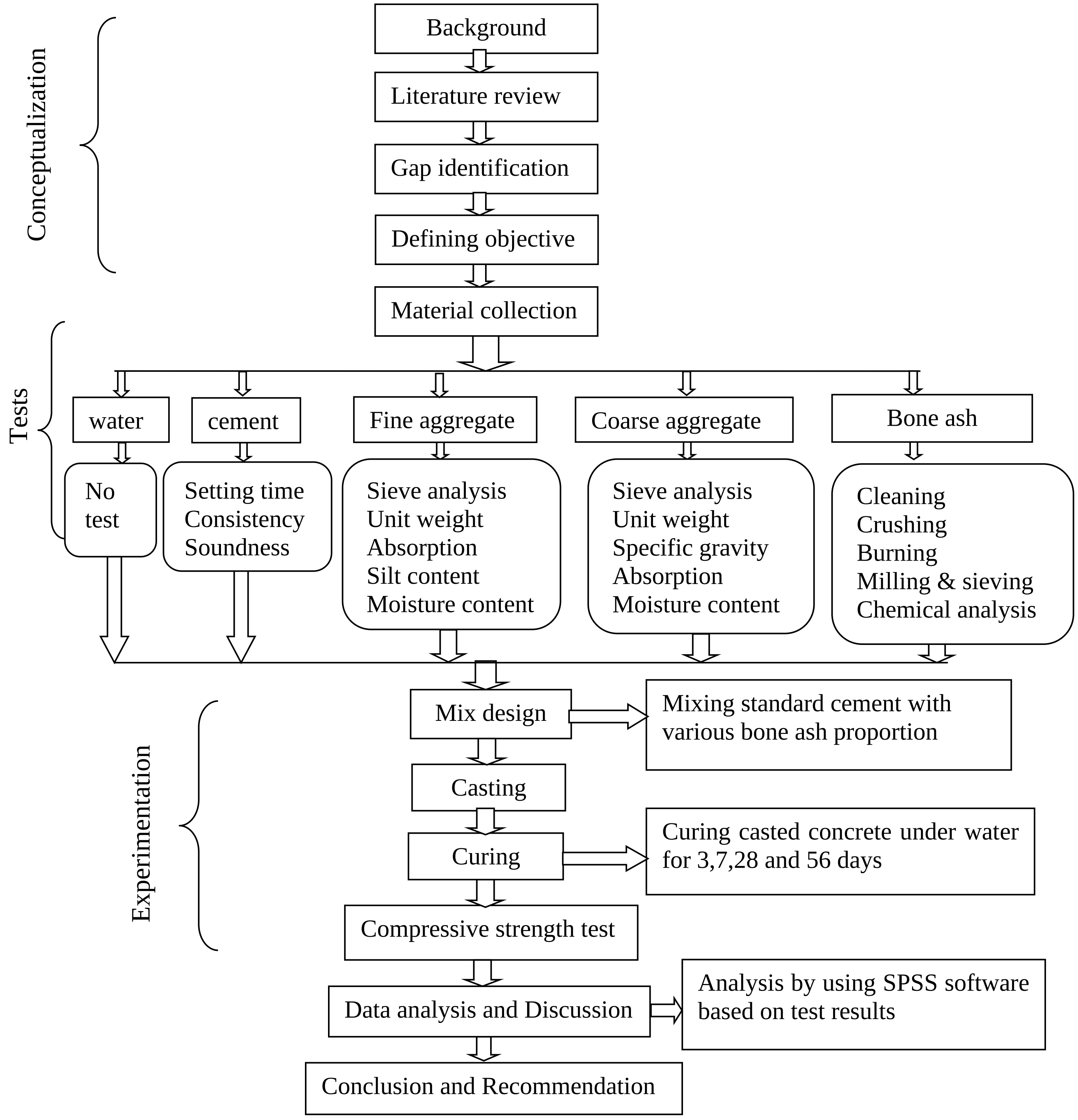

Figure 3-1: Research Methodology Flow Chart

3.3 Materials Required

1.Water: Tap water, free from suspended solids and organic compounds.

2. Coarse aggregate: Well graded crushed, angular basaltic stone washed before use and free from deleterious materials collected from Meshanti quarry site which was located around the Bahir Dar area was used. The coarse aggregate is sieved as per ASTM C33 and the maximum nominal size of selected coarse aggregate is 25mm.

3. Fine aggregate: Lalibela sand that meets ASTM C33 used for this research study. It is natural(river) sand, which has low silt content and black color within good quality used for the investigation and sieved with 7 standard ASTM sieves ranging from 9.5mm to 150µm for all tests.

4. Bone ash: After burning cleaned and size reduced cattle bone, it was pulverized to less than(pass) 75 µm size by disk mill, collected from Bahir Dar Institute of Technology student's cafeteria waste disposal site was used for the experiment.

5. Cement: OPC 42.5 R Dangote cement was used for all mixes except PPC 32.5 R cement mix.

3.4 Design Standards

In this study, ASTM and ACI standards were used for testing the physical properties of aggregates and concrete mix design; respectively.

Table 3-1: Design Standards for Material Tests

No.	**Material type**	**Types of tests**	**Standards used**
1	Fine aggregate	Absorption	ASTM C128
		Free Moisture content	ASTM C566
		Gradation	ASTM C33
		Silt content	ASTM C117
		Organic content	ASTM C40
		Unit weight	ASTM C29
2	Coarse aggregate	Gradation	ASTM C33
		Unit weight	ASTM C29
		Free moisture content	ASTM C566
3	Cement	Setting time	ASTM C191

		Consistency	ASTM C187
		Soundness	IS 4031
4	Concrete	Density	ASTM C138
		Compressive strength	IS, 2006
5	Bone ash	Complete silicate analysis and sulfur trioxide	Geological Survey of Ethiopia test manual

3.5 Required Laboratory Appurtenances

Construction materials testing devices that are available in Bahir Dar Institute of Technology construction materials and operational unit laboratory were used for all physical and chemical testing of materials except mineralogical analysis of bone ash done in geological survey of Ethiopia (geochemical laboratory), which found in Addis Ababa. The most important apparatuses for material testing are stipulated in Table 3-2.

Table 3-2: Apparatuses Used for Material Test

Material tests	**Apparatus**	**Use**
For both fine and coarse Aggr0egates	Digital laboratory Oven (10-D1398), 780liter volume	To dry natural aggregate
	Sieve (different sizes)	for particle size distribution analysis
	Sieve shaker (SW-1115-2 model)	Electro-magnetic sieving device used to create motion of the sieves to cause the aggregate particles to bounce, tumble.
	Balance	To measure the weight of aggregate
	Sample container(pan)	To take and insert aggregate to oven
	Sample splitter	To prepare sample
	Metal tray	To take aggregate samples
	Tamping rod	To compact aggregate (density test)
	Cylindrical metal Container (different volume)	To test the bulk density of aggregate
	Scoop (shovel)	To take aggregate samples

For only fine aggregate	Pycnometer	To test specific gravity of fine aggregate
	Graduated Glass jar	To measure silt, organic compounds of sand and measure volume of water
For coarse aggregate only	Water tanker (metal) and its wire basket container	To soak aggregate sample (absorption &specific gravity test)
Bone ash	Muffle Furnace (10-D1418/A)	To burn bone (ash formation)
	Disk mill (D-55743 Idar-Oberstein model)	To pulverize(mill) crushed and burned bone
	Manual Hammer	To size reduction of bone
Cement paste	Vicat apparatus (STWKY2)	Device used to test normal consistency and setting time of cement paste
	Mortar Mixer HOBART(A200)	To mix cement and water (mortar)
	Trowel	To trim off excess cement paste from mold
	Programmable accelerated Concrete curing tank (55-C0194D)	To boil water at 90°c to 100°c
Concrete	Slump cone with its accessories	To measure slump of fresh concrete
	Metal mold (15cmx15cmx15cm)	To cast fresh mixed concrete
	Concrete mixer	To mix water, cement, aggregate and bone ash
	Table vibrator (55-C0159/11)	To vibrate (compact) fresh concrete
	Automatic Compression testing machine (C23C02)	To test the compressive strength of concrete
	Curing Tank	To soak and cure concrete samples

3.6 Mix Proportions and Data Analysis Methods

The proportion is determined based on Quezon etal.(2018) and Falade etal.(2013) study, they stated that pulverized bone ash can replace cement up to 25 %, but compressive, flexural and split tensile strength of concrete fails highly above 20%

Table 3-3: Mix Methods

No.	Cement	Bone ash (CBA)	Mix designation
1	100%PPC	0	100%PPC
2	100%OPC	0	100%OPC
3	95%OPC	5%	5CBA
4	90%OPC	10%	10CBA
5	85%OPC	15%	15CBA
6	80%OPC	20%	20CBA

Compressive strength test result analysis was done by using IBM SPSS Statistics version 21 software. The compressive strength relationship of Standard concrete within varied CBA percentage was analyzed and interpreted by using the IBM SPSS Statistics version 21 software. Validity of the compressive strength test results was examined according to (IS, 2006) to assure whether experimental measure is valid or not compared to the variable (compressive strength) score intended to achieve.

The descriptive data of the compressive strength were analyzed and interpreted based on the one-way ANOVA tool. The effect of partial replacement of cement with CBA was analyzed using t-test based on the p-value. The Post hoc analysis was also done to analyze the differences exist among the means, post hoc range tests and pairwise multiple comparisons. The correlation and regression analysis are conducted to analyze the strength of association and relationship between the compressive strength and density of concrete.

The environmental and economic advantages of utilizing bone waste as cementitious materials are analyzed by considering the energy saving and material reduction required to produce cement.

4. EXPERIMENTAL WORK

4.1 Introduction

This chapter deals with the tests conducted for the achievement of the specific objectives. After testing cement, fine aggregate and coarse aggregate physical properties, chemical analysis of CBA, concrete mix design was conducted based on the test results of all ingredients. The experiment was done using two sets of control mixes made with OPC 42.5R and PPC 32.5R and four other mixes made with different CBA percentages. The main reason for using PPC as a control mix is that supplementary cementitious materials react slowly after the release of $Ca(OH)_2$ in cement hydration. Consequently, the later strength development of concrete made with CBA can be assessed well through comparison with concrete made from PPC since it has cementitious properties. The following sections describe all the properties of materials and specifications used for this study.

4.2 Material Tests

4.2.1 Cement Tests

A. Standard Consistency Test

This test method is used to determine the amount of water required to prepare hydraulic cement pastes with normal consistency, as required for certain standard tests (ASTM C187). To determine the amount of water required to form cement paste, different trials were taken by varying amount of water starting from a minimum percentage of water (26%) required to produce standard consistency. The paste shall be of normal consistency when the rod settles to a point 9mm to 11mm below the original surface in 30 seconds after being released. For the control mix(100%OPC) test 26% of water is used, because by trial and error test it provides 11 mm plunger penetration. The replacement of cement with 5% to 20% CBA also provides the normal consistency with 27% to 30.5% of water. For all other (different percentage of CBA) mixes, the water content required to get normal consistency (9 to 11 mm penetration) increases. Detail test procedure is shown in Appendix B.

Table 4-1: Standard Consistency Test Results

Mix	100%OPC	5%CBA	10%CBA	15%CBA	20%CBA
Consistency (%)	26	27	27.5	28	30.5

B. Setting Time Test

Initial and final setting time tests were taken as the cement physical tests as per ASTM C191 that meets consistency test conforming to ASTM C187. The initial and final setting time increases as the replacement of cement with Bone ash increases as shown in Appendix B.

C. Soundness Test

Cement soundness is the ability of the cement paste to withstand or retain any change in volume after setting and hardening. Lack of soundness or delayed destructive expansion can be caused by excessive amounts of hard burned free lime or magnesia. Expansion or (L_2- L_1) must not exceed 10 mm for ordinary Portland cement. The 100OPC mix test result (L_2- L_1) is 2.5mm, which is less than 10mm and it conforms IS 4031 in all other mixes, as shown in Appendix B.

4.2.2 Bone Ash Preparation

After collecting two sacks of cattle bone from Bahir Dar Institute of Technology waste disposal site, it was sundried by removing tissues and other detached wastes. But the selected bone sample weight is only 15kg, because the selected specimens are mostly dry cortical(leg) bones due to their low organic content. Bone residue was cleaned, crushed by hand hammering to the maximum size of 25mm that is suitable for disk milling.

To examine the effect of burning temperature on physical property of bone different trials were made based on literature sources. The prepared sample was burned by using controlled electric furnace in open and closed condition of crucible at 600˚C and 900˚C for 3hours at heating rate 10°C/min and afterward it was cooled slowly to room temperature. For this study, burning bone at 900˚C for 3 hours is taken as optimum temperature based on literatures for bone ash formation. Bone ash was burned by using ceramic crucible container in furnace and tested at different temperatures to identify change in calcination, color and mass loss. When bone is burned at 600˚C temperature by furnace, it losses its' carbon, organic compounds (collagen fibers and organic matter). When bone is burned at 900 ˚C temperature the ash completely losses its carbon and exhibits calcined property.

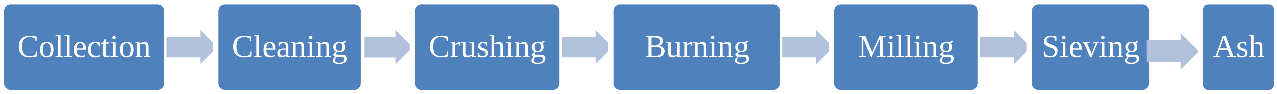

Figure 4-1: Bone Ash Preparation Procedures

A. Crushing bone *B. Crushed bone before burning*

Figure 4-2: Cattle Bone Size Reduction

A. Bone burning inside furnace *B. Muffle furnace used to form bone ash*

Figure 4-3: Burning of Bone

A. Bone burned at 600˚C (partially calcined) *B. Bone burned at 900˚C (calcined)*

C. Bone burned at 600˚C (carbonized) *D. Bone burned at 900˚C (carbonized)*

Figure 4-4: Bone Ash Formation by Different Furnace Temperature

Figure 4-5: Bone Ash Milling by Disk Mill

A. Carbonized ash *B. Calcined ash*

Figure 4-6: Bone Ash Burned at 900˚C and Passing 75µm

Calcination is a process of heating materials at higher temperatures in air or oxygen, mostly takes place in furnaces. For cement production, it includes the decomposition of limestone to drive off carbon dioxide. Carbonization is the term for the conversion of an organic substance into carbon or a carbon containing residue through pyrolysis (decomposition brought about high temperatures) (Mohammed, Aboje, Auta, & Jibril, 2012).

Carbonization/calcination causes color(physical) changes of the residual bone. Bones go through a transition from the natural color of bone to black when carbonized and to white-gray when completely calcined with optimum burning temperature (900 ºC).

The crucible is a cylindrical container used to insert and burn material in the furnace. The test(burning) is done in both open and closed conditions of crucible to get the desired physical property of ash. In closed condition burning (carbonization), the top part of the crucible is firmly closed after packing the crushed bone. Whereas, in the open burning condition(calcination), furnace is closed and crucible containing crushed bone remains open. The main difference between open and closed burning condition is, in closed condition bone ash becomes highly black due to suffocation (blockage to release) of carbon dioxide from the bone. In closed burning condition, it becomes black (it doesn't loss carbon and organic compounds). But in the open condition, almost all carbon is evaporated from the furnace and ash becomes white-gray as shown in Figure 4-4, B. But in both conditions the furnace is still closed; the only difference is whether crucible is closed or not inside the furnace.

The 600 ºC burning temperature was selected, because bone losses its organic component and a carbonate apatite was obtained. At 900 ºC, carbonate was no longer detected in open burning condition. Crystallinity degree and crystallite size progressively increased with the calcination temperature, contrary to porosity that strongly decreased at elevated temperatures due to loss of void spaces due to higher temperature related to loss in weight.

For this study, open burning at 900˚C condition was used because carbon was removed from bone ash and it satisfies the color requirement as per (ES-1176), white-gray when pulverized by disk mill. During the burning process, the bone ash loss weight is calculated as follows, by taking a one-kilogram sample test.

Loss in weight in percent $= \frac{loss\ in\ weight(g)}{inital\ weight(g)}$x100%.............................. Equation 14

$$= \left(\frac{A-B}{A}\right) x100\%$$

Where, A = Initial weight of bone before burning

B = Final weight of bone after burning

i. Loss in weight in 900˚C for 3hours, A=1000 gram and B=963 gram

$$= \frac{loss\ in\ weight(g)}{inital\ weight(g)}\text{x}100\%$$

$$=(\frac{A-B}{A})\text{x}100\%$$

$$=(\frac{1000gram-963gram}{1000gram})\text{x}100\%$$

$$=3.7\%$$

ii. Loss in weight in 600˚C for 3hours, A=1000 gram and B=976.6 gram

$$= \frac{loss\ in\ weight(g)}{inital\ weight(g)}\text{x}100\%$$

$$=(\frac{A-B}{A})\text{x}100\%$$

$$=(\frac{1000gram-976.6gram}{1000\ gram})\text{x}100\%$$

$$=2.34\%$$

From the above calculation results, as the burning temperature of bone increases, the loss in weight increases. Finally, the burned bone is milled by using a disk milling machine to get 75 micrometer and the remaining sample which doesn't pass is pulverized further by using hand mortar (pounding equipment) to get finer powder (passing through 75 micrometer sieve).

4.2.3 Energy Consumption of Devices for Bone Ash Production

For bone ash production, disk mill is used for size reduction process and furnace is used to burn the bone required for ash production. In both cases, electric energy is used. Electric furnace is designed to burn materials up to 1200˚C temperature and it has a capacity to burn 4.5 kg of bone sample at once (cycle). For this study, a maximum of 900 ˚C temperature was used.

Total energy consumption is determined based on the power requirement written(specification) on the machines and multiplying it by total hours used for burning and milling. Optimum power is used for the calculation of energy. Totally, 9 kg of bone ash was prepared by using furnace and milling machine in two cycles(rounds).

$$Disk\ mill\ machine\ power\ required = 2050watt$$

$$Electric\ furnace\ power\ required = 2200watt$$

$$Time\ for\ milling\ = 1\ hour$$

$$Time\ for\ burning\ = 3\ hours$$

$Cost\ of\ energy = 0.237 ETB/kwh$ (Source, Ethiopian Electric Power Corporation)

Power factor is considered to account for the optimum energy used in both devices (the maximum burning capacity of furnace is 1200 ˚C, but for this experiment work the optimum temperature used is 900 ˚C), $Taking\ assumption\ for\ power\ factor\ =\ 0.7$

$$Energy\ required$$
$$= machine\ power\ x\ time\ required\ for\ ash\ production\ x\ power\ factor\ ...Equation\ 15$$

$$Disk\ mill\ energy\ consumption\ = 2050 watt * 1 hour = 2.05 kw * 1 hour$$
$$= 2.05 kwh$$

$$Electric\ furnace\ energy\ consumption = 2200 watt * 3 hours$$
$$= 2.2\ kw * 3 hours = 6.6 kwh$$

$$Total\ energy\ =\ (Disk\ mill\ energy\ +\ electric\ furnace\ energy)\ x\ power\ factor$$

$$=\ (2.05 kwh + 6.6 kwh)\ x\ 0.7$$

$$=\ 6.05 kwh$$

$$=\ 6.05 kwhx 3600 sec/h$$

$$=\ 21{,}780\ kilojoules$$

$$= 21.78\ Megajoule\ for\ 4.5 kg\ OBA\ production$$

$$Energy\ required\ to\ produce\ 1 kg\ of\ OBA = 21.78 Mega\ joule\ (MJ)/4.5 kg$$
$$= 4.9 MJ/kg$$

$$Energy\ cost\ =\ Total\ energy\ required\ for\ 4.5\ kg\ ash/\ cycle\ x\ energy\ cost\ x\ 2\ cycle$$

$$Energy\ cost\ =\ 6.05 kwh\ x\ 0.237 ETB/kwhx 2 = 2.87 ETB$$

4.2.4 Chemical Composition of Cattle Bone Ash

Chemical composition of materials is considered as the most important property to be used as cement additive materials in concrete. As (Quezon et al., 2018) and (J.O Akinyele etal.,2016), the major compounds found in bone ash are calcium oxide (CaO) and phosphorus pentaoxide (P_2O_5). Calcium oxide is the most important chemical found in Portland cement. From the mineralogical test done in the Ethiopian Geological Survey, calcium oxide and phosphorus pentaoxide (P_2O_5) are major compounds comprised in the bone ash. This implies bone ash can be used as a cement additive material for normal concrete. The Loss on Ignition (LOI) content of 2.36% also complies with ASTM C 618, in which the maximum value is set to be 10%. Loss on Ignition shows the amount of carbon content in the bone ash and the test value reveals that the bone ash is completely burnt in the furnace and approximately equals the loss in weight (3.7%) by furnace burning test in open crucible condition at 900˚C.

Table 4-2: Cattle Bone Ash Chemical Composition (Silicate Analysis) Test Result

No.	Compound	Percentage by weight (%)
1	Calcium Oxide (CaO)	43.26
2	Silica Oxide (SiO_2)	<0.01
3	Aluminum Oxide (Al_2O_3)	<0.01
4	Iron Oxide (Fe_2O_3)	<0.01
5	Sodium Oxide (Na_2O)	<0.01
6	Magnesium Oxide (MgO)	0.54
7	Potassium Oxide(K_2O)	<0.01
8	Manganese Oxide (MnO)	<0.01
9	Phosphate (P_2O_5)	44.67
10	Sulfur trioxide (SO_3)	0.08
11	Loss on Ignition (LOI)	2.36
12	Titanium oxide (TiO_2)	<0.01

The calcium oxide and phosphate content test result in this study is approximately similar with Quezon etal,2018 study done shown in Table 2-7, page 18.

4.2.5 Fine Aggregate Tests

As ASTM C33, fine aggregate is an aggregate, in which its' nominal maximum size is 4.75mm and minimum percent is passing through 0.15mm sieve. Washed fine aggregate free of injurious amounts of organic impurities and clay was used for the test. For this study, selected Lalibela natural sand was used that meets ASTM C33 standard. Detail test procedures are shown in Appendix A.

Table 4-3: Physical Properties of Fine Aggregate

Physical properties	**Test method**	**Test result**	**Specification**	**Remark**
Bulk density	ASTM C29	1726 kg/m³	(1200 to 1750) kg/m³ Steven H. kosmatka etal., 2002.	Ok
Moisture content	ASTM C566	1.01 %	Maximum of 3% to 8%, Steven H. kosmatka etal., 2002.	Ok
Specific gravity	ASTM C128	2.73	2.4 to 2.9, Steven H. Kosmatka etal., 2002	Ok
Fineness modulus	ASTM C33	2.84	2.3 to 3.1, ASTM C33	Ok
Absorption capacity	ASTM C128	1.45%	0.2% to 2%, Steven H. Kosmatka etal., 2002.	Ok
Organic content	ASTM C40	Colorless	Colorless, ASTM C40	Ok
Silt content	ASTM C117	1.0%	1% to 6%, Ethiopian standard	Ok

As shown in Figure 4-7, the fine aggregate gradation achieves ASTM C33 maximum and minimum percent passing limits for each sieve size. ASTM C33 recommends that fineness modulus of sand should not be less than 2.3 and nor more than 3.1. The fine aggregate shall have not more than 45% passing any sieve and retained on the next consecutive. Since the fineness modulus of sand sample (2.84) is between 2.3 and 3.1, it complies with the ASTM C 33 standard and can be used for mix design.

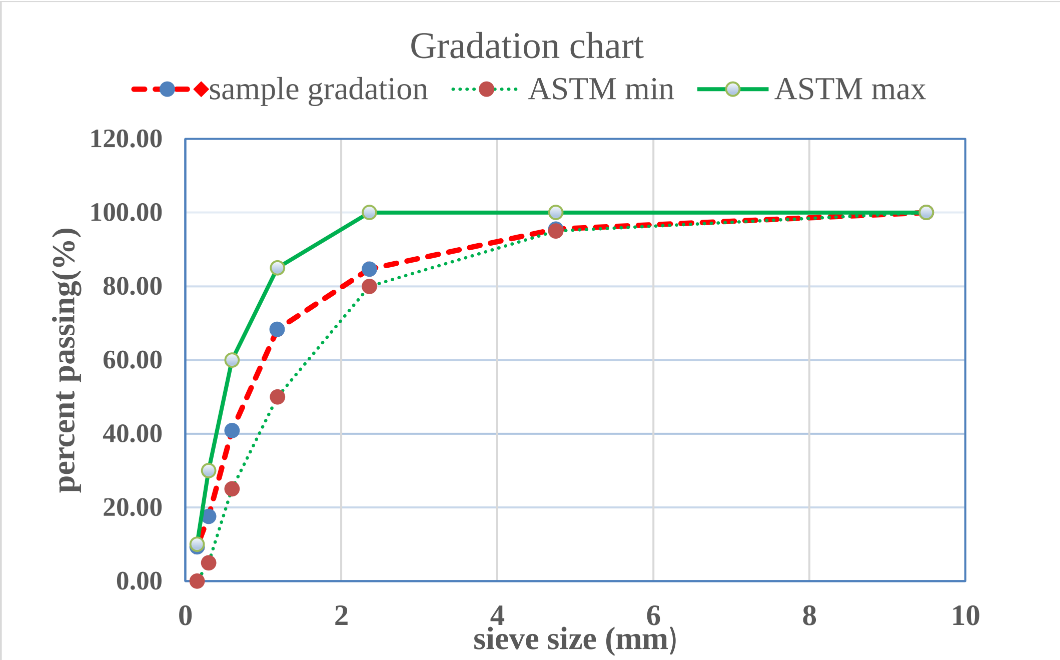

Figure 4-7: Fine Aggregate Gradation

4.2.6 Coarse Aggregate Tests

Coarse aggregate tests are done based on ASTM standard. Aggregate test was conducted after it was washed and stockpiled properly to prevent deleterious materials. To meet ASTM standard requirements, different aggregate sizes were blended. Detail test are shown in Appendix A.

Table 4-4: Physical Properties of Coarse Aggregate

Physical properties	**Test method**	**Test result**	**Specification**	**Remark**
Moisture content	ASTM C566	1.83%	1% to 6 %, Steven H. kosmatka etal., 2002.	Ok
Bulk density	ASTM C29	1602 kg/m³	1200 to 1750 kg/m³, Steven H. kosmatka etal., 2002.	Ok
Specific gravity	ASTM C128	2.76	2.4 to 2.9, Steven H. Kosmatka etal., 2002	Ok
Fineness modulus	ASTM C33	3.0	2.3 to 3.1, ASTM C33	Ok
Absorption capacity	ASTM C128	0.9%	0.2 % to 4%, Steven H. kosmatka etal., 2002.	Ok

As shown in Figure 4-8, coarse aggregate gradation achieve ASTM C33 maximum and minimum limits for the maximum nominal size of aggregate is 25 mm and minimum size of 4.75mm. Since it conforms to ASTM C33 limits, it was used for concrete mix design.

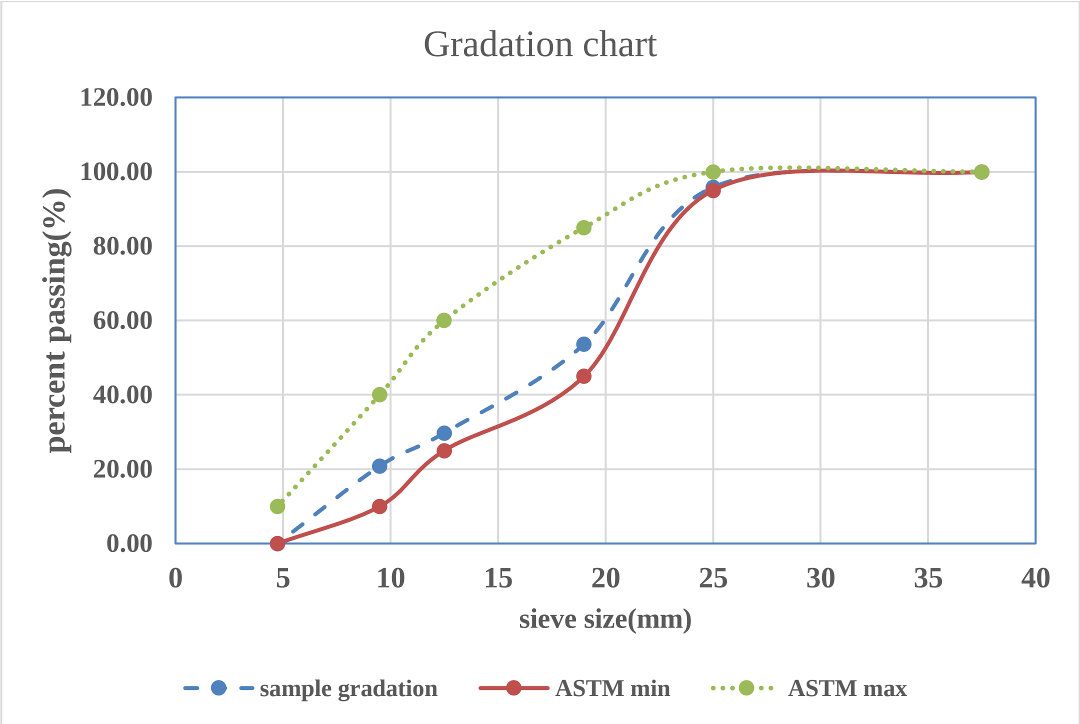

Figure 4-8: Coarse Aggregate Gradation

4.3 Mix Design and Casting

Mix proportion was done per ACI 211.1 mix design procedure. All of the concrete mixes were designed to achieve C-25 grade concrete with a target mean strength of 33.5MPa. A cement content of 365 kg/m^3, a water-cement ratio of 0.49 and a slump of 25 to 50mm was used to achieve the specified target mean strength. Detail mix proportioning calculations are included in Appendix D through E. Table 4-5 summarizes the mix proportions for the control mixes and the various CBA replaced concrete mixes.

Table 4-5: Mix Design Material Proportioning

Mix Type	Cement (kg/m³)	CBA (kg/m³)	Water (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Concrete density (kg/m³)	W/C
PPC (100%)	365.00	0.00	185.30	836.70	1086.53	2473.53	0.49
OPC (100%)	365.00	0.00	185.30	836.70	1086.53	2473.53	0.49
95%OPC+5%CBA	346.75	18.25	185.20	814.26	1086.53	2450.99	0.49
90%OPC+10%CBA	328.50	36.50	185.30	791.53	1086.53	2428.36	0.49
85%OPC+15%CBA	310.25	54.75	185.39	768.90	1086.53	2405.82	0.49
80%OPC+20%CBA	292.00	73.00	185.49	746.06	1086.53	2383.08	0.49

4.4 Density of Concrete

The density of concrete is the ratio of mass of concrete to its occupied volume. Perhaps the easiest and most accurate way to calculate the concrete density is to measure some into a container of known volume and weighing it. The density of concrete is a measure of its unit weight. A normal weight concrete weighs 2400 kg per cubic meter. The unit weight of concrete (density) varies depending on the amount and density of the aggregate, the amount of entrained air (and entrapped air), and the water and cement content (ASTM C138).

Fresh concrete density (unit weight) is calculated by dividing mass(kg) of freshly casted concrete by the volume of concrete mold(m^3). Hardened concrete density was calculated by using concrete cured in curing tanker for 56 days. Conventional concrete, normally used in pavements, buildings, and other structures, has a density (unit weight) in the range of 2200 to 2400 kg/m^3 (Steven H. Kosmatka and Michelle L. Wilson, 2011).

$$\text{Density}(\text{kg/m}^3) = \frac{mass\ of\ concrete\ (kg)}{volume\ of\ mold\ (\text{m}^3)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots Equation\ 16$$

4.5 Curing

Curing plays an important role on strength development and durability of concrete. Curing took place immediately after the concrete was cast and expected to maintain desired moisture and temperature conditions, both at depth and near the surface, for an extended time. Concrete curing facilitates the continuation and extent of cement hydration. In this case, all of the concrete cubes were moist (water) cured in a laboratory curing tank until compressive strength testing.

4.6 Compressive Strength Test

The compressive strength of concrete conditioned in a curing tank for 3, 7, 28 and 56 days was tested after it was dried in free air to remove moisture. Three specimens for different batches were made for testing at each selected age and the average of the three cubes compressive strength was taken as the representative test result for each curing ages. The loading rate of compressive strength machine is 0.15 to 0.5 MPa/sec. For this test 0.35 MPa/sec was used by taking the average loading rate of the compressive strength test machine. Seventy two concrete cube specimens were tested. The overall curing and compressive strength testing procedures were according to STANDARDS (2006).

5. RESULTS AND DISCUSSIONS

5.1 Bogue's Equations for the Chemical Content in CBA Blended Mix

Bogue's equation is used to determine the compound composition of different mixes (0% to 20% CBA replaced concrete) and to verify the effect of CBA chemical composition change in fresh and hardened concrete properties. As ASTM C150, calculation of potential cement phase composition. Bogue's equations for the percentage of main binders are given in Equation 17 to 20. The terms in brackets represent the percentage of the given oxide in the total mass of CBA. From the chemical analysis result in Table 4-2, CBA contains 43.26% CaO, but its' percentage of SiO_2, Fe_2O_3 and Al_2O_3 is less than 0.01%. The calculation is done by mixing the CBA and OPC cement.

Tricalcium silicate$(C_3S) = (4.071 \times \%CaO) - (7.600\ x\%SiO_2) - (6.7183 \times \%Al_2O_3) - (1.430 \times Fe_2O_3) - (2.852 \times \%SO_3) - (5.188 \times \%\ CO_2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots. Equation\ 17$

Dicalcium silicate $(C_2S) = (2.867 \times \%SiO_2) - (0.7544 \times \%C_3S) \ldots\ldots\ldots\ldots Equation\ 18$

Tricalcium aluminate $(C_3A) = (2.650 \times \%Al_2O_3) - (1.692 \times \%Fe_2O_3) \ldots. Equation\ 19$

Tetracalcium aluminoferrite $(C_4AF) = (3.043 \times \%\ Fe_2O_3) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 20$

For 100%OPC mix the Bogue's calculation is as follows using Equation 17 to 20;

$$C_3S = (4.071 \times 66.32) - (7.600\ x22.82) - (6.718 \times 5.41) - (1.430 \times 3.37) = 55.39\%$$

$$C_2S = (2.867 \times 22.82) - (0.7544 \times 55.39) = 23.64\%$$

$$C_3A = (2.650 \times 5.41) - (1.692 \times 3.37) = 8.63\%$$

$$C_4AF = (3.043 \times 3.37) = 10.25\%$$

All mix compound compositions in Table 5-2 is done by the equations 17 to 20 by varying the mix (CBA percentage in concrete).

Table 5-1: Dangote OPC Cement Chemical Composition *(Geremew, 2017)*

Chemical oxides	CaO	SiO_2	Al_2O_3	Fe_2O_3
Content (%)	66.32	22.82	5.41	3.37

Table 5-2: Calculations of Bone Ash Blended Cement Compound Component

Elemental oxides	100%OPC 0%CBA	95%OPC 5%CBA	90%OPC 10%CBA	85%OPC 15%CBA	80%OPC 20%CBA
	Chemical composition (%)				
CaO	66.32	65.17	64.01	62.86	61.71
SiO_2	22.82	22.82	22.82	22.82	22.82
Al_2O_3	5.41	5.41	5.41	5.41	5.41
Fe_2O_3	3.37	3.37	3.37	3.37	3.37
Compounds	**Compound Composition (%)**				
C_3S	55.39	50.71	45.99	41.31	36.62
C_2S	23.64	27.17	30.73	34.26	37.79
C_3A	8.63	8.63	8.63	8.63	8.63
C_4AF	10.25	10.25	10.25	10.25	10.25

Calculated results in Table 5-2 indicates that as the CBA percentage increases, the content of C_2S increases. But the C_3S composition has inverse relationship with the increase of CBA content in cement hydration attributed to the low SiO_2 content of CBA. The C_3A and C_4AF compound composition is the same for all mixes due to low Al_2O_3 and Fe_2O_3 contribution of CBA in hydration. The decrease of C_3S in paste retards the setting time and early strength gain because C_3S is largely responsible for initial set and early strength gain. The higher composition of C_2S contributes to later strength gain of concrete.

5.2 Consistency Test

The normal consistency of the cement paste increases as the percentage of replacement of CBA increases as shown in Table 4-1. It implies that the CBA requires more water content than normal (OPC) cement to form the normal consistency within acceptable range of plunger penetration (9 to 11 mm penetration). The possible reason for the increase of absorption could be the higher surface area of CBA than OPC cement.

5.3 Setting Time Test

Initial and final setting time of control (100%) OPC and all CBA partially replaced cement paste conforms to ASTM C191 standard. The initial and final setting time increases as the percentage replacement of cement with Bone ash increases. This indicates that the hydration process of cement was slowed down because of the increment percentage of bone ash. The reason for the increase in setting time is the presence of the phosphate(P_2O_5) in CBA which exhibits the retarding of cement paste by formation of a complex on the surface of cement particles. The reduction of C_3S percentage in cement paste is also another factor attributed to the delay of setting time since C_3S contributes to initial setting time of cement paste.

The Ethiopian standard limits the cement final setting time not to exceed 10 hours, while the initial setting time not to be less than 45 minutes. ASTM C191 limits the initial setting time of hydraulic cement should be between 49 min and 202min.

Table 5-3: Setting Time Test Result

Proportion of material	**Initial setting time (minute)**	**Final setting time (minute)**	**standard-setting time (minute), ASTM C191**		
			Initial	**Final**	**Remark**
100%PPC	180	590	49 to 202	185 to 600	Ok
100%OPC	142.5	480	49 to 202	185 to 600	Ok
95%OPC + 5%CBA	150	495	49 to 202	185 to 600	Ok
90%OPC + 10%CBA	153	540	49 to 202	185 to 600	Ok
85%OPC + 15%CBA	160	556	49 to 202	185 to 600	Ok
80%OPC + 20%CBA	162	588	49 to 202	185 to 600	Ok

The results for the setting time presented in Table 5-3, indicate that the addition of CBA retarded the setting time; however, setting time was within limits as specified by the Ethiopian standard and ASTM C191. As the CBA content increases, the setting time of cement increases. The PPC mix has longer setting time than all OPC control and 5%CBA to 20%CBA mixes.

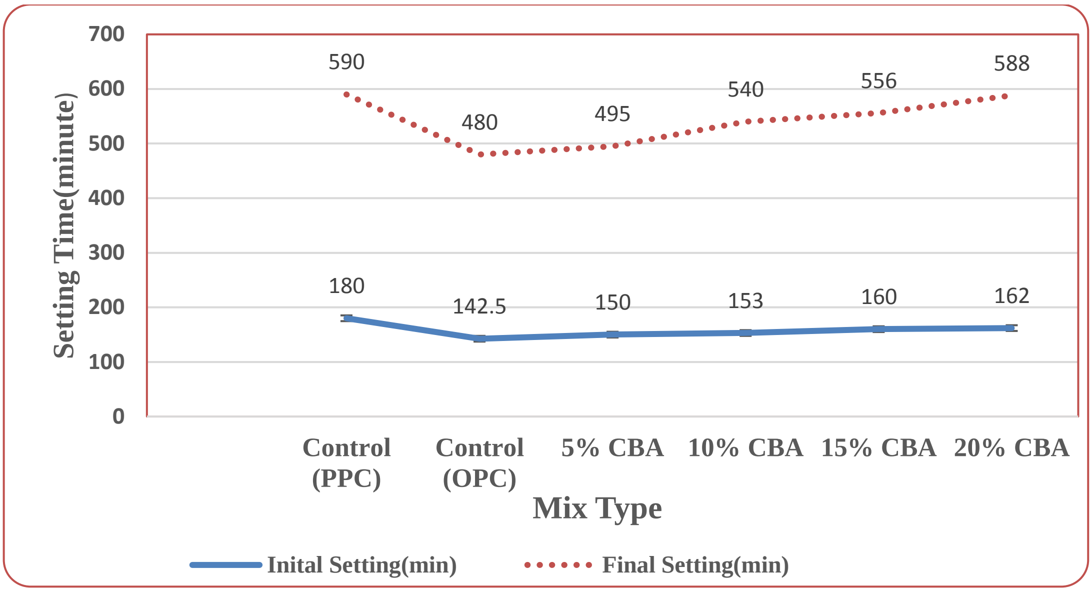

Figure 5-1: Initial and Final Setting Time Test Result

5.4 Soundness Test

Soundness of cement is primarily affected by the presence of excess lime (CaO) in the cement. This excess lime hydrates very slowly and forms slaked lime that occupies a larger volume than the original free calcium oxide. The test result shows that as the percentage of CBA increases in cement paste, the expansion of paste decreases due to the lower calcium oxide content of CBA than cement. In all proportion mixes from 0% to 20% CBA cement paste is sound since its' expansion (L_2- L_1) is less than 10mm.

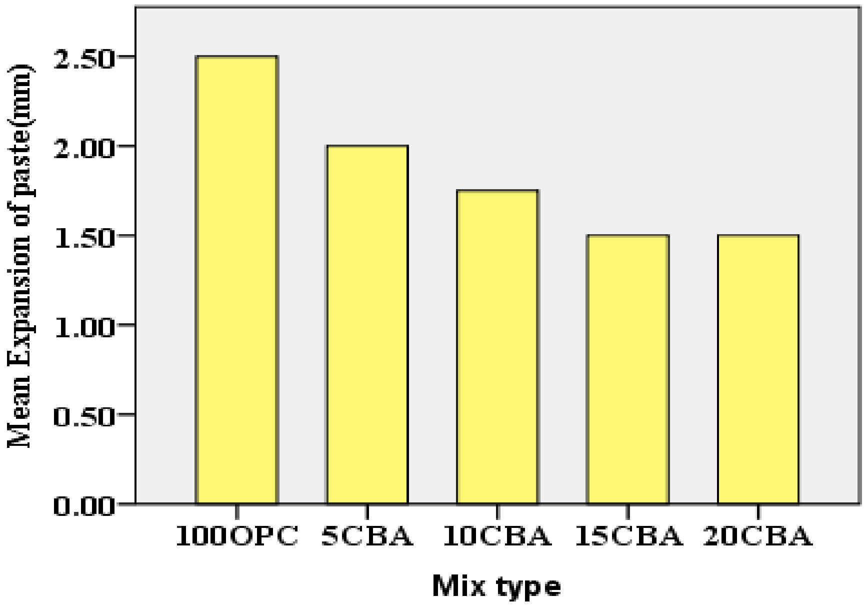

Figure 5-2: Cement Soundness Test Result

5.5 Slump Test

The slump value of a freshly mixed concrete is an indication of its flow and overall workability. The concrete slump decreases as the percentage of replacement of CBA increases in concrete. Thus, the decreasing slump value with increasing CBA content implies that the mix becomes harsh and less workable as the CBA content increases up to 10%CBA replacement. It is attributed to the high-water absorption capacity of CBA compared to the OPC cement. But beyond 10%CBA replacement, the concrete slump increases due to the increment of water content and the reduction of sand content in mix design despite the higher water absorption of CBA in concrete mix.

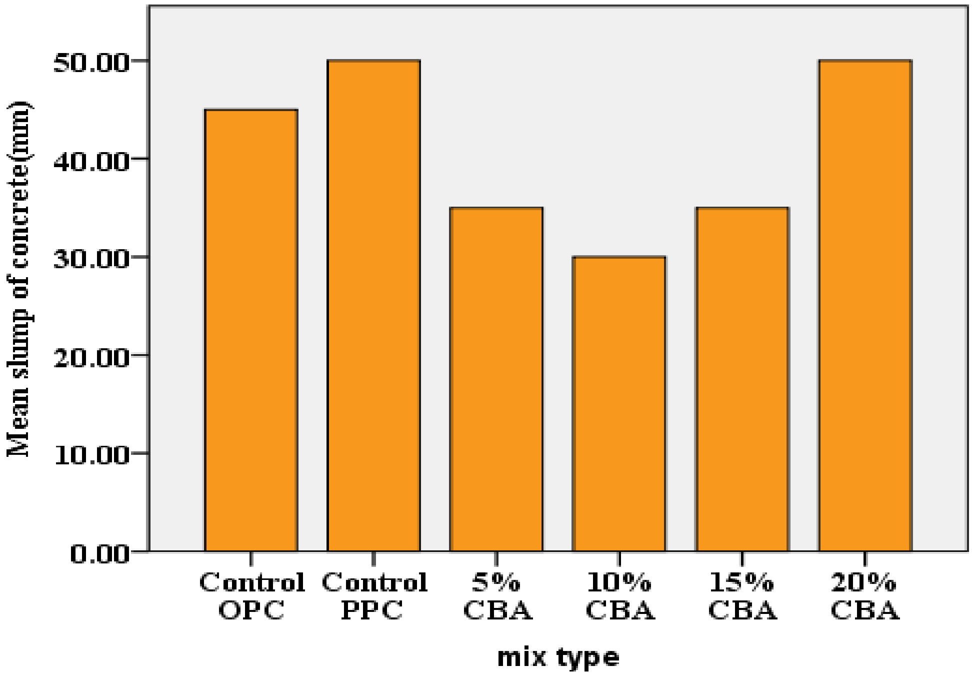

Figure 5-3: Slump Test Results

5.6 Concrete Density Test

Density of concrete (Dc) is Calculated by subtracting mass of the measure (Mm) from the mass of the measure filled with concrete (Mc) and dividing net mass by volume of the measure (Vm) as follows: $Dc = (\frac{Mc - Mm}{Vm})$ as per ASTM C138.

Bone has a lower density than Dangote Ordinary Portland Cement. From the fresh and hardened concrete density tests, the addition of bone ash decreases the unit weight of concrete. Self-weight reduction in concrete structure design saves reinforcement bars, which is the most expensive construction material. The density of bone ash is obtained by dividing the mass by its own volume as follows,

- ✓ $Weight\ of\ bone\ ash\ and\ container\ =\ 6{,}434\ g$
- ✓ $Weight\ of\ container\ =\ 2{,}962\ g$
- ✓ $Volume\ of\ container\ =\ 0.003m^3$

$$\text{Density}(\text{kg/m}^3) = \frac{weight\ of\ bone\ ash\ (kg)}{volume\ (\text{m}^3)}$$

$$= \frac{(\text{Weight of bone ash and container} - \text{weight of container})kg}{volume\ (\text{m}^3)}$$

$$= \frac{\frac{(6{,}434-2{,}962)g}{\frac{1000g}{kg}}}{0.003m^3} = 1{,}157kg/m^3$$

The density of CBA is 17.35% less than the density of ordinary Portland cement(1400kg/m³). The addition of CBA in a concrete cause the reduction of the fresh and hardened concrete density. Fresh casted concrete was taken for fresh concrete and 56th day cured concrete under curing tank was taken for hardened concrete density test as shown in Tables 5-4 and 5-5. Density test was taken in saturated surface dry condition (SSD), that is by drying in air for 3 to 4 hours (to remove water) from the Cured concrete surfaces.

Table 5-4: Density of Fresh Concrete

Mix type	**Weight of concrete (kg)**				**Volume (m³)**	**Density of concrete(kg/m³)**
	Cube 1	**Cube 2**	**Cube 3**	**Average**	**Per cube**	**Average**
100%OPC	8.938	8.744	8.821	8.834	0.0036	2453.89
100%PPC	8.912	8.908	8.706	8.842	0.0036	2456.11
95%OPC+5%CBA	8.730	8.775	8.764	8.756	0.0036	2432.22
90%OPC+10%CBA	8.391	8.484	8.458	8.444	0.0036	2345.56
85%OPC+15%CBA	8.304	8.416	8.405	8.375	0.0036	2326.39
80%OPC+20%CBA	8.342	8.316	8.344	8.334	0.0036	2315.00

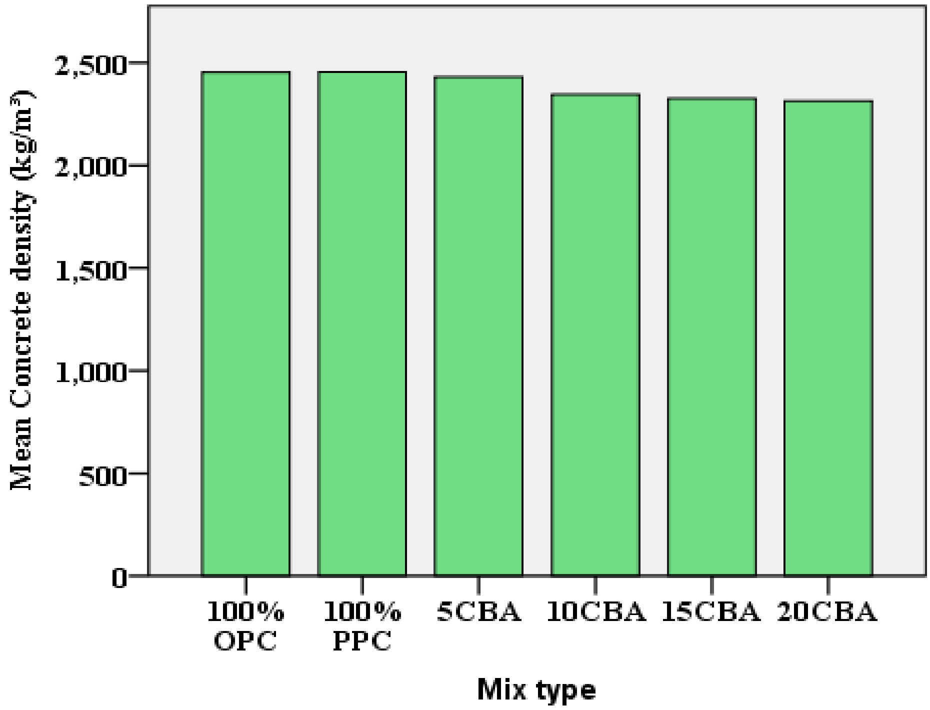

Figure 5-4: Fresh Concrete Density

The density of hardened concrete with different mixes (percentage of CBA) was calculated by dividing the average weight(kg) of three 15cmx15cmx15cm concrete cube by its occupied volume(m^3). Figures 5-4 and 5-5 are generated by IBM SPSS Statistics version 21 software.

Table 5-5: Density of Hardened Concrete

Mix type	**Weight of concrete (kg)**				**Volume (m^3)**	**Density of concrete(kg/m^3)**
	Cube 1	**Cube 2**	**Cube 3**	**Average**	**Per cube**	**Average**
100%OPC	9.082	9.010	9.038	9.043	0.0036	2511.95
100%PPC	8.962	8.925	8.889	8.925	0.0036	2376.85
95%OPC+5%CBA	8.736	8.97	8.928	8.878	0.0036	2466.11
90%OPC+10%CBA	8.650	8.542	8.478	8.556	0.0036	2376.60
85%OPC+15%CBA	8.389	8.338	8.442	8.390	0.0036	2330.46
80%OPC+20%CBA	8.361	8.388	8.130	8.293	0.0036	2303.61

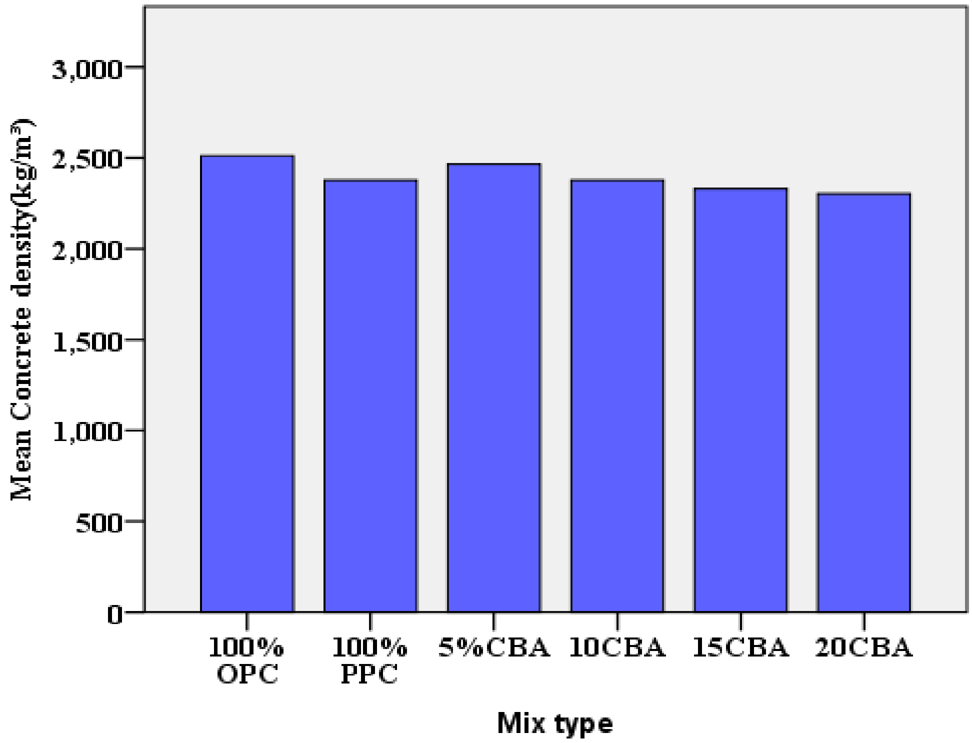

Figure 5-5: Hardened Concrete Density

From the test results, the density of concrete decreases as the percentage of CBA increases due to less unit of bone ash compared to Ordinary Portland Cement. The hardened concrete density is higher than fresh mixed concrete, it could be due to the reduction of capillary pores by continuous hydration of cement paste with time. The reduction of concrete density is an important property of concrete to build low weight buildings, consequently suitable for self-weight reduction of structural members and overall building weight. The reduction overall building weight affords a high reduction of reinforcement bars which is one of the most expensive construction materials. Therefore, replacement of cement with CBA is very important to construct economical buildings and reduce building failures(settlement) due to heavy self-weight.

5.7 Compressive Strength Test

5.7.1 Compressive Strength Test Results

Having the concrete cured under water for different dates and dried in free air for three hours, its compressive strength was tested. As the percentage of CBA increases, the composition of C_3S decreases as shown in Table 5-2, consequently causes the reduction of the compressive strength. The three 15cmx15cmx15cm concrete cubes average (mean) compressive strength was taken for comparison with design (target mean strength) to C-25 concrete grade. As the concrete curing age increases, the compressive strength significantly increases as shown in Table 5-6.

Table 5-6: Mean Concrete Compressive Strength Test Results

Cement proportion	Mix designation	Mean compressive strength (MPa)			
		3 day	7 day	28 day	56 day
100% PPC	100% PPC	11.96	17.48	32.18	36.19
100% OPC	100% OPC	18.94	31.86	41.07	46.03
95%OPC+5% CBA	5% CBA	17.30	22.74	34.94	35.53
90%OPC+10% CBA	10% CBA	14.20	17.74	27.52	31.28
85%OPC+15% CBA	15% CBA	12.56	12.67	22.29	22.95
80%OPC+20% CBA	20% CBA	7.26	9.58	16.73	17.73

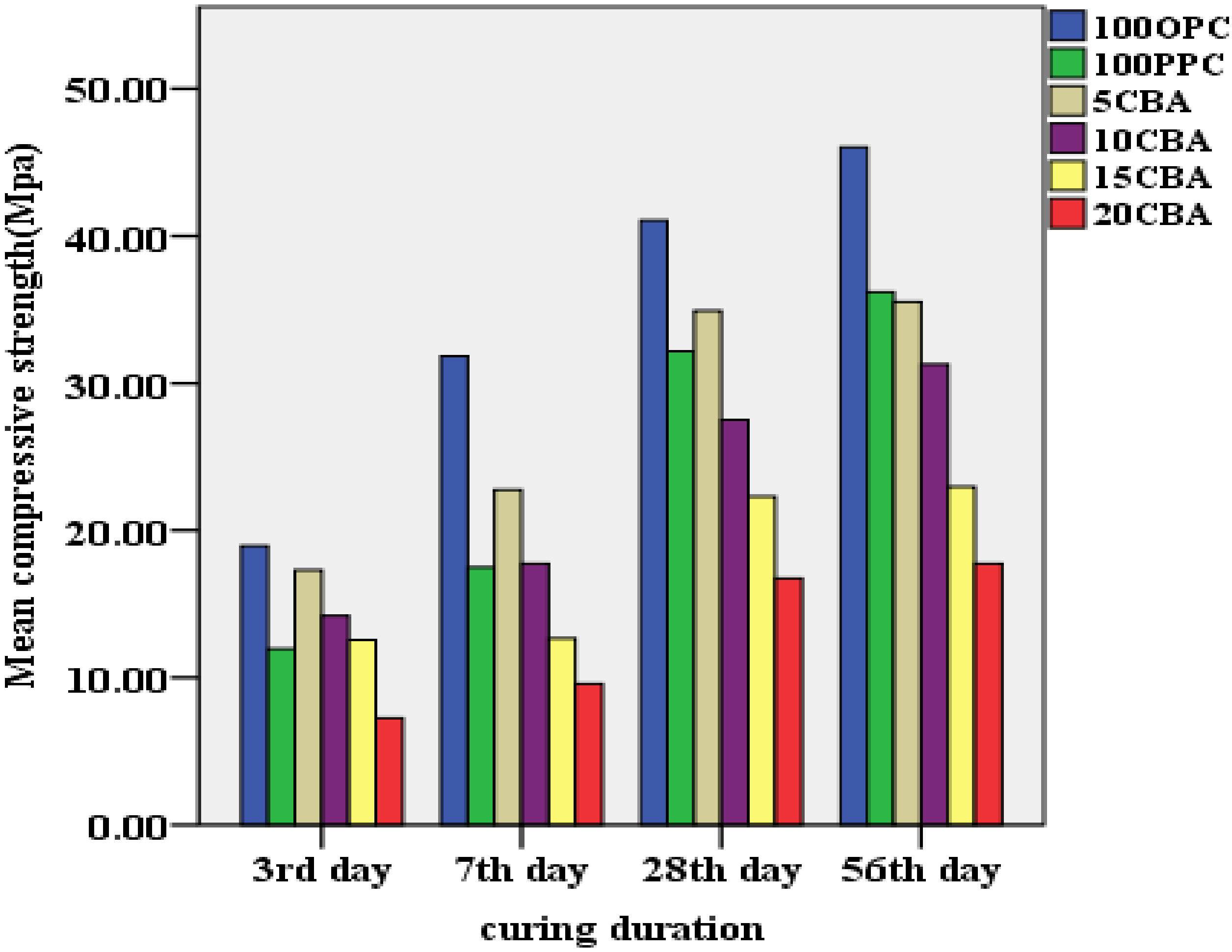

Figure 5-6: Compressive Strength Test Result

Figure 5-6 is generated by IBM SPSS Statistics version 21 software. Table 5-6 shows that the 3^{rd} day compressive strength with varying percentage of CBA declined from the control specimen(100%OPC), but it is greater than 100%PPC. The 3^{rd} day average control specimen (100%OPC) compressive strength was 18.94MPa (0% CBA replacement). The test has revealed that the reduction of the compressive strength is directly proportional to an increase in the percentage of CBA.

The 3^{rd} day lesser 100%PPC strength proves that PPC has lower early strength than OPC mix concrete (control) and varying percentage of CBA except 20%CBA, due to its pozzolanic property. The 3^{rd} day 100% PPC, 100%OPC, 5%CBA, 10%CBA, 15%CBA and 20%CBA compressive strength achieves; 37.16%, 46.16%, 49.51%, 51.60%, 56.35% and 43.39% of its corresponding 28^{th} day mean compressive strength respectively.

The 7^{th} day 100% PPC, 100%OPC, 5%CBA, 10%CBA, 15%CBA and 20%CBA compressive strength achieves; 54.32%, 77.57%, 65.08%, 64.46%, 56.84% and 57.26% of its corresponding 28^{th} day mean compressive strength respectively. This shows that PPC cement has lower early strength than other mixes because the 3^{rd} and 7^{th} day mean compressive achieves 37.16% and 54.32% of its respective 28^{th} day mean compressive strength respectively, which is less than all other types of OPC mixes.

The 28^{th} day 100% PPC, 100%OPC, 5%CBA, 10%CBA, 15%CBA and 20%CBA compressive strength achieves; 88.92%, 89.22%, 98.34%, 87.98%, 97.12%and 94.36% of 56^{th} day mean compressive strength respectively. This shows that there is no significant difference between 28^{th} and 56^{th} day compressive strength compared to the difference between 3^{rd} and 7^{th} days mean compressive strength.

The 3^{rd} day mean compressive strength for the control mix(100%OPC) was 18.94Mpa. There was reduction of 1.64MPa (8.66%), 4.74MPa (25.03%), 6.38MPa (33.69%), 11.68MPa (61.67%) strength in 5%CBA, 10%CBA, 15%CBA and 20%CBA replacement respectively from the control value.

The 7^{th} day mean compressive strength for the control mix(100%OPC) was 31.86MPa. There was reduction of 9.12MPa (28.62%), 14.12MPa (44.32%), 19.19MPa (60.23%), 22.28MPa (69.93%) strength in 5%CBA, 10%CBA, 15%CBA and 20%CBA replacement respectively from the control value.

The 28th day mean compressive strength for the control mix(100%OPC) was 41.07Mpa. There was reduction of 6.13MPa (14.93%), 13.55MPa (32.99%), 18.78MPa (45.73%), 24.34MPa (59.26%) strength in 5%CBA, 10%CBA, 15%CBA and 20%CBA replacement respectively from the control value.

The 56th day mean compressive strength for the control mix(100%OPC) was 46.03MPa. There was reduction of 10.5MPa (22.81%), 14.75MPa (32.04%), 23.08MPa (50.14%), 28.33MPa (61.48%) strength in 5%CBA, 10%CBA, 15%CBA and 20%CBA replacement respectively from the control value.

Based on the 28th day mean compressive strength results, the 5%CBA replacement has comparable compressive strength value with the control specimen (100%OPC); It achieved 85.07% 28th day mean compressive strength of the control specimen. The 28th day 5%CBA mean compressive strength was 34.94 MPa, which was greater than 28th day C-25 required target mean strength(33.5MPa). Similarly, 28th day 10%CBA mean compressive strength was 27.52MPa, which achieved 82.14% of the 28th day C-25 required target mean strength(33.5MPa), but it is greater than 25Mpa.

The 28th day mean compressive strength of 15%CBA and 20%CBA achieved 66.54% and 50.00% of the 28th day C-25 required target mean strength(33.5MPa) respectively. The results of 15% and 20% CBA mixed concrete samples showed that the replacement of 15% and 20% CBA with OPC has a significant effect on the compressive strength of concrete. The decrease in compressive strength is mainly attributed to the effect of the percentage of replacement of cement with CBA causing less formation of C_3S. Although CBA has high calcium oxide content, it contains few percentages of silicate oxides; consequently, caused less formation of tricalcium silicate(C_3S) in hydration.

5.7.2 Validity of Compressive Strength Test Results

Validity is the extent to which the scores from a measure (experimental work) represent the variable they are intended to. In this study, the mean compressive strength of concrete for each specimen and curing age was considered as the major experimental work(test) variable compared with the design required target mean strength and the standard deviation between concrete cube specimens for each curing duration was analyzed.

The compressive strength of concrete increases as the curing age increases. All mixes proved that the compressive strength increases as the hydration reaction continues. The 28th day mean compressive strength for the control mix(100%OPC) test result is 41.07MPa, which is 7.57MPa (22.5%) higher than the required target mean strength(33.5MPa) due to high quality of aggregates and proper mix. But the 5%CBA 28th day mean compressive strength is 34.94MPa, which is 1.44MPa (4.29%) higher than the required target mean strength(33.5MPa). The 28th day 10%CBA mean compressive strength is 27.52MPa, which achieves 82.15% of the required target mean strength(33.5MPa).

The standard deviation between the concrete cube specimen is one way to check the validity of the mean compressive strength test results. In this regard, according to Indian Standard, 2006, Average of three specimen values shall be taken as the representative of the batch provided the Individual variation is not more than ± 15 percent of the average. From the test result, the mean standard deviation for all proportion of CBA with their respective curing ages is less than 15% except 3rd day 5%CBA mix and 7th day 15%CBA has 15.60% and 16.34% mean standard deviation from the average value respectively as shown in Table 5-7. This insignificant (0.6% and 1.34%) variation from expected Standard deviation (15%) might be mixing, measuring and other personal errors. Generally, from Table 5-7, test result standard deviation states that the concrete mix was done with correct procedures and appropriate techniques set by mix design.

Table 5-7: Compressive Strength Test Mean Standard Deviation from Average Value

	Mean standard deviation value (%)			
Curing age	3rd day	7th day	28th day	56th day
Control (OPC)	4.83	3.57	9.46	5.67
Control (PPC)	7.22	3.50	4.35	8.43
5% CBA	15.60	10.80	4.80	8.34
10% CBA	4.58	2.96	6.87	3.55
15% CBA	4.06	16.34	7.87	4.46
20% CBA	5.78	13.17	2.19	7.01

5.7.3 Hypothesis Formulation and Testing Factorial ANOVA

The hypothesis formulation is based on the Factorial one-way ANOVA. In One-way ANOVA, Hypothesis should be tested using ANOVA. There are two types of hypothesis in statistics, null hypothesis(H_0) and Alternative hypothesis (H_a).

H_0: $\mu_1 = \mu_2 = \ldots = \mu_k$ all population means are the same, against: H_a: $\mu_1 \neq \mu_2 \neq \ldots \neq \mu_k$ Not all population means are the same. For this study the following null hypotheses are taken.

H_{o1}= The partial replacement of cement with CBA doesn't affect the average compressive strength of concrete (compared with control mix).

H_{o2}= The length of curing age(days) doesn't affect the average compressive strength of concrete.

Table 5-8: Tests of Between-Subject Effects

Dependent Variable: compressive strength (MPa)					
Source	**Type II Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.(p)**
Corrected Model	4532.635[a]	4	1133.159	22.203	0.000
Intercept	16621.072	1	16621.072	325.678	0.000
age * percent	2317.434	3	772.478	15.136	0.000
Percent	2215.201	1	2215.201	43.405	0.000
Error	3419.365	67	51.035		
Total	46971.142	72			
Corrected Total	7952.000	71			
a. R Squared = .570 (Adjusted R Squared = .544)					

From the Table 5-8, the variable interaction analysis was made by univariate analysis. The p-value is less than 0.05, so that the null hypothesis is rejected and it shows that curing age significantly affects the compressive strength of concrete. Similarly, between different groups or the addition of different percentage CBA significantly affects the compressive strength of concrete.

As shown in Table 5-9, there is statistically significant difference between different mix groups mean compressive strength at all curing ages (0% to 20% CBA mixes).

Table 5-9: Analysis of Variance Between Groups and Within Groups

ANOVA						
Compressive strength (MPa)		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
3rd day	Between Groups	259.462	5	51.892	32.054	0.000
	Within Groups	19.427	12	1.619		
	Total	278.889	17			
7th day	Between Groups	934.388	5	186.878	86.347	0.000
	Within Groups	25.971	12	2.164		
	Total	960.359	17			
28th day	Between Groups	1166.471	5	233.294	52.490	0.000
	Within Groups	53.334	12	4.445		
	Total	1219.805	17			
56th day	Between Groups	1536.636	5	307.327	63.668	0.000
	Within Groups	57.925	12	4.827		
	Total	1594.560	17			

5.7.4 Descriptive Statistics Analysis

The data were analyzed using IBM SPSS Statistics version 21 software. Statistical analysis was done by using One-Way ANOVA. One-Way ANOVA is used to compare the means of two or more groups by investigating the relevant variances or to compare means of two or more levels of independent variables. The One-Way ANOVA procedure produces a one-way analysis of variance for a quantitative dependent variable by a single factor (independent) variable. Analysis of variance is used to test the hypothesis that several means are equal. In this case, the independent variable is time and the dependent variable is the compressive strength of concrete at different curing ages(time).

For each group (percentage of replacement of CBA) containing three concrete cube test specimens, mean, standard deviation, standard error of the mean, minimum and maximum compressive strengths (MPa) for each curing duration(days) was analyzed with 95% confidence interval for the mean and is shown in Table 5-10.

Table 5-10: Compressive Strength Test Descriptive Statistics

Descriptives									
		N	**Mean**	**Std. Deviation**	**Std. Error**	**95% Confidence Interval for Mean**		**Minimum**	**Maximum**
						Lower Bound	**Upper Bound**		
3rd day compressive strength (MPa)	PPC 100%	3	11.9600	0.86366	0.49863	9.8146	14.1054	10.98	12.61
	OPC 100%	3	18.9400	0.91477	0.52814	16.6676	21.2124	18.26	19.98
	5% CBA	3	17.2967	2.69660	1.55688	10.5979	23.9954	14.22	19.25
	10% CBA	3	14.2000	0.65023	0.37541	12.5847	15.8153	13.56	14.86
	15% CBA	3	12.5600	0.51029	0.29462	11.2924	13.8276	11.98	12.94
	20% CBA	3	7.2567	0.41932	0.24210	6.2150	8.2983	6.99	7.74
	Total	18	13.7022	4.05034	0.95467	11.6880	15.7164	6.99	19.98
7th day compressive strength (MPa)	PPC 100%	3	17.4800	0.61213	0.35341	15.9594	19.0006	16.95	18.15
	OPC 100%	3	31.8567	1.13615	0.65596	29.0343	34.6790	30.64	32.89
	5% CBA	3	22.7400	2.45575	1.41783	16.6396	28.8404	20.25	25.16
	10% CBA	3	17.7367	0.52539	0.30333	16.4315	19.0418	17.20	18.25
	15% CBA	3	12.6667	2.06984	1.19502	7.5249	17.8084	10.28	13.97
	20% CBA	3	9.5770	0.85389	0.49299	7.4558	11.6982	8.68	10.38
	Total	18	18.6762	7.51610	1.77156	14.9385	22.4138	8.68	32.89
28th day compressive strength (MPa)	PPC 100%	3	32.1833	1.40051	0.80859	28.7043	35.6624	30.60	33.26
	OPC 100%	3	41.0700	3.88634	2.24378	31.4158	50.7242	36.71	44.17
	5% CBA	3	34.9367	1.67840	0.96903	30.7673	39.1060	33.20	36.55
	10% CBA	3	27.5200	1.88963	1.09098	22.8259	32.2141	25.75	29.51

	15% CBA	3	22.2900	1.75519	1.01336	17.9299	26.6501	20.52	24.03
	20% CBA	3	16.7267	0.36556	0.21106	15.8186	17.6348	16.33	17.05
	Total	18	29.1211	8.47073	1.99657	24.9087	33.3335	16.33	44.17
56th day compressive strength (MPa)	PPC 100%	3	36.1900	3.05069	1.76132	28.6117	43.7683	32.76	38.60
	OPC 100%	3	46.0300	2.60799	1.50572	39.5514	52.5086	43.07	47.99
	5% CBA	3	35.5333	2.96497	1.71182	28.1679	42.8987	32.39	38.28
	10% CBA	3	31.2833	1.10943	0.64053	28.5274	34.0393	30.10	32.30
	15% CBA	3	22.9467	1.13443	0.65496	20.1286	25.7647	22.12	24.24
	20% CBA	3	17.7267	1.24307	0.71769	14.6387	20.8146	16.41	18.88
	Total	18	31.6183	9.68492	2.28276	26.8021	36.4345	16.41	47.99

5.7.5 Post Hoc Tests

Once the differences existing among the means, post hoc range tests and pairwise multiple comparisons are analyzed, means difference can be determined. The average compressive strength of the three 15cmx15cmx15cm cubes were taken as the group mean for each mix.

Table 5-11: Multiple Variable Comparisons

Multiple Comparisons (Tukey HSD)							
Dependent Variable	**(I) percentage replacement of CBA**	**(J) percentage replacement of CBA**	**Mean Difference (I-J)**	**Std. Error**	**Sig.(p)**	**95% Confidence Interval**	
						Lower Bound	**Upper Bound**
3rd day compressive strength (MPa)	OPC 100%	PPC 100%	6.98000*	1.03888	0.000	3.4905	10.4695
		5% CBA	1.64333	1.03888	0.624	-1.8462	5.1328
		10% CBA	4.74000*	1.03888	0.007	1.2505	8.2295
		15% CBA	6.38000*	1.03888	0.001	2.8905	9.8695
		20% CBA	11.68333*	1.03888	0.000	8.1938	15.1728
7th day	OPC 100%	PPC 100%	14.37667*	1.20119	0.000	10.3420	18.4114
		5% CBA	9.11667*	1.20119	0.000	5.0820	13.1514

compressive strength (MPa)		10% CBA	14.12000*	1.20119	0.000	10.0853	18.1547
		15% CBA	19.19000*	1.20119	0.000	15.1553	23.2247
		20% CBA	22.27967*	1.20119	0.000	18.2450	26.3144
28th day compressive strength (MPa)	OPC 100%	PPC 100%	8.88667*	1.72134	0.002	3.1048	14.6685
		5% CBA	6.13333*	1.72134	0.035	0.3515	11.9152
		10% CBA	13.55000*	1.72134	0.000	7.7682	19.3318
		15% CBA	18.78000*	1.72134	0.000	12.9982	24.5618
		20% CBA	24.34333*	1.72134	0.000	18.5615	30.1252
56th day compressive strength (MPa)	OPC 100%	PPC 100%	9.84000*	1.79389	0.001	3.8145	15.8655
		5% CBA	10.49667*	1.79389	0.001	4.4711	16.5222
		10% CBA	14.74667*	1.79389	0.000	8.7211	20.7722
		15% CBA	23.08333*	1.79389	0.000	17.0578	29.1089
		20% CBA	28.30333*	1.79389	0.000	22.2778	34.3289
*. The mean difference is significant at the 0.05 level.							

Pairwise multiple comparisons test the difference between each pair of means (the percentage of CBA replacement) and yield a matrix where asterisks indicate significantly different group means at an alpha level of 0.05. From Table 5-11, 3rd day 5%CBA compared to the 3rd day control(100%OPC) has no statistical difference, since the P value is 0.624, which is greater than alpha value (0.05), initial hypothesis is accepted. But in all other mixes, the 3rd, 7th, 28th and 56th day mean compressive strength has statistical difference, because the P value is less than 0.05 as shown in Table 5-11 column 6.

5.8 Regression and Correlation Between Variables

5.8.1 Regression Between Density and Compressive Strength

Regression analysis is used to predict the value of a dependent variable based on the value of at least one independent variable. It explains the impact of changes in an independent variable on the dependent variable. In this case, the compressive strength was taken as dependent variable and density was taken as the independent variable. Linear regression equation was driven by using Microsoft excel 2016. It is expressed by linear mathematical equation in terms of X and Y variables. Whereas,

X, is the average density of concrete for three 15cmx15cmx15cm cube specimen.

Y, is the average compressive strength of concrete within varied OPC and CBA proportion

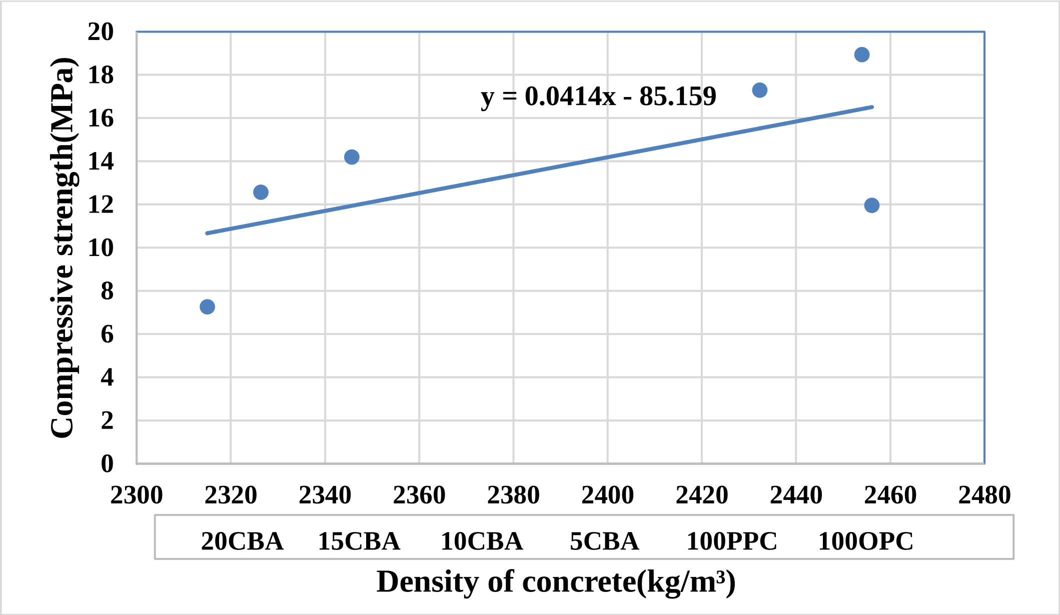

Figure 5-7: 3rd Day Cured Concrete Compressive Strength and Density Regression

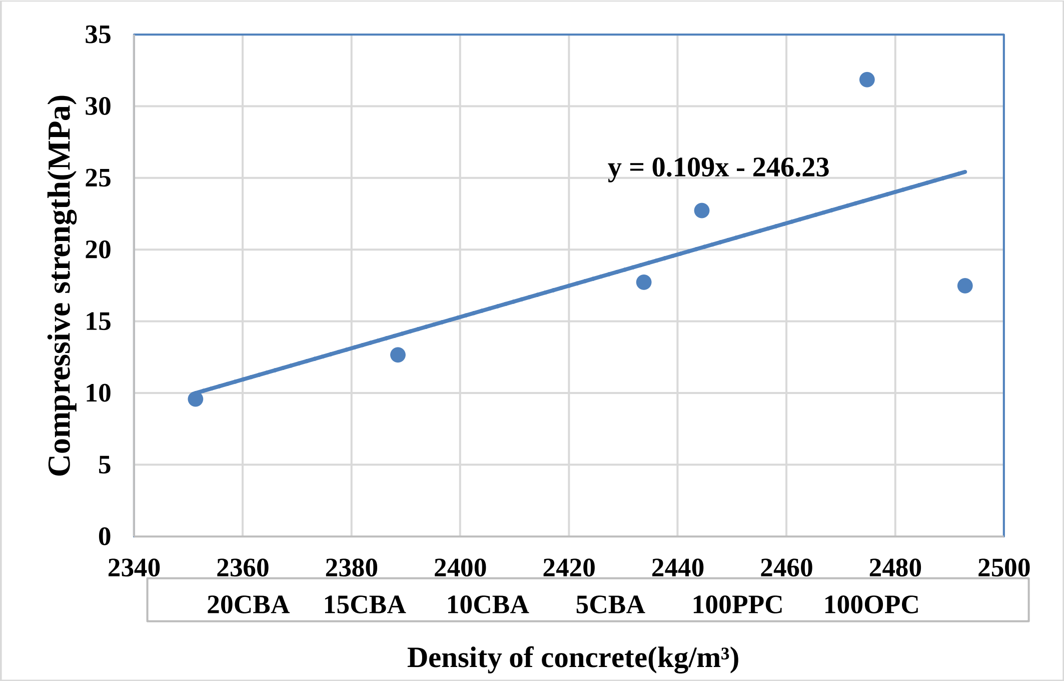

Figure 5-8: 7th Day Cured Concrete Compressive Strength and Density Regression

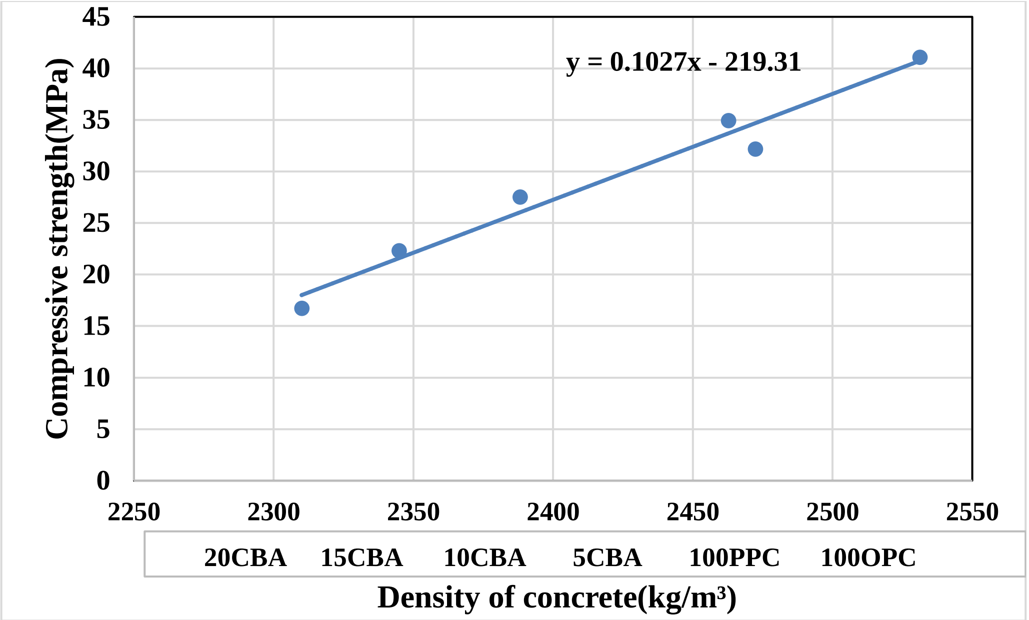

Figure 5-9: 28th Day Cured Concrete Compressive Strength and Density Regression

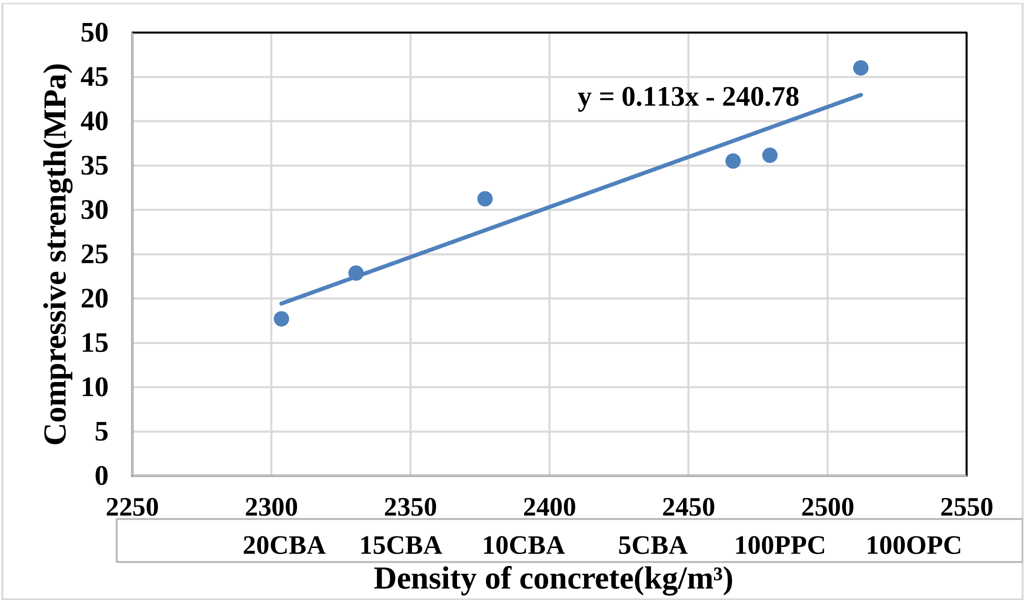

Figure 5-10: 56th Day Cured Concrete Compressive Strength and Density Regression

From the all above Figures 5-7 to Figure 5-10, the compressive strength of concrete increases as density the of the concrete increases with in different curing ages of concrete. It shows that the compressive of concrete and the density of concrete are direct proportional variables.

5.8.2 Correlation Between Density and Compressive Strength

Correlation analysis is used to measure the strength of the association (linear relationship) between two variables. It is concerned with the strength of the relationship between variables.

The population correlation coefficient ρ (rho) measures the strength of the association between the variables. The sample correlation coefficient r is an estimate of ρ and is used to measure the strength of the linear relationship in the sample observations. The correlation was taken by accounting the average of all mix's (100OPC to 20CBA) density and compressive strength with their respective curing ages.

Table 5-12: Correlation Between Concrete Density and Compressive Strength

Correlations			
		3rd day Compressive strength	**3rd day density**
3rd day compressive strength	Pearson Correlation	1	0.659
	Sig. (2-tailed)		0.155
3rd day density	Pearson Correlation	0.659	1
	Sig. (2-tailed)	0.155	
	N	6	6
Correlations			
		7th day Compressive strength	**7th day Density**
7th day Compressive Strength	Pearson Correlation	1	0.733
	Sig. (2-tailed)		0.097
7th day density	Pearson Correlation	0.733	1
	Sig. (2-tailed)	0.097	
	N	6	6
Correlations			
		28th day compressive strength	**28th day Density**
28th day Compressive strength	Pearson Correlation	1	0.984**
	Sig. (2-tailed)		0.000
28th day density	Pearson Correlation	0.984**	1
	Sig. (2-tailed)	0.000	
	N	6	6
**. Correlation is significant at the 0.01 level (2-tailed).			
Correlations			
		56th day compressive strength	**56th day Density**
56th day Compressive strength	Pearson Correlation	1	0.961**
	Sig. (2-tailed)		0.002
56th day density	Pearson Correlation	0.961**	1
	Sig. (2-tailed)	0.002	
	N	6	6

Analysis is done by using IBM SPSS Statistics 21 software. Pearson correlation coefficient(r) is unit free; it ranges between -1 and 1.

- ✓ The closer to -1, the stronger the negative linear relationship.

- ✓ The closer to 1, the stronger the positive linear relationship.
- ✓ The closer to 0, the weaker the linear relationship.

From Table 5-12, the 3rd day compressive strength has a significant positive correlation (0.659) with the 3rd day concrete density. The 7th day Compressive strength has a positive correlation (0.733) with 7th day concrete density. The 28th day and 56th day Compressive strength has a positive correlation (0.984 and 0.961) with their respective concrete density respectively. Since the 28th day and 56th day correlation coefficients are nearly 1, the 28th and 56th day compressive strength has almost perfect positive correlation with their respective concrete density.

5.9 Environmental and Economic Benefits of CBA Blended Concrete

5.9.1 Environmental Benefits

Disposing of bone wastes to the environment highly pollutes the natural environment, causes bad smell, generates toxic chemicals that can pollute rivers, soil and plants. The land requirement for solid waste disposal in a large city, such as Bahir Dar, is a burning issue now. Proper waste management is very important to overcome the above problems. One of the useful waste management is recycling wastes to construction materials, such as using bone ash as cement material. Therefore, the recycling of bone waste material is imperative to provide environmentally friendly construction material and helps to forward ways to create a clean environment.

5.9.2 Reduction in Material Usages

Cement manufacturing process is a high-volume process, which demands high natural resources. limestone, shells, and chalk or marl combined with shale, clay, slate, blast furnace slag, silica sand, and iron ore are common materials used in cement production. But the exploration of these materials highly degrades the natural environment. The use of bone waste will save a great deal of material from the concrete production. For one ton of OPC production, 1.52 tons of raw materials are required (Stajanča M., 2012). Therefore, the use of CBA saves a high amount of material required for cement production. Table 5-13 shows that using CBA as a partial cement replacement saves the use of raw materials for the production of cement. For example, the 10 % replacement saved about 55.48 kg of raw materials required to produce 365 kg of cement, which means 36.5 kg of cement per meter cube of concrete compared to the control concrete, which approximately equals one bag of raw material per one-meter cubic of concrete.

Table 5-13: Material Saving of Using CBA in Concrete

Mix code	100OPC	95OPC+5CBA	90OPC+10CBA	85OPC+15CBA	80OPC+20CBA
OPC (kg/m³)	365	346.75	328.50	310.25	292.00
CBA (kg/m³)	0	18.25	36.50	54.75	73.00
Saving of raw Materials (kg/m³)	0	27.74	55.48	83.22	110.96

In 2018 in Ethiopia, we got an average of 400.5 million Kgs (0.4million tons) animal bone generation annually as waste (Quezon et al., 2018). For one ton of cement production, it consumes 1.52 ton of raw materials, which is equivalent to 10 % of CBA, thus reducing the raw materials for cement production with 0.4 million ton of CBA, hence saving (0.4million tonx1.52ton/ton) which equals, 0.608 million ton of raw materials each year.

5.9.3 Energy Saving

Cement production is a highly energy-dependent process and comprises 40% to 50% of total cement manufacturing cost. For one-ton cement production, it needs an average of 6000MJ energy, but by using CBA replacement the energy required for cement production can be reduced to 4905MJ, thus it saves 18.25% of the energy required to produce one ton of Portland cement. An average temperature required to form cement clinker is 1450 ˚C, but CBA can be produced at 900˚C temperature so that it minimizes temperature required to form clinker by 550 ˚C, which reduces 37.93% of temperature and this plays a great role in addressing global warming and energy cost.

5.10 Cost Analysis

One of the major advantages of using CBA in normal concrete is the cost saving required to purchase cement in addition to the self-weight reduction of concrete. For bone ash cost estimation, Burning and milling Energy cost, collection and transportation cost was included. Transportation cost from disposing site to laboratory, energy cost consumed by both milling (disk mill) and burning (electric furnace) expenses are the main costs considered in bone ash production. Energy cost calculation is based on the current Ethiopian Electric power energy unit cost per hour for customers. Total energy cost was obtained by multiplying the total energy required as per machine specification by unit cost of electricity. (Detail calculation shown on page 38). To estimate the total cost of concrete per cubic meter, current (July, 2019 G.C) Dangote ordinary Portland cement price per kilogram, fine aggregate and coarse aggregate cost per cubic meter, tap water cost per liter based on current Bahir Dar city water supply price, were considered as a material cost. Materials Transportation, overhead and labor costs were taken for cost estimation of concrete per cubic meter. The cost saving in percent form due to the partial replacement of cement with CBA is calculated by dividing the difference of CBA replaced concrete from the control mix(0%CBA) by control mix(0%CBA) and multiplying by 100% concrete per meter cube.

A. Cost of Cement

$$Total\ cost = Material\ Cost + Transportation\ Cost + Overhead\ Cost \ldots Equation\ 21$$

B. Cost of Coarse Aggregate

$$Total\ cost = Material\ Cost + Transportation\ Cost + \ Overhead\ Cost \ldots Equation\ 22$$

C. Cost of Fine Aggregate

$$Total\ cost = Material\ Cost + Transportation\ Cost + Overhead\ Cost \ldots Equation\ 23$$

D. Cost of water

$$Total\ cost = cost\ based\ on\ Bahir\ Dar\ city\ water\ supply\ price \ldots \ldots \ldots .. Equation\ 24$$

E. Cost of CBA

$$Total\ cost = Material\ Cost + Transportation\ Cost + Overhead\ Cost + Process\ cost \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ Equation\ 25$$

F. Cost of concrete

$$Total\ Cost\ = (Cement\ +\ Coarse\ Aggregate\ +\ Fine\ Aggregate +\ water\ +\ OBA)\ costs \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots Equation\ 26$$

Material costs of Dangote OPC cement, Fine aggregate, Coarse aggregate, Water and CBA were 4.5 ETB/kg, 0.9 ETB/kg, 1.2 ETB/kg, 4.0 ETB/m^3 and negligible ETB/kg respectively.

Table 5-14: Concrete Cost Per Meter Cube

Cement composition	Units	Total Material Cost				
		Cement	**Coarse aggregate**	**Fine aggregate**	**Water**	**CBA**
100%OPC	Quantity(kg/m³)	365	1067	828	179	-
	Unit-cost (ETB/kg)	4.80	1.37	1.05	0.004	-
	Cost (ETB/m³)	1752.0	1461.80	869.40	0.716	-
	Total cost (ETB/m³)	**4083.90**				
95%OPC+ 5%CBA	Quantity(kg/m³)	346.75	1067.0	806.1	179.0	18.25
	Unit-cost (ETB/kg)	4.80	1.37	1.05	0.004	4.29
	Cost (ETB/m³)	1644.00	1461.80	846.50	0.716	78.29
	Total cost (ETB/m³)	**4031.30**				
90%OPC+ 10%CBA	Quantity(kg/m³)	328.5	1067.0	783.6	179.0	36.5
	Unit-cost (ETB/kg)	4.80	1.37	1.05	0.004	4.29
	Cost (ETB/m³)	1576.80	1461.80	822.80	0.716	156.59
	Total cost (ETB/m³)	**4018.70**				
85%OPC+ 15%CBA	Quantity(kg/m³)	310.25	1067.00	761.10	179.0	54.75
	Unit-cost (ETB/kg)	4.80	1.37	1.05	0.004	4.29
	Cost (ETB/m³)	1489.20	1461.80	800.00	0.716	234.88
	Total cost (ETB/m³)	**3986.60**				
80%OPC+ 20%CBA	Quantity(kg/m³)	292	1067	739	179	73
	Unit-cost (ETB/kg)	4.80	1.37	1.05	0.004	4.29
	Cost (ETB/m³)	1401.60	1461.80	775.53	0.716	313.17
	Total cost (ETB/m³)	**3952.82**				

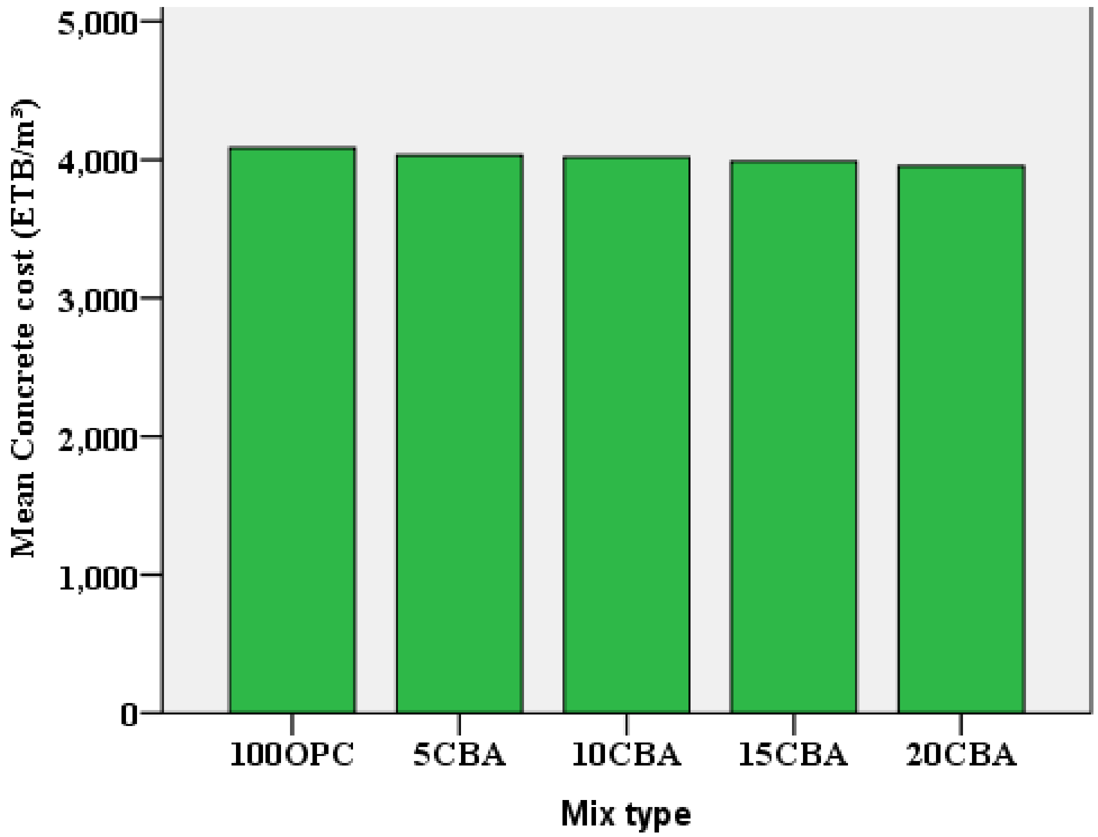

Figure 5-11: Cost Analysis of Concrete Per Meter Cube

From the Table 5-14, as the percentage of cement replacement with the CBA increases, the concrete cost per meter cube decreases. The CBA concrete is cheaper than control(100%OPC) mix concrete. The CBA is 10.63% lesser cost than cost of OPC cement. Even though the CBA material cost is very less(zero), but the processing energy and collection cost escalates the total cost of CBA per kilogram.

The cement replacement with 5% CBA saves 52.6 (ETB per meter cube of concrete) or 1.29% of total cost per meter cube of concrete. Similarly, the partial replacement of cement with 10%CBA, 15%CBA, 20%CBA can save 65.2ETB/m³ (1.6%), 97.3ETB/m³ (2.28%) and 131.1ETB/m³ (3.21%) of total concrete cost per meter cube respectively. Generally, the recycling of bone waste to cementitious material production provides an alternative way of finding low-cost cement material and seeking environmentally friendly construction material, thus helps the way of creating sustainable environment.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Finally, from the study, the following conclusions are drawn from the test results and discussions,

- ✓ Bone ash cannot be considered as pozzolanic material since the percentage sum of silicate aluminate and ferrite is less than 50%. But it can be used as cement additive material since it has high calcium oxide content.
- ✓ As the percentage of bone ash in cement paste increases, the normal consistency of cement paste increases attributed to high water absorption of CBA than OPC.
- ✓ Initial and final setting time of cement paste increases, as the percentage of replacement of cement with cattle bone ash increases due to retarding characteristics of phosphate in CBA and low formation of C_3S in hydration.
- ✓ The cement paste expansion (L_2-L_1) decreases as the percentage of CBA increases, because of the lower calcium oxide content of CBA than OPC cement.
- ✓ Concrete slump decreases as the percentage of replacement of cement with cattle bone ash increases, due to high water absorption capacity of CBA than cement.
- ✓ As the percentage of bone ash in concrete increases, the compressive strength decreases due to low formation of C_3S composition in hydration compared to control mix.
- ✓ The optimum percentage of replacement cement with CBA, without significantly affecting the compressive strength of concrete is 10%, based on 28^{th} day average strength.
- ✓ As the percentage of CBA in concrete increases, the density of concrete decreases because of low unit weight of CBA than cement.

The use of CBA in concrete provides economical concrete and saves natural resources required for cement production.

6.2 Recommendation

- ✓ To compensate for the low silicate content of bone ash, the addition of silicate containing materials with bone ash, such as rice husk ash and glass powder will improve the compressive strength of concrete containing CBA.
- ✓ To increase the economic feasibility of bone ash production, burning and milling should be done with more advanced machines like bone crushing plant to reduce energy consumption per kilogram of ash.

6.3 Areas for Future Studies

The effect of partial replacement of CBA on the durability of normal concrete should be studied to examine its resistance to chemical actions in concrete.

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APPENDICES

A. Appendix 1: Aggregate Quality Tests

1. Fine Aggregate Tests

a. Moisture Content

Objective

The main aim of this test is to determine the moisture content of natural fine aggregate(sand).

Theory

The moisture content of fine aggregate is the total amount of water present in internal pores and on the surface of aggregate. This moisture content affects workability and the compressive strength of concrete. It is subtracted from the water demand for a specific concrete mix design to compensate for the excess water (free moisture) present on the surface of aggregate. The mixing water added to the batch must be reduced by the amount of free moisture contributed by the aggregates. The free moisture content is the difference between total moisture content and absorption. The moisture content will vary based on the fineness of the sand. The finer the sand, the more surface area and consequently it needs more moisture.

Apparatus

- ✓ Dish (Metal tray)
- ✓ Balance
- ✓ Oven
- ✓ Trowel

Procedure

1. Prepared fine aggregate sample by splitter was weighed (A).

2. The sample was oven-dried for about 24 hours at a temperature of 105˚C to 110˚C.

3. The samples were removed from the oven and placed them on the desiccators for about an hour to cool without absorbing water from the atmosphere.

4. The oven dried aggregate was then weighed after cooling (oven dry weight, B).

5. The moisture content of the fine aggregate is then calculated as shown below;

Test Results

A = weight of original sample = 902 g

B = weight of oven dry sample = 893 g

Calculation

Moisture content = $(\frac{A-B}{B})$ *100%

$= (\frac{902\ g - 893\ g}{893\ g})$ *100%

=1.01%

Discussion of results

The free water content of sand should be subtracted from the water content required for concrete mix design to compensate excess water amount in the mix. Free water content is obtained by subtracting absorption from total moisture content.

b. Bulk Density

Objective

This method is used to determine the bulk density (unit weight) of fine aggregate.

Theory

The bulk density is the ratio of total mass of fine aggregate to total volume occupied by aggregate and void between aggregate particles. The unit weight is simply measured by filling a container of known volume and weighing it. The moisture content affects bulk density by varying the mass of aggregate and the degree of compaction will change the amount of void space. Since the weight of the aggregate is dependent on the moisture content of the aggregate, a constant moisture content is required.

Apparatus

- ✓ Balance
- ✓ Tamping rod
- ✓ Cylindrical metal container, provided with known volume

Procedure

1. One-third full fill of Cylindrical metal, aggregate was measured and the surface was leveled with the fingers. the layer of aggregate was rodded with 25 strokes of the tamping rod evenly distributed over the surface. Two-thirds full was filled and measured again and leveled rod as above. Finally, overflowing fill was measured again by rod as above.

2. The surface of the aggregate was leveled with fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregates approximately balance the larger voids in the surface below the top of the measure.

3. In rodding the first layer, striking the bottom of the measure forcibly by rod is not allowed. In rodding the second and third layers, only enough force was used to cause the tamping rod to penetrate the previous layers of aggregate.

4. Weight and its content were measured and the net weight of the aggregate was recorded. Finally, weight is divided by its volume. The result is the compact unit weight of the aggregate.

Test Results

Weight of container = 2961 g

Weight of aggregate + container = 8139 g

Calculation

Weight of container = 2961 g

Weight of aggregate + container = 8139g

Volume of container = 0.003 m^3

$$\text{Bulk unit weight} = \frac{weight\ of\ fine\ aggregate}{volume\ of\ container}$$

$$= \left(\frac{8139\ g - 2961\ g}{0.003\text{m}^3}\right)$$

$$= \frac{5178\ g}{0.003\text{m}^3}\text{x1kg/1000g}$$

$$= 1726\ kg/m^3$$

Discussion of results

According to Steven H. Kosmatka, 2002, The approximate bulk density of aggregate commonly used in normal-weight concrete ranges from about 1280 to 1920 kg/m³. Since the 1726kg/m³ lays between range, fine aggregate density lays within acceptable range.

c. **Absorption Capacity**

Objective

To determine the absorption capacity of fine aggregate.

Theory

Absorption is the process by which a liquid is drawn into and tends to fill permeable pores in a porous solid body; also, the increase in mass of a porous solid body resulting from the penetration of a liquid into its permeable pores. To calculate the mixing water content of concrete, the absorption of the aggregates and their total moisture contents must be known. Absorption is computed as a percentage by subtracting the oven-dry mass from the saturated surface-dry mass, dividing by the oven-dry mass, and multiplying by 100. Absorption capacity is the maximum amount of water the aggregate can absorb under the prevailing circumstances. In Concrete technology, aggregate moisture is expressed as a percent of the dry weight of the aggregate.

Apparatus

- ✓ Balance: A weighing device that is sensitive, readable, and with accuracy of 0.1gram.
- ✓ Sample container: Metallic pan
- ✓ Oven

Procedure

1. A portion of fine aggregate from the sample by use of sample splitter was obtained and soaked in water.
2. The weight of the sand at SSD condition was measured.
3. Using the metallic pan, the sample was dried at a temperature of 100˚C in an oven for 24 hours.

4. Finally, the sample was taken out from the oven and cooled it in a room temperature till it was comfortable to handle, and weighed.

Test Results

A = Weight of the SSD sample in air = 1960 g

B = Weight of the oven dried (OD) sample in air =1932 g

Calculation

$$Absorption = (\frac{A-B}{B})x100\%$$

$$= \left(\frac{1960\ g - 1932\ g}{1960\ g}\right)x100\%$$

$$= 1.45\%$$

Discussion of results

According to Steven H. Kosmatka, 2002, the absorption capacity of the fine aggregate should be in the range of 0.2% to 2%. Since the 1.45% lays in the range, the absorption capacity of sand complies for mix design.

d. Silt Content

Objective

The objective of the test is to determine the silt (finer than No.200 sieve) content of a sand.

Theory

Sand is a natural aggregate obtained from rivers, lakes and marine deposits. These deposits often contain materials (dust, loam and clay) that are finer than sand. The presence of silt in sand used to make concrete decrease the bond between the materials to be bound together and hence the strength of the mixtures. In the hand test, simply picking up a little sample of sand and rubbing it between hands will show the silt content somewhat. If the palm stays clean, the sand is alright from the cleanliness point of view. If it stained, something is wrong silt test must be performed. The finer particles do not only decrease the strength but also the quality of mixture produced resulting in fast deterioration. Therefore, it is necessary that one makes a test on the silt content and checks against permissible limits.

Apparatus

- ✓ Graduated cylinder
- ✓ Dish for taking sample of sand
- ✓ Small size spoon
- ✓ Sample sand
- ✓ Funnel and Clean water (tap water)

Procedure

1. Sand was filled up to 100 cc mark and water added up to 150 cc. To perform this test, more correctly better dissolve one spoon salt in the water (one test spoonful to 250cc is the right proportion).

2. The sample was shaken vigorously for one minute and the last few shakes being in a sidewise direction to level off the sand.

3. A cylinder was allowed to stand for three hours during which time any silt present will settle in a layer on the top of the sand and its thickness can be read off on the cylinder itself.

Test Results

Silt Content (%) = $\frac{A}{B}$ x100%

A = amount of silt deposited above the sand (layer height) = 6 cc

B = amount of clean sand (layer height) = 94 cc

Calculation

Before washing, Silt Content (%) = $\frac{6cc}{94cc}$ x100% = 6.4 %

After washing, Silt Content (%) = $\frac{1cc}{99cc}$ x100% = 1.0 %

Discussion of results

According to the Ethiopian Standard, if the silt content of the sand is more than 6%, it shall not be used for construction. Since silt content of washed sand is less than 6%, it is suitable for concrete production.

e. Gradation

Objective

The objective of the test is to determine the particle size distribution fine aggregate & to determine the fineness modulus of aggregate.

Theory

An aggregate, for concrete making, is any hard, inert material composed of fragments in a wide gradational range of sizes, which is mixed with a cementing material and water to form concrete. Aggregates should be clean, sound, tough, durable and uniform in quality. Sieve analysis is a procedure for the determination of the particle size distribution of aggregates using a series of square or round openings starting with the largest. It is used to determine the grading of aggregate and the fineness modulus, an index to the fineness and coarseness and uniformity of aggregates. This analysis is carried out to classify aggregates as well graded, poorly graded, uniformly graded, gap graded, etc. each of the above aggregate categories has close association with a range of quality of concrete produced using the aggregate.

Apparatus

- ✓ Balance
- ✓ Shovel Sieve
- ✓ Brush and Sieve shaker
- ✓ Series of standard sieves (9.5mm, 4.75 mm, 2.36 mm, 1.18mm,600µm, 300µm & 150µm)

Procedure

1. The samples were prepared with quartering method.

2. Empty sieves and the pan were weighed and recorded after proper cleaning.

3. Having arranging sieves based on their size order, the pan was placed at the bottom of the sieve shaker and the other sieves into the pan with increasing opening sizes of the sieves.

4. The air-dry sample was weighed and sieved successively with the appropriate sieves starting with the largest size sieve. Care was taken to ensure that the sieves were clean before use.

5. Sieving was carried out with a nest of sieves on a sieve shaker for a period of at least 3 minutes.

6. The retained materials on each successive sieve were weighed together with the sieve and recorded.

Test Results and Calculation

Table 7-1: Sieve Analysis of Fine Aggregate (Sand)

Sieve size (mm)	**Sieve weight (g)**	**Sieve + sample weight (g)**	**Retained weight (g)**	**Percentage retained (%)**	**Cumulative percent retained (%)**	**Cumulative percent pass (%)**	**ASTM C-33 limits**		**Remark**
							Min	Max	
9.5	686	688	0	0.00	0.00	100.00	100	100	ok
4.75	726	753	24	4.48	4.48	95.52	95	100	ok
2.36	728	786	58	10.82	15.30	84.70	80	100	ok
1.18	613	693	88	16.42	31.72	68.28	50	85	ok
0.6	604	751	147	27.43	59.14	40.86	25	60	ok
0.3	577	702	125	23.32	82.46	17.54	5	30	ok
0.15	570	610	44	8.21	90.67	9.33	0	10	ok
Pan	273	278	14	2.61	93.28	6.72	-	-	-
Sum of cumulative percent retained					283.77	-			

Sum of cumulative percent retained = 283.77

Fineness modulus = $\frac{\text{Sum of cumulative percent retained}}{100} = \frac{283.77}{100} = 2.84$

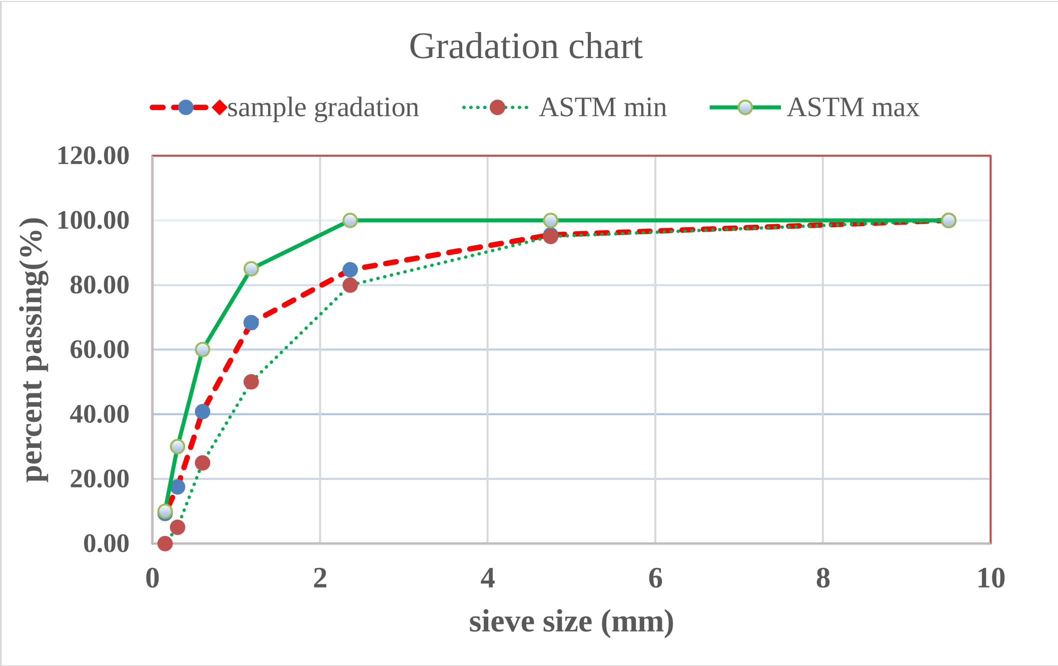

Figure 7-1: Particle Size Distribution of Fine Aggregate

Discussion of results

ASTM 33 recommends that fineness modulus of sand should not be less than 2.3 and nor more than 3.1. The fine aggregate shall have not more than 45% passing any sieve and retained on the next consecutive. Since the fineness modulus of sand sample (2.84) is between 2.3 and 3.1, it complies with the ASTM C33 standard and can be used for mix design.

f. Organic Content

Objective

The objective of this test is to determine the amount of organic matter content in natural fine aggregate.

Theory

Natural aggregates may be sufficiently strong and resistant to wear and yet may not be satisfactory for concrete making if they contain organic impurities, which interfere with the hydration process. The organic matter consists of products of decay of vegetable matter in the form of human or organic loam, which is usually present in sand rather than in coarse aggregate and is easily removed by washing. Besides, there are materials that can prove harmful to the concrete if present in sufficient quantity. A representative sample of fine aggregates is put in a bottle and a solution of NaOH is added in that bottle. Then the bottle is shaken vigorously and allowed to stand for 24 hours. After this period, the color of the liquid retained above the sample is compared with the standard solution color. It should not be darker than the reference color. The darker color means the more organic impurities in the aggregates.

Apparatus

- ✓ Glass Bottles
- ✓ Glass Color Standard
- ✓ Reagent Sodium Hydroxide Solution (3 gram)

Procedure

1. 350 ml clear glass medicine bottle was filled up to 75ml mark with a 3% solution of caustic soda or sodium hydroxide. A 3% solution of caustic soda is made by dissolving 3gram of sodium hydroxide in 100ml of water preferably distilled. The solution should be kept in glass Bottle tightly closed with a rubber stopper.

2. The sand is next added gradually until the volume measured by the sandy layer is 125ml. The volume is then made up to 200 ml by the addition of more of the solution. The bottle is then crocked and shaken vigorously and allowed to stand for 24 hours.

3. At the end of this period, the color of the liquid will indicate whether the sand contains a dangerous amount of matter. A colorless liquid indicates clean sand free from organic matter. A straw-colored solution indicates some organic matter but not enough to be seriously objectionable. Darker color means that the sand contains injurious amounts and should not be used unless it is washed, and a re-test then shows that is satisfactory.

Test Results

The test result indicates that liquid has no color.

Discussion of results

A colorless liquid indicates clean sand free from organic matter and this shows that it is suitable for concrete mix design.

g. Specific Gravity Test

Objective

To determine bulk and apparent specific gravity of fine aggregates.

Theory

The specific gravity is the ratio of the density of a substance to the density of a reference substance(water); equivalently, it is the ratio of the mass of a substance to the mass of a reference substance for the same given volume.

Bulk specific gravity (at SSD) – is the ratio of the weight in air of a unit volume of aggregate, including the weight of water within the voids filled to the extent achieved by submerging in water for approximately 24 hours (but not including the voids between particles) at a stated temperature, compared to the weight in air of an equal volume of gas free distilled water at a stated temperature.

Apparatus

- ✓ Balance to measure weight
- ✓ Water tank – A watertight tanker.
- ✓ Pycnometer – a flask or other suitable container into which the fine aggregate easily introduced.
- ✓ Mold – a metal mold in the form of a frustum of a cone 38mm in top diameter.
- ✓ Tamper

Procedure

1. Prepared sample of fine aggregate (SSD) was added immediately into the pycnometer and filled with water to approximately 90% of the capacity.

2. In order to eliminate all air bubbles the pycnometer was rolled, inverted and agitated. Finally, the level of water was brought to the calibrated capacity of the pycnometer.

3. Then the total weight of the pycnometer, sample and water was determined and recorded(C).

4. The fine aggregate was removed from the pycnometer in order to dry in an oven, and then cooled at a room temperature for about an hour and then the dried sample was weighed(D).

5. The weight of pycnometer and water was measured(B).

Test Results

A= Weight of the sample, SSD = 500 g

B = Pycnometer + water = 1760 g

C= Pycnometer + sand+ water = 2081 g

D= weight of oven dry= 488 g

Calculation

Bulk specific gravity = $\frac{D}{A+B-C}$

$= \frac{488g}{(500+1760-2081)g}$

$= \frac{488\ g}{179\ g} = 2.7$

Discussion of results

The specific gravity of aggregates suitable for concrete is 2.4 to 2.9. Since the calculated specific gravity of the sample lays in range, it can be used for mix design.

2. Coarse Aggregate Tests

- ✓ Gradation
- ✓ Absorption capacity & Specific gravity
- ✓ Bulk unit weight
- ✓ Free moisture content

a. Gradation

Objective

This test method covers the determination of particle size distribution of coarse aggregates by sieving.

Theory

Grading is the particle-size distribution of an aggregate as determined by a sieve analysis. There are several reasons for specifying grading limits and nominal maximum aggregate size; they affect relative aggregate proportions as well as cement and water requirements, workability, pump ability, economy, porosity, shrinkage, and durability of concrete. Variations in grading can seriously affect the uniformity of concrete from batch to batch. Very fine aggregates are often uneconomical; very coarse aggregates can produce harsh, unworkable mixtures. This test is done according to ASTM 136. The maximum nominal size of coarse aggregate used for this study is 25mm.

Apparatus

- ✓ Series of sieves (ASTM standard)
- ✓ Balance
- ✓ Shovel
- ✓ Sieve brush
- ✓ Electromagnetic sieve shaker

Procedure

1. The samples were prepared with quartering method.

2. Empty sieves and the pan were weighed and recorded after proper cleaning.

3. After arranging sieves based on their size order, the pan was placed at the bottom of the sieve shaker and the other sieves into the pan with increasing opening sizes of the sieves.

4. The air-dry sample was weighed and sieved successively with the appropriate sieves starting with the largest size sieve. Care was taken to ensure that the sieves were clean before use.

5. Sieving was carried out with a nest of sieves on a sieve shaker for a period of 2 minutes.

6. The retained materials on each successive sieve were weighed together with the sieve and recorded.

Test Results and calculation

Table 7-2: Coarse Aggregate Sieve Analysis

Sieve size (mm)	Sieve weight (g)	Sieve + sample weight (g)	Retained weight (g)	Percent retained (%)	Cumulative percent retained (%)	Cumulative percent pass (%)	ASTM C-33 limits		Remark
							Min	Max.	
37.5	707	707	0	0.00	0.00	100.00	100	100	Ok
25	711	920	209	4.18	4.18	95.82	95	100	Ok
19	718	2828	2110	42.20	46.38	53.62	-	-	-
12.5	666	1860	1194	23.88	70.26	29.74	25	60	Ok
9.5	688	1132	444	8.88	79.14	20.86	-	-	-
4.75	725	1768	1043	20.86	100.00	0.00	0	10	Ok
pan	-	-	0	0.00	-	100.00	-	-	-

Total sample weight= 5,000 g

$$\text{Fineness modulus} = \frac{\text{Sum of cumulative percent retained}}{100} = \frac{300}{100} = \mathbf{3.0}$$

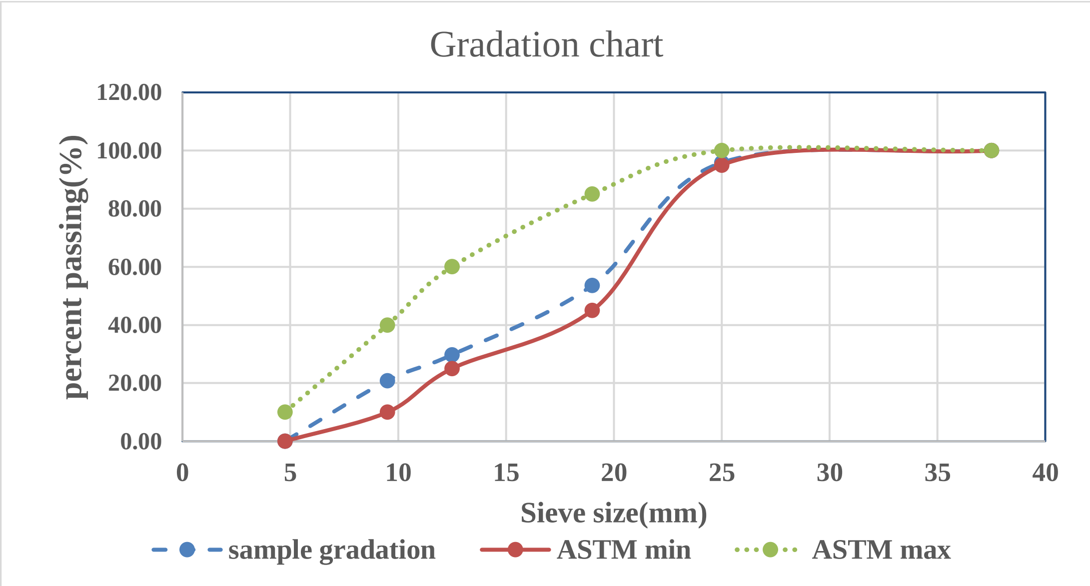

Figure 7-2: Coarse Aggregate Gradation Chart

Discussion of results

As shown in Figure 7-2, coarse aggregate size achieve ASTM C33 maximum and minimum limits for a maximum nominal size of aggregate is 25 mm and minimum size of 4.75mm.

Aggregate used for this test is collected from Meshanti aggregate site that meets ASTM C33 limits.

b. Absorption & Specific Gravity

Objective

This test method covers the determination of absorption and specific gravity of coarse aggregate.

Theory

Absorption– the increase in the weight of aggregate due to water in the pore of the material, but not including water adhering to the outside surface of the particles, expressed as percentage of the dry weight.

Specific gravity– the ratio of the mass (or weight in air) of a unit volume of material to the mass of the same volume of water at stated temperature.

Apparent specific gravity– the ratio of the weight in air of unit volume of the Impermeable portion of the aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

Bulk specific gravity– the ratio of the weight in air of a unit volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids Between particles) at a stated temperature to the weight in air of equal volume of gas-free distilled water at a stated temperature.

Bulk specific gravity (at SSD) – the ratio of the weight in air of a unit volume of aggregate, including the weight of water within the voids filled to the extent achieved by submerging it in water for approximately 24 hours. (but not including the voids between particles) at a stated temperature, compared to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

Apparatus

- ✓ Balance
- ✓ Oven
- ✓ Sample container – a wire basket of No. 6 (3 mm) or finer mush, or bucket, of approximately equal breadth and height with a capacity of 4000 to 7000 cm^3.

- ✓ Suitable apparatus for suspending the sample container in water from the center of the scale pan or balance.

Procedure

1. Aggregate sample was prepared by sample splitter.

2. After thoroughly washing to remove dust from the surface of the particles, the sample was dried to constant weight at a temperature of 110 ± 5˚C for 24 hours, the oven dried sample was then cooled in air at room temperature for 1 to 3 hours., and then measured (A), after that the sample was immersed in water at room temperature for a period of 24 ± 4 hour.

3. The sample was removed from the water and rolled in a large absorbent cloth until all visible firms of water are removed. The larger particles were wiped individually. Care was taken to avoid evaporation of water from aggregate pores during the operation of surface drying.

4. The sample was measured in the SSD in air & recorded (B).

5. Immediately after placing the SSD sample container its weight in water at room temperature was measured. Care was taken to remove all entrapped air by shaking the container while immersed and the test sample was fully immersed before weighing (C).

Test Results

A = weight of oven-dry sample in air = 4,910 g

B = weight of saturated surface dry sample in air = 4,955 g

C = weight of saturated sample in water = 3,162 g

Calculation

Bulk specific gravity in saturated surface dry

$$\text{Specific gravity (SSD)} = \frac{B}{B-C} = \frac{4955\ g}{(4955-3162)g} = \frac{1994\ g}{1793\ g} = 2.76$$

Absorption capacity $= (\frac{B-A}{A}) * 100\% = \frac{(4955-4910)g}{4910\ g} * 100\%$

$$= \frac{45\ g}{4910\ g} * 100\% = 0.9\ \%$$

Discussion of results

According to Steven H. Kosmatka, 2002, Coarse aggregate will generally have absorption levels (moisture contents at SSD) in the range of 0.2% to 4%. Most natural aggregates have relative densities between 2.4 and 2.9. Since the tested coarse aggregate sample satisfies both conditions, it can be used for concrete mix design.

c. **Bulk unit Weight**

Objective

The main aim of this test is to determine bulk unit weight(density) of coarse aggregate.

Theory

Unit weight can be defined as the weight of a given volume of graded aggregate. It is a density measurement and also known as bulk density. It includes the volume of aggregate and the void between them. The moisture content affects bulk density by varying the mass of aggregate and the degree of compaction will change the amount of void space. Since the weight of the aggregate is dependent on the moisture content of the aggregate, a constant moisture content is required.

Apparatus

- ✓ Balance
- ✓ Tamping rod
- ✓ Cylindrical metal container
- ✓ Scoop

Procedure

1. One-third full fill of cylinder, aggregate sample (oven dry) was measured and the surface was leveled with the fingers. the layer of aggregate was rodded with 25 strokes of the tamping rod evenly distributed over the surface. two-thirds full was filled and measured again and leveled rod as above. Finally, overflowing fill was measured again by rod as above.

2. The surface of the aggregate was leveled with fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregates approximately balance the larger voids in the surface below the top of the measure.

3. In rodding the first layer, striking the bottom of the measure forcibly by rod is not allowed. In rodding the second and third layers, only enough force was used to cause the tamping rod to penetrate the previous layers of aggregate.

4. Weight and its content were measured and the net weight of the aggregate was recorded. Finally, weight is divided by its volume. The result is the compact unit weight of the aggregate.

Test Results and Calculation

Weight of container = 1,683 g

Weight of aggregate + container = 25,715 g

Volume of container = 0.015 m^3

Bulk Unit Weight = $\frac{weight\ of\ coarse\ aggregate}{volume\ of\ container}$

$$= \frac{\frac{(25{,}715-1{,}683)g}{1000 g/kg}}{0.015 m^3}$$

$$= 1602.02\ \mathrm{kg/m^3}$$

Discussion of Results

According to Steven H. Kosmatka, 2002, The approximate bulk density of aggregate commonly used in normal-weight concrete ranges from about 1200 to 1750 kg/m^3. Therefore, the sample bulk density satisfies the standard and it is suitable for mix.

d. Free Moisture Content

Objective

The main objective of this test is to determine the moisture content of coarse aggregate.

Theory

Aggregates used for concrete mix design are considered to be inert materials (neither absorb nor contribute water to the mix). But, natural and artificial aggregates from different sources usually don’t comply with the required(inert) state. wet aggregate give water to the mix and drier aggregates (with those below saturation level moisture content) take water from the mix affecting, in both cases, the design water-cement ratio and therefore workability and strength of the mix. In order to correct for these discrepancies, the moisture content of aggregates has to be determined.

Apparatus

- ✓ Oven
- ✓ Balance and Dish

Procedure

1. The sample was prepared by quartering method, weight was measured (A).

2. The sample was oven-dried for about 24 hours. with a temperature of 105 ˚C to 110 ˚C.

3. The samples were removed from the oven and placed them on the desiccators for about an hour in order to cool without absorbing water from the atmosphere.

4. The aggregate was then measured after cooling (oven dry weight, B).

Test Results

A = weight of original sample = 5,000 g

B = weight of oven dry sample = 4,910 g

Calculation

$$W = \left(\frac{A-B}{B}\right)x100\%$$

$$= \left(\frac{5,000g-4,910g}{4,910\ g}\right)x100\%$$

$$= 1.83\%$$

Discussion of results: This moisture content should be deducted from total water required for concrete mix design to compensate for excess water content (greater than absorption capacity).

B. Appendix 2: Cement Tests

1. Normal Consistency of Cement Test

Objective

To determine the percentage of water required to prepare cement paste.

Theory

A cement is a binder material, used for construction that sets, hardens, and adheres to other materials to bind them together. Cement is seldom used on its own, but rather to bind sand and gravel (aggregate) together. Cement mixed with fine aggregate produces mortar for masonry, or with sand and gravel, produces concrete. The normal consistency of hydraulic cement refers to the amount of water required to make a neat paste of satisfactory workability. It is determined using Vicat apparatus.

Apparatus required

- ✓ Vicat apparatus
- ✓ Balance
- ✓ Mixing dish
- ✓ Trowel
- ✓ Graduated jar
- ✓ Mortar Mixer (HOBART)

Procedure

1. 500-gram OPC 42.5R cement and 130gram of water was measured.
2. Prepared cement and water were mixed by a mixer for 3minutes to form cement paste.
3. Having prepared cement paste was filled and leveled to a mold, plunger was lowered gently and brought to contact to the surface of the paste.
4. The screw was tightened by setting the movable indicator to the upper zero mark of the scale and the plunger was released immediately.
5. Thirty seconds after releasing the plunger, its penetration was recorded.
6. The paste is said to be of normal consistency when the rod settles 10±1 mm below the original surface within thirty seconds.
7. The above procedures were repeated with varying the proportion of water until a normal consistency is obtained.

8. The amount of water required for normal consistency is then expressed as a percentage by weight of the dry cement.

Calculation

Percent of water (%) $=\frac{weight\ of\ water\ (g)}{weight\ of\ cement\ (g)}x100\%$

$$=\frac{130g}{500g}x100\%$$

$$=26\%$$

Result and Discussion

The usual range of water-cement ratio for normal consistency is between 26% and 33%. Since the percentage of water is in the range of 26% to 33%, it has good consistency. The needle penetration of the test is 11mm so that this result conforms to the ASTM C187 standard. According to ASTM C187, the paste shall be of normal consistency when the rod settles to a point 10±1 mm below the original surface in 30 seconds after being released. For all other CBA replacement mixes the penetration is between 26% and 33% that meets the requirement.

2. Setting Time Test of Cement

Objective

The objective of this test is to determine the Initial Setting Time and Final Setting Time of cement paste with normal consistency.

Theory

The action of changing mixed cement from a fluid state to a solid state is called setting of cement and the time required for it to set is called setting time of cement. cement paste requires to undergo setting is its setting time. As the setting is the consequence of hydration of cement, setting time is affected by the amount of water used to prepare cement paste, i.e. its water-cement ratio. Cement pastes with different water-cement ratio will, generally, have different setting times. There are two types of setting time to be determined in the laboratory, initial and final setting times. The initial setting time is the duration of cement paste related to 25mm penetration of the Vicat needle into the paste in 30 seconds after it is released while the final setting time is that related to zero penetration of the Vicat needle into the paste. 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.

Apparatus required

- ✓ Vicat apparatus
- ✓ Graduated jar
- ✓ Balance
- ✓ Mixer and trowel

Procedure

1. Cement paste was prepared from normal consistency test.
2. The paste was inserted into conical mold and Excess cement paste trimmed off from mold(ring).
3. The specimen was allowed to remain for 30 minutes after molding without disturbing. The needle was lowered until it rests on the surface of the specimen.
4. The screw was tightened and the indicator at the upper end of the scale was set for taking an initial reading. The rod was released quickly and the needle was allowed to settle for 30 seconds.
5. The penetration of the 1mm (diameter) needle after 30 min was determined and the results of all penetration tests in every 15minutes thereafter until a penetration of 25mm or less is obtained and recorded.

Results and discussion

Table 7-3: Cement Setting Time Test with Different Percentage of CBA

Proportion of material	Initial setting time (minute)	Final setting time(minute)	Standard setting time (minute), ASTM C191		
			Initial setting	Final setting	Remark
100%cement + %CBA	142.5	480	49 to 202	185 to 600	Ok
95%cement + 5%CBA	150	495	49 to 202	185 to 600	Ok
90%cement + 10%CBA	153	540	49 to 202	185 to 600	Ok
85%cement + 15%CBA	160	556	49 to 202	185 to 600	Ok
80%cement + 20%CBA	162	588	49 to 202	185 to 600	Ok

3. Soundness Test of Cement

Objective

The main objective of this test is to determine the expansion of hydraulic cement.

Theory

Cement soundness is the ability of the cement paste to withstand or retain any change in volume after setting and hardening. Lack of soundness or delayed destructive expansion can be caused by excessive amounts of hard burned free lime or magnesia. Cement is a composition of lime (calcium oxide), silica, alumina, magnesia, sulfur trioxide and iron oxide. Among them, lime constitutes 60% to 70%. Hence, a cement deficient in lime will set quickly and will affect the property of the cement. Lime content in higher amount will make the cement unsound. An unsound cement will affect the quality of the cement work performed and this will cause the durability problem of structure made of such cement.

Apparatus required

- ✓ Le- Chatelier mold
- ✓ Glass sheets
- ✓ Mixing pan
- ✓ Trowel
- ✓ Wight
- ✓ Water bath

Procedure

1. Cement paste of standard consistency was prepared by using 500g OPC 42.5R cement.
2. Having mold and glass sheets were oiled lightly, mold was filled with cement paste and glass sheets were attached in the top and bottom of the mold.
3. Small weight was placed on a glass sheet covering and immediately, the whole assembly was submerged in water at a temperature of 27 ± 2°C and kept there for 24 hours.
4. The distance separating the indicator needle points was measured to the nearest 0.5 mm (L_1).
5. Having the assembly was brought to the water boiling at 100˚C in 25 to 30 minutes, it was kept boiling for three hours.
6. Having the assembly was removed from the water and it was allowed to cool in air, the distance between the indicator needle points was measured (L_2).
7. The difference between these two measurements (L_2- L_1) indicates the expansion of the cement.

Test Results and Calculation

Table 7-4: Cement Soundness Test Result

Material proportion	Test	Test result (L_2- L_1) in mm	Average (L_2- L_1) in mm	Remark
100%cement + 0%CBA	1	2	2.5	Ok
	2	3		Ok
95%cement + 5%CBA	1	2	2.0	Ok
	2	2		Ok
90%cement + 10%CBA	1	2	1.75	Ok
	2	1.5		Ok
85%cement + 15%CBA	1	2	1.5	Ok
	2	1		Ok
80%cement + 20%CBA	1	2	1.5	Ok
	2	1		Ok

Discussion

(L_2- L_1) must not exceed 10 mm for ordinary Portland cement. Since in this case, the expansion is less than 10 mm as tested above, the cement is said to be sound and suitable for mix design.

Chemical Analysis of Cattle Bone Ash

Issue Date: -16/07/2019

Customer Name:- Shumet Getahun

Request No:- GLD/RN/376/19

Report No:- GLD/TR/404/19

Sample type:-bone Ash

Sample Preparation: - 200 Mesh

Date Submitted: - 31/05/2019

Number of Sample:- One (1)

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

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

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	SO_3
S-G-01	<0.01	<0.01	<0.01	43.26	0.54	<0.01	<0.01	<0.01	44.67	<0.01	3.63	2.36	0.08

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

NB : - The sample result is above the expected, may be either the sample is synthetic or its sampling ... needs further analysis.

Analysts	Checked By	Approved By	Quality Control
Yirgalem Abriham	Dessie Abebe	Gosa Haile	Negash Worku
Tihitna Beletkachew			
Tizita Zemene			
Yohanis Getachew			
Bethelhem Tefera			

Figure 7-3: Chemical Analysis of CBA

C. Appendix 3: Mix Proportioning for Control Mixes

Mix design is the process of determining the required and specifiable characteristics of a concrete mixture. These characteristics of concrete includes both fresh (slump) and hardened concrete (compressive strength) properties. For this study C-25 non air entrained normal strength concrete was selected and designed as per ACI 211. Data's required for mix design are the following;

a. Aggregate Properties

The data from aggregate test results used for mix design are tabulated as follows;

Table 7-5: Coarse Aggregate Properties

Properties of coarse aggregate	
Nominal maximum aggregate size	25mm
Bulk density	1602 kg/m³
Specific gravity	2.76
Absorption capacity	0.90%
Moisture content	1.83%

Table 7-6: Fine Aggregate Properties

Properties of fine aggregate	
Fineness modulus	2.84
Bulk density	1726 kg/m³
Specific gravity	2.73
Absorption capacity	1.45%
Moisture content	1.01%

b. Grade of concrete

C-25 concrete is taken for this test.

c. Degree of site control

All experimental tests are controlled fairly to get desirable result.

d. **Type of exposure**

Since there is no extreme hot or cold climate, site condition is taken as moderate(normal).

e. **Grade of cement**

OPC 42.5R Dangote cement is used for this experimental test.

Mix design steps

1. **Slump**

Slump is an indicative parameter of the workability of concrete mixtures. Workability is a measure of how easy or difficult it is to place, consolidate, and finish concrete. A slump of 25mm to 50mm (minimum slump) is selected for a test from ACI 211.1.

2. **Maximum size of aggregate**

The nominal maximum size of aggregate is 25mm, based on the selected aggregate sample.

3. **Strength requirements**

For specified 25MPa average compressive strength, the required average compressive strength is taken from ACI 318 when data is not available to establish a Standard deviation. For specified compressive strength 21 to 35 MPa, 8.5 MPa is added as standard deviation margin to get required compressive strength (target mean strength).

Table 7-7: Required average compressive strength when data are not available

Specified compressive strength, $f'c$, MPa	**Required average compressive strength, $f'cr$, MPa**
Less than 21	$f'c + 7.0$
21 to 35	$f'c + 8.5$
Over 35	$1.10 f'c + 5.0$

Adapted from ACI 318

$$f'cr = fc' + 8.5 = 25\ \text{MPa} + 8.5\ \text{MPa} = 33.5\text{MPa}$$

4. **Selection of water to cement ratio (W/C)**

The water-cement ratio is simply the mass of water divided by the mass of cement material (Portland cement). Water cement ratio depends on compressive strength and entrained air in concrete.

Table 7-8: Relation Between Water Cementitious Material Ratio and Compressive Strength

Compressive strength at 28 days, MPa	Water-cementitious materials ratio by mass	
	Non-air-entrained concrete	Air-entrained concrete
45	0.38	0.30
40	0.42	0.34
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

For fcr=33.5MPa, water to cement material ratio for non-air-entrained concrete is determined by linear interpolation between 30 and 35 MPa strength.

Compressive strength (MPa)	W/C
35	0.47
33.5	X
30	0.54

$$W/C=\left(\frac{33.5-35}{35-30}\right)*(0.47-0.54)+0.47=0.491$$

5. Determination of water and air content

The water content of concrete is highly affected by nominal aggregate size and slump(workability) of concrete.

Table 7-9: Approximate Mixing Water and Target Air Content Requirements

Slump, mm	**Water content kilograms per cubic meter of concrete, for indicated nominal maximum Sizes of aggregate**							
	9.5mm	12.5mm	19mm	25mm	37.5mm	50mm	75mm	150mm
	Non-air-entrained concrete							
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	-
Approximate amount of entrapped air in non-air entrained concrete (%)	3	2.5	2	1.5	1	0.5	0.3	0

From the above Table 7-9, for nominal maximum size of aggregate of 25mm, slump 25 to 50mm (minimum range) and non-air entrained concrete, the mixing water requirement is 179kg/m³ and air content is 1.5%.

6. **Cement content**

The cement content can be found by dividing the mixing water content to a water/cementitious materials ratio.

Cement content = $\frac{water\ content}{W/C} = \frac{179\ kg/m^3}{0.491}$ = 365 kg/m³

7. **Coarse aggregate content determination**

The quantity of 25-mm nominal maximum-size coarse aggregate can be estimated from Table 7-10. The bulk volume of coarse aggregate recommended when using sand with a fineness modulus of 2.84 is obtained by linear interpolation between 2.80 and 3.0. Since it has a bulk density of 1602 kg/m³, the oven dry mass of coarse aggregate for a cubic meter of concrete is calculated as follows,

Bulk volume = 0.666m³

Mass= density*volume=1602 kg/m³ x 0.666 m³=1067 Kg/m³

Table 7-10: Bulk Volume of Coarse Aggregate Per Unit volume of Concrete

Nominal maximum size of aggregate, mm(in)	**Bulk volume of dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate***			
	2.4	**2.6**	**2.8**	**3.0**
9.5 (3⁄8)	0.50	0.48	0.46	0.44
12.5 (1⁄2)	0.59	0.57	0.55	0.53
19 (3⁄4)	0.66	0.64	0.62	0.60
25 (1)	0.71	0.69	0.67	0.65
37.5 (11⁄2)	0.75	0.73	0.71	0.69
50 (2)	0.78	0.76	0.74	0.72
75 (3)	0.82	0.80	0.78	0.76
150 (6)	0.87	0.85	0.83	0.81

8. Fine aggregate content determination

At this step, the amounts of all ingredients except the fine aggregate are known. In the absolute volume method, the volume of fine aggregate is determined by subtracting the absolute volumes of the known ingredients from 1 cubic meter.

Volume (m^3)= $\frac{weight(kg)}{specific\ gravity\ x\ density\ of\ water(\frac{kg}{m^3})}$

Water = $\frac{179\ kg}{1x1000(\frac{kg}{m^3})}$ =0.179m^3

Air = 0.015m^3

Cement = $\frac{365\ kg}{3.15x1000(\frac{kg}{m^3})}$ =0.116m^3

Coarse aggregate= $\frac{1067\ kg}{2.76x1000(\frac{kg}{m^3})}$ =0.3866m^3

Volume of concrete= (Water+ Air+ Cement+ Coarse aggregate+ fine aggregate) volume

Volume of fine aggregate =1 m^3- (Water+ Air+ Cement+ Coarse aggregate) volume

=1 m^3-(0.179+0.015+0.116+0.3866) m^3=0.304m^3

Weight of fine aggregate= density x volume=2.73x1000 kg/m^3x0.304m^3=828.3kg/m^3

9. **Moisture adjustment**

Moisture corrections are needed to compensate for moisture in the aggregates. The mixing water added to the batch must be reduced by the amount of free moisture contributed by the aggregates.

Unadjusted weight

Water=179kg/m^3

Cement=365kg/m^3

Fine aggregate=828.3kg/m^3

Coarse aggregate=1067kg/m^3

Adjusted Weight of fine aggregate= (1+moisture content) un adjusted Weight of fine aggregate

Fine aggregate = 828.3kg/m^3+ (1.01) % x828.3kg/m^3 = 828.3kg/m^3+8.37kg/m^3

= 836.7 kg/m^3

Adjusted Weight of coarse aggregate= (1+moisture content) un adjusted Weight of coarse aggregate

Coarse aggregate =1067kg/m^3+(1.83) % x1067kg/m^3= 1067kg/m^3+1.83/100x1067kg/m^3

=1067kg/m^3+19.53kg/m^3

=1086.53 kg/m^3

Water content = 179kg/m^3+828.3kg/m^3 x (1.01-1.45) % +1067kg/m^3 x (1.83-0.9) %

= 179kg/m^3+ 828.3 kg/m^3 x (-0.44/100) +1067 kg/m^3 x (0.93/100)

= 179kg/m^3- 3.64kg/m^3+ 9.92kg/m^3

= 185.3 kg/m^3

Weight of concrete, adjusted = weight of fine aggregate +weight of coarse aggregate +weight of water+ weight of cement

= 836.7 kg/m^3+1086.53 kg/m^3+185.3kg/m^3+365kg/m^3

= 2473.6 kg/m^3

10. Trial mix calculation

Proportion of ingredients for trial mix to six cubes were calculated to find the required quantity of each ingredient by assuming 20% wastage.

Trial mix volume = [0.15*0.15*0.15] m^3*6+20% of wastage x [0.15*0.15*0.15] m^3x6

= 0.02025 m^3+ 0.00405 m^3=0.0243m^3

Weight of ingredients per 0.0243m^3 for control mix (100% cement with 0%CBA)

- ✓ Water weight =185.3kg/m^3x 0.0243m^3 = 4.50kg
- ✓ Cement weight = 365 kg/m^3 x 0.0243m^3 = 8.87kg
- ✓ Coarse aggregate weight = 1086.53 kg/m^3x0.0243m^3= 26.40kg
- ✓ Fine aggregate weight = 836.7kg/m^3x0.0243m^3= 20.33kg

D. Appendix 4: Mix Proportioning for CBA Replaced Concrete

In this case all aggregate properties, concrete grade, degree of control and cement type are the same with control mix, but only difference is the partial replacement of the cement with CBA by 5%,10%,15% and 20%. There is slight weight and volume change of concrete ingredients, due to replacement of CBA in controlled (0%CBA) concrete.

Mix Design Steps

1. **Slump**

A slump of 25mm to 50mm (minimum slump) is selected for a test from ACI 211.1.

2. **Maximum size of aggregate**

The nominal maximum size of aggregate is 25mm, based on the selected aggregate sample.

3. **Strength requirements**

For specified 25MPa average compressive strength, the required average compressive strength is taken from ACI 318 when data is not available to establish a Standard deviation. For specified compressive strength 21 to 35 MPa, 8.5 MPa is added as standard deviation margin to get required compressive strength (target mean strength).

Table 7-11: Required Average Compressive Strength When Data are not available

Specified compressive strength, *f′* c, MPa	**Required average compressive strength, *f′*cr, MPa**
Less than 21	*f′* c + 7.0
21 to 35	*f′* c + 8.5
Over 35	1.10 *f′* c + 5.0

f'cr=fc'+8.5= 25 MPa +8.5 MPa =33.5MPa

4. **Selection of water to cement ratio (W/C)**

The water-cement ratio is simply the mass of water divided by the mass of cement material (Portland cement). Water cement ratio depends on compressive strength and entrained air in concrete.

Table 7-12: Relation Between Water Cementitious Material Ratio & Compressive strength

Compressive strength at 28 days, MPa	**Water-cementitious materials ratio by mass**	
	Non-air-entrained concrete	**Air-entrained concrete**
45	0.38	0.30
40	0.42	0.34
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

For fcr=33.5MPa, water to cement material ratio for non-air-entrained concrete is determined by linear interpolation between 30 and 35 MPa strength.

Compressive strength (MPa)	W/C
35	0.47
33.5	X
30	0.54

W/C=$\left(\frac{33.5-35}{35-30}\right) * (0.47 - 0.54) + 0.47 = 0.491$

5. **Determination of water and air content**

The water content of concrete is highly affected by nominal aggregate size and slump(workability) of concrete.

Table 7-13: Approximate Mixing Water and Target Air Content Requirements

Slump, mm	**Water content kilograms per cubic meter of concrete, for indicated nominal maximum sizes of aggregate**							
	9.5mm	**12.5mm**	**19mm**	**25mm**	**37.5mm**	**50mm**	**75mm**	**150mm**
	Non-air-entrained concrete							
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	-
Approximate amount of entrapped air in non-air entrained concrete (%)	3	2.5	2	1.5	1	0.5	0.3	0

From the above Table 7-13, for nominal maximum size of aggregate of 25mm, slump 25 to 50mm (minimum range) and non-air entrained concrete, the mixing water requirement is 179kg/m³ and air content is 1.5%.

6. **Cement content**

The cement content can be found by dividing the mixing water content by a water/cementitious materials ratio.

Cement content = $\frac{water\ content}{W/C} = \frac{179\ kg/m^3}{0.491}$ = 365 kg/m³

7. **Coarse aggregate content determination**

The quantity of 25-mm nominal maximum-size coarse aggregate can be estimated from Table 7-14, The bulk volume of coarse aggregate recommended when using sand with a fineness modulus of 2.84 is obtained by linear interpolation between 2.80 and 3.0. Since it has a bulk density of 1602 kg/m³, the oven dry mass of coarse aggregate for a cubic meter of concrete is calculated as follows, Bulk volume = 0.666m³

Mass= density*volume=1602 kg/m³ x 0.666 m³=1067 Kg/m³

Table 7-14: Bulk Volume of Coarse Aggregate Per Unit volume of concrete

Nominal maximum size of aggregate, mm(in)	**Bulk volume of dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate***			
	2.4	**2.6**	**2.8**	**3.0**
9.5 (3⁄8)	0.50	0.48	0.46	0.44
12.5 (1⁄2)	0.59	0.57	0.55	0.53
19 (3⁄4)	0.66	0.64	0.62	0.60
25 (1)	0.71	0.69	0.67	0.65
37.5 (11⁄2)	0.75	0.73	0.71	0.69
50 (2)	0.78	0.76	0.74	0.72
75 (3)	0.82	0.80	0.78	0.76
150 (6)	0.87	0.85	0.83	0.81

8. Fine aggregate content determination

At this step, the amounts of all ingredients except the fine aggregate are known. In the absolute volume method, the volume of fine aggregate is determined by subtracting the absolute volumes of the known ingredients from 1 cubic meter.

Volume (m³)= $\frac{weight(kg)}{specific\ gravity\ x\ density\ of\ water(\frac{kg}{m^3})}$

Water = $\frac{179\ kg}{1x1000(\frac{kg}{m^3})}$ =0.179m³

Air = $\frac{1.5}{100}$ =0.015m³

Cement = $\frac{365\ kg}{3.15x1000(\frac{kg}{m^3})}$ =0.116m³

Coarse aggregate= $\frac{1067\ kg}{2.76x1000(\frac{kg}{m^3})}$ =0.3866m^3

Volume calculation for partial replacement of cement with CBA

Cement 100%=365kg/ m^3

CBA 5% = 5%x 365kg/m^3=5/100x365kg=18.25kg/m^3

CBA 5%, Volume= $\frac{18.25kg}{1.3\ x1000(\frac{kg}{m^3})}$ =0.014m^3

Cement with 5%CBA=0.95x365kg=346.8kg/m^3

Cement, with CBA 5%, Volume= $\frac{346.8kg}{3.15\ x1000(\frac{kg}{m^3})}$ =0.11m^3

CBA 10%=10/100x 365kg/m^3 =36.5kg/m^3

CBA 10%, Volume= $\frac{36.5kg}{1.3\ x1000(\frac{kg}{m^3})}$ =0.028m^3

Cement with 10%CBA=0.9x365kg/m^3 =328.5kg/m^3

Cement, with CBA 10%, Volume= $\frac{328.5kg}{3.15\ x1000(\frac{kg}{m^3})}$ =0.104m^3

CBA15%=15/100X 365kg/m^3=54.75kg/m^3

CBA 15%, Volume= $\frac{54.75kg}{1.3\ x1000(\frac{kg}{m^3})}$ =0.042m^3

Cement with 15%CBA=0.85x365kg/m^3=310.3kg/m^3

Cement, with CBA 15%, Volume= $\frac{310.3kg}{3.15\ x1000(\frac{kg}{m^3})}$ =0.099m^3

CBA 20%=20/100x 365kg/m^3=73kg/m^3

CBA 20%, Volume= $\frac{73kg}{1.3\ x1000(\frac{kg}{m^3})}$ =0.056m^3

Cement with 20%CBA=0.80x365kg/m^3=292kg/m^3

Cement, with CBA 20%, Volume= $\frac{292\ kg}{3.15\ x1000(\frac{kg}{m^3})}$ =0.0927m^3

Volume of concrete= (Water+ Air+ Cement+ Coarse aggregate+ fine aggregate) volume

5%CBA

Volume of fine aggregate=1 m^3- (Water+ Air+ Cement+ CBA+ Coarse aggregate) volume

=1 m^3- (0.179+0.015+0.11+0.014+0.3866) m^3

= 0.296m^3

Weight of fine aggregate= density x volume=2.73x1000 kg/m^3x0.296m^3=806.12kg/m^3

10%CBA

Volume of fine aggregate =1 m^3- (Water+ Air+ Cement+ CBA+ Coarse aggregate) volume

=1 m^3- (0.179+0.015+0.104+0.028+0.3866) m^3

= 0.288m^3

Weight of fine aggregate = density x volume=2.73x1000 kg/m^3x0.288m^3=783.24kg/m^3

15%CBA

Volume of fine aggregate =1 m^3- (Water+ Air+ Cement+ CBA+ Coarse aggregate) volume

=1 m^3- (0.179+0.015+0.099+0.042+0.3866) m^3

= 0.278m^3

Weight of fine aggregate = density x volume=2.73x1000 kg/m^3x0.278m^3=761.1kg/m^3

20%CBA

Volume of fine aggregate =1 m^3- (Water+ Air+ Cement+ CBA+ Coarse aggregate) volume

=1 m^3- (0.179+0.015+0.0927+0.056+0.3866) m^3=0.271 m^3

Weight of fine aggregate= density x volume=2.73x1000 kg/m^3x0.271m^3=738.6 kg/m^3

9. Moisture adjustment and trial mix

Moisture adjustment is necessary to determine the required amount of water per mix by considering absorption and moisture content of aggregates.

Generally, all mix design calculation values for different percentages of CBA were analyzed as follows, from Table 7-15 to 7-18.

I. 5% CBA Replacement Mix Design

Table 7-15: 5%CBA Replacement Mix Design

Material density	Cement (kg/m³)	CBA (kg/m³)	Water (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Concrete (kg/m³)
Per m³	346.75	18.25	179	806.12	1067	-
Moisture content (%)	-	-	-	1.01	1.83	-
Free moisture (%)	-	-	-	-0.44	0.93	-
Density (SSD)	-	-	-	814.26	1086.53	-
Adjust. Per m³	346.75	18.25	185.2	814.26	1086.53	2450.99
trial 0.0243 m³	**8.43**	**0.44**	**4.50**	**19.79**	**26.40**	**59.56**

II. 10%CBA Replacement Mix Design

Table 7-16: 10%CBA Replacement Mix Design

Material density	Cement (kg/m³)	CBA (kg/m³)	Water (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Concrete (kg/m³)
Per m³	328.5	36.5	179	783.24	1067	-
Moisture content (%)	-	-	-	1.01	1.83	-
Free moisture (%)	-	-	-	-0.44	0.93	-
Density (SSD)	-	-	-	791.53	1086.53	-
Adjust. Per m³	328.5	36.5	185.3	791.53	1086.53	2428.36
trial 0.0243 m³	**7.98**	**0.89**	**4.50**	**19.23**	**26.40**	**59.01**

III. 15%CBA Replacement Mix Design

Table 7-17:15%CBA Replacement Mix Design

Material density	Cement (kg/m³)	CBA (kg/m³)	Water (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Concrete (kg/m³)
Per m³	310.25	54.75	179	761.1	1067	-
Moisture content (%)	-	-	-	1.01	1.83	-
Free moisture (%)	-	-	-	-0.44	0.93	-
Density (SSD)	-	-	-	768.9	1086.53	-
Adjust. Per m³	310.25	54.75	185.39	768.9	1086.53	2405.82
trial 0.0243 m³	**7.54**	**1.33**	**4.50**	**18.68**	**26.40**	**58.46**

IV. 20%CBA Replacement Mix Design

Table 7-18: 20%CBA Replacement Mix Design

Material density	Cement (kg/m³)	CBA (kg/m³)	Water (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Concrete (kg/m³)
Per m³	292	73	179	738.6	1067	-
Moisture content (%)	-	-	-	1.01	1.83	-
Free moisture (%)	-	-	-	-0.44	0.93	-
Density (SSD)	-	-	-	746.06	1086.53	-
Adjust. Per m³	292	73	185.49	746.06	1086.53	2383.08
trial 0.0243 m³	**7.10**	**1.77**	**4.51**	**18.13**	**26.40**	**57.91**

E. Appendix 5: Compressive Strength Test Results

For all compressive strength tests, 15cmx15cmx15cm cube was used to cast concrete for different curing days. Compressive strength was read from a compressive strength machine, which calculates by dividing the applied load by its effective load area (15cmx15cm).

Table 7-19: 3rd Day Compressive Strength Test Results

3rd day test										
Mix	**Cube 1**			**Cube 2**			**Cube 3**			
	Weight (kg)	**Load (KN)**	**Stress (MPa)**	**Weigh t (kg)**	**Load (KN)**	**Stress (MPa)**	**Weight (kg)**	**Load (KN)**	**Stress (MPa)**	**Average stress (MPa)**
Control (OPC)	8.938	410.4	18.26	8.744	418.1	18.58	8.821	449.6	19.98	18.94
Control (PPC)	8.912	247	10.98	8.908	276.5	12.29	8.706	283.7	12.61	11.96
5% CBA	8.73	297.4	14.22	8.775	433.1	19.25	8.764	414.4	18.42	17.29
10% CBA	8.391	334.3	14.86	8.484	318	14.18	8.458	303	13.56	14.20
15% CBA	8.304	269.5	11.98	8.416	287.1	12.76	8.405	291.2	12.94	12.56
20% CBA	8.342	158.4	7.04	8.316	157.4	6.99	8.344	174.2	7.74	7.26

Table 7-20: 7th Day Compressive Strength Test Results

7th day test										
Mix	**Cube 1**			**Cube 2**			**Cube 3**			
	Weigh t(kg)	**Load (KN)**	**Stress (MPa)**	**Weigh t(kg)**	**Load (KN)**	**stress (MPa)**	**Weigh t(kg)**	**Load (KN)**	**Stress (MPa)**	**Average stress (MPa)**
Control (OPC)	8.496	689.3	30.64	9.319	720.9	32.04	8.913	740.1	32.89	31.86
Control (PPC)	8.946	390.2	17.34	8.964	408.4	18.15	9.013	381.4	16.95	17.48
5% CBA	8.718	513.3	22.81	8.81	455.7	20.25	8.872	566.1	25.16	22.74
10% CBA	8.745	399.7	17.76	8.708	387	17.2	8.832	410.7	18.25	17.74
15% CBA	8.466	309.3	13.75	8.749	231.4	10.28	8.581	314.4	13.97	12.67
20% CBA	8.367	233.6	10.38	8.347	195.3	8.68	8.680	217.6	9.67	9.58

Table 7-21: 28th Day Compressive Strength Test Results

28th day test										
Mix	**Cube 1**			**Cube 2**			**Cube 3**			
	Weigh t(kg)	**Load (KN)**	**Stress (MPa)**	**Weigh t(kg)**	**Load (KN)**	**stress (MPa)**	**Weig ht(kg)**	**Load (KN)**	**Stress (MPa)**	**Average stress (MPa)**
Control (OPC)	9.068	993.9	44.17	9.140	952.3	42.33	9.130	826	36.71	41.07
Control (PPC)	8.740	688.5	30.6	9.023	784.4	33.26	8.938	735.4	32.69	32.18
5% CBA	8.878	747	33.2	8.813	788.9	35.06	8.906	822.3	36.55	34.94
10% CBA	8.505	614.5	27.3	8.791	664	29.51	8.496	579.4	25.75	27.52
15% CBA	8.408	540.7	24.03	8.503	461.7	20.52	8.413	502.3	22.32	22.29
20% CBA	8.380	383.7	17.05	8.299	378.1	16.8	8.270	367.5	16.33	16.72

Table 7-22: 56th Day Compressive Strength Test Results

56th day test										
Mix	**Cube 1**			**Cube 2**			**Cube 3**			
	Weigh t(kg)	**Load (KN)**	**Stress (MPa)**	**Weigh t (kg)**	**Load (KN)**	**stress (MPa)**	**Weigh t(kg)**	**Load (KN)**	**Stress (MPa)**	**Average stress (MPa)**
Control (OPC)	9.082	1058.2	47.03	9.010	1079.7	47.99	9.038	969.2	43.07	46.02
Control (PPC)	8.962	868.5	38.6	8.925	737.1	32.76	8.889	837.3	37.21	36.19
5% CBA	8.736	808.4	35.93	8.97	861.4	38.28	8.928	728.7	32.39	35.53
10% CBA	8.650	677.3	30.10	8.542	726.9	32.3	8.478	707.6	31.45	31.28
15% CBA	8.389	540.9	24.04	8.338	497.7	22.12	8.442	505.8	22.48	22.88
20% CBA	8.361	424.7	18.88	8.388	402.5	17.89	8.130	369.1	16.41	17.73

F. Appendix 6: SPSS Analysis Results

Table 7-23: Descriptive Statistics

Descriptive statistics									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
3rd day compressive strength (MPa)	PPC 100%	3	11.960	0.863	0.4986	9.8146	14.1054	10.98	12.61
	OPC 100%	3	18.940	0.914	0.5281	16.666	21.2124	18.26	19.98
	5% CBA	3	17.297	2.696	1.5568	10.599	23.9954	14.22	19.25
	10% CBA	3	14.200	0.650	0.3754	12.585	15.8153	13.56	14.86
	15% CBA	3	12.560	0.510	0.2946	11.292	13.8276	11.98	12.94
	20% CBA	3	7.257	0.419	0.2421	6.2150	8.2983	6.99	7.74
	Total	18	13.702	4.050	0.9546	11.688	15.7164	6.99	19.98
7th day compressive strength (MPa)	PPC 100%	3	17.480	0.612	0.3534	15.959	19.0006	16.95	18.15
	OPC 100%	3	31.857	0.136	0.6559	29.034	34.6790	30.64	32.89
	5% CBA	3	22.740	2.456	1.4178	16.639	28.8404	20.25	25.16
	10% CBA	3	17.737	.5254	0.3033	16.431	19.0418	17.20	18.25
	15% CBA	3	12.667	2.069	1.1950	7.525	17.8084	10.28	13.97
	20% CBA	3	9.577	0.854	0.4929	7.4558	11.6982	8.68	10.38

	Total	18	18.676	7.516	1.7716	14.9385	22.4138	8.68	32.89
28th day compressive strength (MPa)	PPC 100%	3	32.183	1.400	.80859	28.7043	35.6624	30.60	33.26
	OPC 100%	3	41.070	3.886	2.2438	31.4158	50.7242	36.71	44.17
	5% CBA	3	34.937	1.678	0.9690	30.7673	39.1060	33.20	36.55
	10% CBA	3	27.520	1.889	1.0909	22.8259	32.2141	25.75	29.51
	15% CBA	3	22.290	1.755	1.0133	17.9299	26.6501	20.52	24.03
	20% CBA	3	16.727	0.365	0.2110	15.8186	17.6348	16.33	17.05
	Total	18	29.121	8.470	1.9967	24.9087	33.3335	16.33	44.17
56th day compressive strength (MPa)	PPC 100%	3	36.190	3.050	1.7613	28.6117	43.7683	32.76	38.60
	OPC 100%	3	46.030	2.607	1.5057	39.5514	52.5086	43.07	47.99
	5% CBA	3	35.533	2.964	1.7118	28.1679	42.8987	32.39	38.28
	10% CBA	3	31.283	1.109	0.6405	28.5274	34.0393	30.10	32.30
	15% CBA	3	22.947	1.134	0.6549	20.1286	25.7647	22.12	24.24
	20% CBA	3	17.727	1.243	0.7177	14.6387	20.8146	16.41	18.88
	Total	18	31.618	9.685	2.2827	26.8021	36.4345	16.41	47.99

Table 7-24: Analysis of Variables Between Groups

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
3rd day compressive strength (MPa)	Between Groups	259.462	5	51.892	32.054	0.00
	Within Groups	19.427	12	1.619		
	Total	278.889	17			
7th day compressive strength (MPa)	Between Groups	934.388	5	186.878	86.347	0.00
	Within Groups	25.971	12	2.164		
	Total	960.359	17			
28th day compressive strength (MPa)	Between Groups	1166.471	5	233.294	52.490	0.00
	Within Groups	53.334	12	4.445		
	Total	1219.805	17			
56th day compressive strength (MPa)	Between Groups	1536.636	5	307.327	63.668	0.00
	Within Groups	57.925	12	4.827		
	Total	1594.560	17			

Table 7-25: Post Hoc Tests (Multiple comparisons)

Multiple Comparisons							
Tukey HSD							
Dependent Variable	(I) percentage replacement of CBA	(J) percentage replacement of CBA	Me Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
3rd day compressive strength (MPa)	PPC 100%	OPC 100%	-6.98000*	1.03888	0.000	-10.469	-3.4905
		5% CBA	-5.33667*	1.03888	0.003	-8.8262	-1.8472
		10% CBA	-2.24000	1.03888	0.323	-5.7295	1.2495
		15% CBA	-0.60000	1.03888	0.991	-4.0895	2.8895

		20% CBA	4.70333*	1.03888	0.007	1.2138	8.1928
	OPC 100%	PPC 100%	6.98000*	1.03888	0.000	3.4905	10.4695
		5% CBA	1.64333	1.03888	0.624	-1.8462	5.1328
		10% CBA	4.74000*	1.03888	0.007	1.2505	8.2295
		15% CBA	6.38000*	1.03888	0.001	2.8905	9.8695
		20% CBA	11.68333*	1.03888	0.000	8.1938	15.1728
	5% CBA	PPC 100%	5.33667*	1.03888	0.003	1.8472	8.8262
		OPC 100%	-1.64333	1.03888	0.624	-5.1328	1.8462
		10% CBA	3.09667	1.03888	0.093	-0.3928	6.5862
		15% CBA	4.73667*	1.03888	0.007	1.2472	8.2262
		20% CBA	10.04000*	1.03888	0.000	6.5505	13.5295
	10% CBA	PPC 100%	2.24000	1.03888	0.323	-1.2495	5.7295
		OPC 100%	-4.74000*	1.03888	0.007	-8.2295	-1.2505
		5% CBA	-3.09667	1.03888	0.093	-6.5862	0.3928
		15% CBA	1.64000	1.03888	0.626	-1.8495	5.1295
		20% CBA	6.94333*	1.03888	0.000	3.4538	10.4328
	15% CBA	PPC 100%	0.60000	1.03888	0.991	-2.8895	4.0895
		OPC 100%	-6.38000*	1.03888	0.001	-9.8695	-2.8905
		5% CBA	-4.73667*	1.03888	0.007	-8.2262	-1.2472
		10% CBA	-1.64000	1.03888	0.626	-5.1295	1.8495
		20% CBA	5.30333*	1.03888	0.003	1.8138	8.7928
	20% CBA	PPC 100%	-4.70333*	1.03888	0.007	-8.1928	-1.2138
		OPC 100%	-11.6833*	1.03888	0.000	-15.173	-8.1938
		5% CBA	-10.0400*	1.03888	0.000	-13.529	-6.551
		10% CBA	-6.94333*	1.03888	0.000	-10.433	-3.4538
		15% CBA	-5.30333*	1.03888	0.003	-8.7928	-1.8138

7th day compressive strength (MPa)	PPC 100%	OPC 100%	-14.3767*	1.20119	0.000	-18.414	-10.342
		5% CBA	-5.26000*	1.20119	0.009	-9.2947	-1.2253
		10% CBA	-0.25667	1.20119	1.000	-4.2914	3.7780
		15% CBA	4.81333*	1.20119	0.017	0.7786	8.8480
		20% CBA	7.90300*	1.20119	0.000	3.8683	11.9377
	OPC 100%	PPC 100%	14.37667*	1.20119	0.000	10.3420	18.4114
		5% CBA	9.11667*	1.20119	0.000	5.0820	13.1514
		10% CBA	14.12000*	1.20119	0.000	10.0853	18.1547
		15% CBA	19.19000*	1.20119	0.000	15.1553	23.2247
		20% CBA	22.27967*	1.20119	0.000	18.2450	26.3144
	5% CBA	PPC 100%	5.26000*	1.20119	0.009	1.2253	9.2947
		OPC 100%	-9.11667*	1.20119	0.000	-13.152	-5.0820
		10% CBA	5.00333*	1.20119	0.013	0.9686	9.0380
		15% CBA	10.07333*	1.20119	0.000	6.0386	14.1080
		20% CBA	13.16300*	1.20119	0.000	9.1283	17.1977
	10% CBA	PPC 100%	0.25667	1.20119	1.000	-3.7780	4.2914
		OPC 100%	-14.1200*	1.20119	0.000	-18.155	-10.085
		5% CBA	-5.00333*	1.20119	0.013	-9.0380	-0.9686
		15% CBA	5.07000*	1.20119	0.012	1.0353	9.1047
		20% CBA	8.15967*	1.20119	0.000	4.1250	12.1944
	15% CBA	PPC 100%	-4.81333*	1.20119	0.017	-8.8480	-0.7786
		OPC 100%	-19.1900*	1.20119	0.000	-23.225	-15.155
		5% CBA	-10.0733*	1.20119	0.000	-14.108	-6.0386
		10% CBA	-5.07000*	1.20119	0.012	-9.1047	-1.0353
		20% CBA	3.08967	1.20119	0.178	-.9450	7.1244
	20% CBA	PPC 100%	-7.90300*	1.20119	0.000	-11.938	-3.8683

		OPC 100%	-22.2797*	1.20119	0.000	-26.314	-18.245
		5% CBA	-13.1630*	1.20119	0.000	-17.198	-9.1283
		10% CBA	-8.15967*	1.20119	0.000	-12.194	-4.1250
		15% CBA	-3.08967	1.20119	0.178	-7.1244	0.9450
28th day compressive strength (MPa)	PPC 100%	OPC 100%	-8.88667*	1.72134	0.002	-14.669	-3.1048
		5% CBA	-2.75333	1.72134	0.614	-8.5352	3.0285
		10% CBA	4.66333	1.72134	0.144	-1.1185	10.4452
		15% CBA	9.89333*	1.72134	0.001	4.1115	15.6752
		20% CBA	15.45667*	1.72134	0.000	9.6748	21.2385
	OPC 100%	PPC 100%	8.88667*	1.72134	0.002	3.1048	14.6685
		5% CBA	6.13333*	1.72134	0.035	0.3515	11.9152
		10% CBA	13.55000*	1.72134	0.000	7.7682	19.3318
		15% CBA	18.78000*	1.72134	0.000	12.9982	24.5618
		20% CBA	24.34333*	1.72134	0.000	18.5615	30.1252
	5% CBA	PPC 100%	2.75333	1.72134	0.614	-3.0285	8.5352
		OPC 100%	-6.13333*	1.72134	0.035	-11.915	-0.3515
		10% CBA	7.41667*	1.72134	0.010	1.6348	13.1985
		15% CBA	12.64667*	1.72134	0.000	6.8648	18.4285
		20% CBA	18.21000*	1.72134	0.000	12.4282	23.9918
	10% CBA	PPC 100%	-4.66333	1.72134	0.144	-10.445	1.1185
		OPC 100%	-13.5500*	1.72134	0.000	-19.332	-7.7682
		5% CBA	-7.41667*	1.72134	0.010	-13.199	-1.6348
		15% CBA	5.23000	1.72134	0.085	-0.5518	11.0118
		20% CBA	10.79333*	1.72134	0.000	5.0115	16.5752
	15% CBA	PPC 100%	-9.89333*	1.72134	0.001	-15.675	-4.1115
		OPC 100%	-18.7800*	1.72134	0.000	-24.562	-12.998

		5% CBA	-12.6467*	1.72134	0.000	-18.429	-6.8648
		10% CBA	-5.23000	1.72134	0.085	-11.012	0.5518
		20% CBA	5.56333	1.72134	0.062	-0.2185	11.3452
	20% CBA	PPC 100%	-15.4567*	1.72134	0.000	-21.239	-9.6748
		OPC 100%	-24.3433*	1.72134	0.000	-30.125	-18.562
		5% CBA	-18.2100*	1.72134	0.000	-23.992	-12.428
		10% CBA	-10.7933*	1.72134	0.000	-16.575	-5.0115
		15% CBA	-5.56333	1.72134	0.062	-11.345	0.2185
56th day compressive strength (MPa)	PPC 100%	OPC 100%	-9.84000*	1.79389	0.001	-15.866	-3.8145
		5% CBA	0.65667	1.79389	0.999	-5.3689	6.6822
		10% CBA	4.90667	1.79389	0.138	-1.1189	10.9322
		15% CBA	13.24333*	1.79389	0.000	7.2178	19.2689
		20% CBA	18.46333*	1.79389	0.000	12.4378	24.4889
	OPC 100%	PPC 100%	9.84000*	1.79389	0.001	3.8145	15.8655
		5% CBA	10.49667*	1.79389	0.001	4.4711	16.5222
		10% CBA	14.74667*	1.79389	0.000	8.7211	20.7722
		15% CBA	23.08333*	1.79389	0.000	17.0578	29.1089
		20% CBA	28.30333*	1.79389	0.000	22.2778	34.3289
	5% CBA	PPC 100%	-0.65667	1.79389	0.999	-6.6822	5.3689
		OPC 100%	-10.4967*	1.79389	0.001	-16.522	-4.4711
		10% CBA	4.25000	1.79389	0.240	-1.7755	10.2755
		15% CBA	12.58667*	1.79389	0.000	6.5611	18.6122
		20% CBA	17.80667*	1.79389	0.000	11.7811	23.8322
	10% CBA	PPC 100%	-4.90667	1.79389	0.138	-10.932	1.1189
		OPC 100%	-14.7467*	1.79389	0.000	-20.772	-8.7211
		5% CBA	-4.25000	1.79389	0.240	-10.275	1.7755

		15% CBA	8.33667*	1.79389	0.006	2.3111	14.3622
		20% CBA	13.55667*	1.79389	0.000	7.5311	19.5822
	15% CBA	PPC 100%	-13.2433*	1.79389	0.000	-19.269	-7.2178
		OPC 100%	-23.0833*	1.79389	0.000	-29.109	-17.058
		5% CBA	-12.5867*	1.79389	0.000	-18.612	-6.5611
		10% CBA	-8.33667*	1.79389	0.006	-14.362	-2.3111
		20% CBA	5.22000	1.79389	0.105	-.8055	11.2455
	20% CBA	PPC 100%	-18.4633*	1.79389	0.000	-24.489	-12.438
		OPC 100%	-28.3033*	1.79389	0.000	-34.329	-22.278
		5% CBA	-17.8067*	1.79389	0.000	-23.832	-11.781
		10% CBA	-13.5567*	1.79389	0.000	-19.522	-7.5311
		15% CBA	-5.22000	1.79389	0.105	-11.245	0.8055
*. The mean difference is significant at the 0.05 level.							

Table 7-26: Homogenous Subsets Test

3rd day compressive strength (MPa)					
Tukey HSD[a]					
percentage replacement of CBA	N	Subset for alpha = 0.05			
		1	2	3	4
20% CBA	3	7.2567			
PPC 100%	3		11.9600		
15% CBA	3		12.5600		
10% CBA	3		14.2000	14.2000	
5% CBA	3			17.2967	17.2967
OPC 100%	3				18.9400
Sig.		1.000	0.323	0.093	0.624
Means for groups in homogeneous subsets are displayed.					
a. Uses Harmonic Mean Sample Size = 3.000.					

7th day compressive strength (MPa)					
Tukey HSD[a]					
percentage replacement of CBA	N	Subset for alpha = 0.05			
		1	2	3	4
20% CBA	3	9.5770			
15% CBA	3	12.6667			
PPC 100%	3		17.4800		
10% CBA	3		17.7367		
5% CBA	3			22.7400	
OPC 100%	3				31.8567
Sig.		0.178	1.000	1.000	1.000
Means for groups in homogeneous subsets are displayed.					
a. Uses Harmonic Mean Sample Size = 3.000.					

28th day compressive strength (MPa)						
Tukey HSD[a]						
percentage replacement of CBA	N	Subset for alpha = 0.05				
		1	2	3	4	5
20% CBA	3	16.7267				
15% CBA	3	22.2900	22.2900			
10% CBA	3		27.5200	27.5200		
PPC 100%	3			32.1833	32.1833	
5% CBA	3				34.9367	
OPC 100%	3					41.0700
Sig.		0.062	0.085	0.144	0.614	1.000
Means for groups in homogeneous subsets are displayed.						
a. Uses Harmonic Mean Sample Size = 3.000.						

56th day compressive strength (MPa)		
Tukey HSD[a]		
	N	Subset for alpha = 0.05

percentage replacement of CBA		1	2	3
20% CBA	3	17.7267		
15% CBA	3	22.9467		
10% CBA	3		31.2833	
5% CBA	3		35.5333	
PPC 100%	3		36.1900	
OPC 100%	3			46.0300
Sig.		0.105	0.138	1.000
Means for groups in homogeneous subsets are displayed.				
a. Uses Harmonic Mean Sample Size = 3.000.				

G. Appendix 7: Assessment on Availability of Cattle Bone Waste in Bahir Dar

In January 2019, there were 217 registered meet shops in Bahir Dar city. These shops get meat from informal slaughtering centers and sell to their customers. There is one governmental slaughtering house in Bahir Dar city. (source Bahir Dar city Administration)

Bahir Dar city administration slaughter service provides 15 to 17 beef /day meat to Bahir Dar University and Amhara leadership academy on Saturday and Wednesday/week to each. Total supply was 2840 cows and oxen are slaughtered per year, from this total 90% of slaughtered animals in Bahir Dar city Administration Abattoir service (kerra) are oxen. In addition to the above meat consumption, local people highly use meat for ceremonies, holidays, weddings and other cultural occasions. One cattle has an average of 400kg weight which is covered by 20% bone of weight, 45% raw meat, 35% interior food, intestine and other waste tissues. Bahir Dar city slaughtered animal wastes are disposed to Sebtamit solid waste disposing site, which is found in 5km far in south direction from Bahir Dar.

This data (Table 7-27) is collected by using purposive interviewing local butchers and Bahir Dar city administration slaughter service, about their annual work on cattle slaughter based on the effective working days (excluding fastening days).

Table 7-27: Number of cattle Slaughtered Per Year in Bahir Dar

Locations	**Number of cattle slaughtered per Year**
Kebele 07 (Around Selassie church)	2733
Kebele 13 (near Felege Hiowt hospital)	4628
Kebele 14	1355
Kebele 16 (near to police commission)	1570
Bahir Dar city Administration Abattoir service (kerra)	2840
Total	**11,626**

Total number of cattle slaughtered per year=<u>13,126</u>

Average weight of cattle =400kg, Percentage of bone waste per cattle =20%

Total bone waste kg per year = total number of cattle slaughtered per year **x** Percentage of bone waste per cattle **x** average weight of cattle

Total bone waste ton per year = 13,126 cattle **x** 0.2 **x** 400kg/cattle

= 1,050,080 kg

= 1,050,080 kg **x** 1ton/1000kg

= **<u>1,050.08-ton bone</u>**

H. Appendix 8: Some Photos During the Research Work

Figure 7-4: Aggregate Selection in Bahir Dar(left) & Aggregate gradation test (right)

Figure 7-5: Selected Lalibela Sand in Bahir Dar (left) and Silt Content Test (right)

Figure 7-6: Concrete Mixing (left) and Slump Measurement (right)

Figure 7-7: Hardened Concrete (left) and Concrete Compressive Strength Test(right)