Experimental Investigation on Common Bean Straw Ash as A Partial Replacement of Cement in Non-structural Concrete

Adem Bedaso Wako

A Thesis Submitted to the Department of Civil Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement of Masters of Science in Civil Engineering (Specialization in Construction Engineering and Management)

Office of Graduate Studies

Adama Science and Technology University

June, 2022

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DECLARATION

I hereby declare that this Master Thesis **"Experimental Investigation on Common Bean Straw Ash as a Partial Replacement of Cement in Non-Structural Concrete,"** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Adem Bedaso Wako ____________________ ________________

Name of the student Signature Date

RECOMMENDATION

I, the principal advisor/supervisor of this thesis, hereby certify that I have closely advised/supervised the student while developing this thesis and read the draft thesis entitled **"Experimental Investigation on Common Bean Straw Ash as A Partial Replacement of Cement in Non-structural Concrete,"** prepared under my guidance by Adem Bedaso Wako.

Therefore, I recommend submitting the thesis to the department for further review and evaluation.

Fikreyesus Demeke (Ph.D.)	_______________	________________
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APPROVAL PAGE OF ADVISOR

I, the advisor of the thesis entitled, **"Experimental Investigation on Common Bean Straw Ash as A Partial Replacement of Cement in Non-structural Concrete,"** and developed by Adem Bedaso Wako, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Fikreyesus Demeke (Ph.D.)	________________________	________________
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APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the thesis by Adem Bedaso Wako have read and evaluated the thesis entitled **"Experimental Investigation on Common Bean Straw Ash as A Partial Replacement of Cement in Non-structural Concrete,"** and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Civil Engineering (Specialization in Construction Engineering and Management).

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ABSTRACT

Cement is one of the most expensive and environmentally unfriendly concrete ingredients. Its manufacturing depletes natural resources, emits carbon dioxide, and raises cost. However, using supplementary cementitious materials derived from agricultural waste products as a partial cement replacement in concrete helps to reduce the environmental and economic impacts of cement production. Therefore, the current study aimed to investigate the use of common bean straw ash as a partial cement replacement in non-structural concrete production, along with its effect on the workability, compressive strength, water absorption, and microstructure of concrete, including its environmental and economic implications. Common bean straw ash was prepared from common bean straw, and its chemical composition investigated through a complete silica analysis. The American Concrete Institute's mix design method was used to develop concrete mix design for C-15 concrete grade. The control mix was made from a mixture of cement, water, and fine and coarse aggregate, whereas the replacement mix was made with common bean straw ash added at 5, 10, and 15% of the cement by weight. As a result, common bean straw ash is classified as a pozzolanic material with a high silicon dioxide content. Due to the extra water demand of the ash, the workability of the concrete decreased as the amount of common bean straw ash in the concrete mix increased. The compressive strength of concrete was improved by 3.65 %t for 5% replacement at 28 days of curing as compared to control mix. This is due to the formation of additional calcium silicate hydrate gel in the concrete. However, it decreased at 10 and 15% replacement due to the water-absorbent of the ash and reduction in cement amount. As a result, concrete with 5% replacement had the maximum compressive strength. Furthermore, water absorption of the concrete increased as the percentage of replacement increased because of the porous surface of the ash. In comparison to the control mix, microstructural analysis of the concrete indicated more calcium silicate hydrate gels at 5% replacement. In conclusion, based on the findings of the current study, common bean straw ash can be utilized as a partial replacement for cement, enhancing the compressive strength of concrete while reducing the environmental impact of cement manufacturing.

Keywords/terms*: Cement; Common bean straw ash; Concrete; Compressive strength*

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LIST OF ACRONYMS

ACI	American Concrete Institute	LHC	Low Heat Cement
AEC	Air entraining Cement	LOI	Loss of Ignition
ASTM	American Society for Testing and Materials	OPC	Ordinary Portland Cement
AWP	Agricultural Waste Product	PC	Portland Cement
BTSA	Brown Teff Straw Ash	PPC	Portland Pozzolana Cement
BFSC	Blast Furnace Slag Cement	QSC	Quick Setting Cement
CBS	Common Bean Straw	RHA	Rice Husk Ash
CBSA	Common Bean Straw Ash	RHC	Rapid Hydration Cement
EDS	Energy Dispersive Spectroscopy	SCM	Supplementary Cementitious Material
FAO	Food and Agricultural organization of the United Nations	SCBA	Sugar Cane Bagasse Ash
GDP	Gross Domestic Product	SEM	Scanning Electron Microscope
GHG	Green House Gas	SRC	Sulfate Resistance Cement
HAC	High Alumina Cement	SSD	Saturated Surface Dry
IS	International Standard	WAB	Waste Agricultural Biomass
LBPA	Locust Bean Pod Ash	TSA	Teff Straw Ash
LEED	Leadership in Energy and Environmental Design	XRD	X-Ray Diffraction

LIST OF CHEMICAL FORMULAS

Al	Aluminum	C_4AF	TetraCalcium Alumino Ferrite
Al_2O_3	Aluminum Oxide	C-S-H	Calcium Silica Hydrate
Ca	Calcium	CH	Calcium Hydroxide
CaO	Calcium Oxide	CO_2	Carbon Dioxide
$CaCO_3$	Calcium Carbonate	Fe	Iron
Ca_3SiO_5	Alite	Fe_2O_3	Iron Oxide
Ca_2SiO_5	Belite	K_2O	Potassium Oxide
Ca_2AlFeO_5	Ferrite	MgO	Magnesium Oxide
$Ca_3Al_{12}O_6$	Aluminate	Na_2O	Sodium Oxide
C_2S	Dicalcium Silicate	Si	Silicon
C_3S	Tricalcium Silicate	SiO_2	Silicon Oxide
C_3A	Tricalcium Aluminate	SO_3	Sulfur Trioxide

1. INTRODUCTION

1.1. Background of the Study

Today, on a global scale, the construction industry is booming because it plays a pivotal role in its development. The construction industry is critical to the economic development of developing countries. This industry contributes highly to economies in terms of gross domestic product (GDP) and employment. Hence, talking about construction is indirectly speaking about concrete.

Concrete is the most widely used building material in the construction industry due to its high strength and durability. Besides, it is easy to shape, fits, non-flammable, affordable, and available on site. A major benefit of concrete is its favorable mechanical and physical properties when properly designed and produced (Snellings et al., 2012). It is a coarse-grained composite material contained in an inflexible material matrix that fills the gap between aggregate particles and binds them together (Gagg, 2014). In some cases, the paste additionally comprises additives and chemical admixtures in addition to cement and water. While the aggregate is composed of fine and coarse aggregates. The paste joins the aggregate, which is a relative filler and accounts for 70-80 % of concrete (Demissew et al., 2019). From concrete ingredients, the environmentally unfriendly and costliest is cement.

Cement is a building material that is widely utilized in the construction industry. Cement manufacturing is an environmentally unfriendly procedure because of carbon dioxide (CO_2) gases released into the surroundings and natural resource degradations (Abubakar et al., 2020). The cement industry is the third-largest industrial electricity consumption in the world. It utilizes 8% of the industry's total electricity and is the second-largest industrial CO_2 emitter, responsible for nearly 8% of total global emissions (Akpenpuun et al., 2019). The manufacturing of Portland clinker is an energy-in depth process, wherein raw substances are burned at 1450°C (Babor et al., 2009). According to global cement production Statista annual global cement production reached around 2.8 billion tons per year in 2015, which increased to 4.1 billion tons in 2019 (Miller & Moore, 2020). This significant increase in cement manufacturing creates issues such as increased energy costs, insufficient requirements to minimize carbon dioxide emissions, and a shortage of raw material supply (Aprianti et al., 2015).

The construction cost is kept high due to the excessive reliance on the building for cement-based concrete as a binder. This discourages developing countries from building homes for their largest proportion of average-income people (Adama & Jimoh, 2012). For this reason, the necessity to decrease the sky scraping cost of cement to supply sustainable and cost-effective structure for the public and private sectors. This led researchers to focus on some nearby obtainable construction materials that can be used as a partial replacement for cement in construction industries (Demissew et al., 2019). Supplementary cementitious materials (SCMs) had been proffered as a solution via their powerful and successful utilization in construction materials. The adoption of SCMs in construction also results in a great discount on carbon emissions (Akpenpuun et al., 2019).

SCMs are utilized in concrete production as cement replacement or cement manufacturing as partial clinker replacement. These SCMs are by-products of various sectors, such as industrial, agrictural, and wastes from rural and urban society. They contain soluble siliceous, alumino, siliceous, or calcium alumino siliceous powders (Aprianti, et al., 2015). If these waste materials are not deposited in a proper way, they may be hazardous (Snellings et al., 2012). Processing these natural wastes for utilization requires less energy than the energy required for the manufacturing of Portland cement (Juenger & Siddique, 2015).

Due to increasing industrial and agricultural activities, tons of waste materials are deposited into the environment with little effective waste management or recycling (Ghrici et al., 2007). Rice husks, sawdust, sugarcane waste, palm kernel shells, locust bean pod are some of waste agricultural biomass (WAB), which are produced from agricultural process during harvesting. These wastes are usually poses health problems to human and pollute the environment where they accumulated in large quantities. As such, efforts should be made to find alternative ways and methods for recycling WAB and achieve environmental friendliness that beneficial for human beings (Ojewumi et al., 2017). Previously, many studies were conducted on the use of different agricultural waste products (AWP) as supplementary cementitious materials in the production of concrete. However, there is no study conducted on the use of common bean straw (CBS) as supplementary cementitious material.

CBS is a waste product from the common bean (Phaseolus vulgaris). The common bean is an essential and internationally used legume rich in extremely good proteins, micronutrients, vitamins, and antioxidants. Likewise, it is a crucial source of vitamins and serves as a supply of iron, potassium, magnesium, zinc, and folic acid (Rodríguez De Luque & Creamer, 2014). Based on the Food and Agriculture Organization of the United Nations (FAO) statistics, the total global common bean production was 28.9 million tons that harvested from 33.1 million hectares in 2019. While in Ethiopia, 514,000 tons of common bean harvested from 323,400 hectares with average productivity of 1.59 tons per hectare in 2015. Furthermore, this production increased to 797,331.88 tons from 311,583.58 hectares during harvesting season of 2020/2021 (CSA, 2021).

The current study was conducted on the use of the common bean straw ash (CBSA) as a partial cement replacement in non-structural concrete. To realize this, physical properties of concrete ingredients and the chemical properties of CBSA were experimentally investigated. The effect of CBSA on fresh and hardened concrete also determined. In addition, environmental and economic implications of using CBSA as a partial replacement of cement also explored.

1.2. Statement of the Problem

Cement manufacture requires a lot of energy, depletes natural resources, and releases a large amount of CO_2 into the atmosphere. In 2019, more than 4.1 billion tons of cement products were produced, which is responsible for about 8% of the world's total CO_2 emissions (Liu, et al., 2020). Limestone and clay are major raw materials for cement manufacturing, but both of them are non-renewable materials, making cement the most expensive ingredient of concrete when compared to other concrete ingredients. Many researchers throughout the world are looking for ways to replace cement with SCMs to reduce raw material depletion, CO_2 emissions, and the high cost of cement. Several studies encourage using waste materials with SCMs properties to partially replace cement (Harison et al., 2013).

SCMs are commonly used as a partial replacement of cement in concrete production or as a partial replacement of clinker in cement manufacturing. The use of SCMs as a cement replacement has had positive results in recent years (Ochola & Otaru, 2021).They develop additional strength via pozzolanic reaction in high strength concrete, increase the workability of concrete through reduce permeability, and amend the durability of the concrete (Marchetti, 2020). Waste materials, which have pozzolanic characteristics, are widely used in construction as SCMs. The most common used pozzolanic materials include fly ash, silica fume, and blast furnace slag (Sáez del Bosque et al., 2021). In addition, AWPs are used as SCMs to replace cement.

Various researchers have undertaken several investigations on the applicability of various AWPs as supplementary cementitious materials in the production of concrete. However, the use of CBSA as a partial replacement of cement in concrete has not been studied yet. Therefore, this study investigates the effect of CBSA on concrete as a partial replacement for cement. CBSA was produced at a controlled temperature using agricultural waste products, specifically CBS. CBSA was used as a partial cement replacement in non-structural concrete to explore the properties of fresh and hardened concrete with a set replacement percentage.

1.3. Objective of the Study

1.3.1. General Objective

The main objective of this study was to investigate the effect of common bean straw ash on non-structural concrete as a partial replacement of cement.

1.3.2. Specific Objectives

- To characterize the physical and chemical composition of common bean straw ash.
- To investigate the effect of common bean straw ash on workability of the concrete.
- To investigate the effect of common bean straw ash on compressive strength, durability, and microstructure of the concrete.
- To explore the environmental and economic implications of using common bean straw ash as a partial replacement of cement.

1.4. Research Questions

Q1. Does the common bean straw ash satisfies the requirements of pozzolanic materials?

Q2. Does the common bean straw ash affect workability of the concrete?

Q3. Does the common bean straw ash affect compressive strength, durability, and microstructure of the concrete?

Q4. What are the environmental and economic implication of using the common straw ash as a partial replacement of cement in non-structural concrete?

1.5. Significance of the Study

Considering that production of cement contributes to 8% of the global CO_2 emission (Liu, et al., 2020). The current study intends to partly substitute cement content with agricultural waste materials, which creates environmental problems, wherein accumulated in large amounts and disposed of inadequately. Partial cement replacement can be helpful in decreasing cement demand and eventually minimize CO_2 emissions. Simultaneously, it can reduce the accumulation of common bean straw waste. Furthermore, this research plays a great role as a benchmark for further investigation.

1.6. Scope of the Study

The experimental study looked at the physical properties of concrete ingredients and the chemical characteristics of CBSA. The effect of CBSA on the workability of concrete was determined. Furthermore, the current study scope includes casting, curing, and conducting compressive strength tests of a concrete sample on the 7^{th}, 14^{th}, and 28^{th} day with the specified combinations of common bean straw ash and comparing it to the controlled concrete specimen's sample. The study was limited to C-15 non-structural concrete.

1.7. Study Limitations

The CBSA and its incineration process are the study's primary limitations. CBSA was not studied according to data gathered from various previous works. As the result, obtaining some references for the current work is main challenge. In other hand, due to limitation of the furnace at Adama, incineration took place at the Ethiopian Defiance University Laboratory in Bishoftu. The furnace has the capacity of burning temperature up to 500 ^oC only. This the main reason for incineration of CBS at 500 ^oC only. In addition, due to this reason incineration at different temperature to obtain the optimum burning temperature for CBSA is not possible for current study. High LOI values which reflects the presence of unburned substance in ash is due low incineration temperature. Because of limitations in availability of furnace, it was not possible to incinerate more than 20 kg of common bean straw during the development of this study, yielding approximately 5 kg of CBSA. Only compressive strength, water absorption, and microstructural tests were possible with this amount. However, it was insufficient to conduct tensile and flexural strength tests. Additionally due to limitation of resources other durability of the concrete tests were not conducted.

1.8. Organization of the Study

The current study article is organized into five chapters. The first chapter is an introductory section that covers the study's background, problem, objective, scope, significance, and limitations. The second chapter provides a concise review of concrete, cement, agricultural waste products used as supplementary cementitious materials, and common beans. The third chapter discusses the materials utilized and the experimental methodologies used to conduct various experiments. The fourth chapter contains the results of various tests as well as their discussion. Finally, the final chapter presents the study's conclusion and a researcher's recommendation.

2. LITERATURE REVIEW

2.1. Introduction

The problem of environmental pollution and scarcity of resources for future generations has led to use various industrial and agricultural wastes. Using these by-products as cement replacement materials solves both environmental and economic problems. Cement production necessitates a large amount of energy and fuel. Using cementitious materials instead of cement reduces the large amounts of energy required for cement production, lowering carbon dioxide emissions. This is not the only advantage of cementitious materials; using them can reduce the consumption of virgin materials. Many studies on the feasibility of materials that replace cement have been conducted around the world in recent years. According to their findings, some of these materials improve the properties of concrete.

This chapter discussed a comprehensive review of the literature on the subject. To begin, a comprehensive review of concrete, its composition, mix design, and properties are presented. The concrete composition included a detailed discussion of cement, its types, manufacturing process, hydration, and environmental impacts from various authors' perspectives. Second, SCM was explored from different researchers' perspectives. Following that, agricultural waste products as supplementary cementitious material were reviewed. Finally, the common bean and its production were reviewed.

2.2. Concrete

Concrete is the most widely used human-produced construction material in the world, after water the most widely used material on the earth (Gambhir, 2013). Its main materials are aggregates, cement and water. Because concrete is the most available material on the planet, its production has increased to satisfy the growing demand for construction activity (Sakai & Noguchi, 2012).

2.2.1. Composition of Concrete

Concrete consists of cement, aggregates (fine and coarse), water and chemical additives, and, if necessary, additional cementitious materials (Kurdowski, 2014). The formulations of the binders and the type of aggregates used are directly related to concrete types. In addition, the strength and density of concrete as well as the chemical and thermal resistance of the end products are also determined by these variables (Gagg, 2014a).

Cement is a fine gray powder that, when mixed with water and other components, is used to make mortar or concrete. It hardens and sets due to hydration reactions and processes when mixed with water, allowing it to increase strength after hardening (demissew, 2020).

Construction aggregates derived from primary resources either by crushing of sound rock plenty (crushed stone aggregates) or from present unbound clastic sediments (natural sand and gravel aggregates) build the foremost voluminous mineral stuff exploited by humans these days (Přikryl, 2021). Fine and coarse aggregates are occupied around 60 to 80 % of the total volume of concrete. The properties of fresh and hardened concrete are directly affected by the quality of the fine and coarse aggregates. Better quality aggregates should consist of particles with adequate strength and desirable properties such as resistance to exposure conditions. While the availability of materials such as coatings, reactive silica, sulfate, clay, feldspar, and mica on aggregate can have an impact on the short and long-term strength of concrete (Nweke & Okogbue, 2021).

Water is one of the main components of concrete, that actively participates in the chemical reaction with cement (Shabalala & Ekolu, 2019). Because it helps in the formation of the cementitious gel that gives concrete its strength. Before using water for concrete manufacturing, the volume and quality of the water should be thoroughly evaluated (Kurdowski, 2014).

2.2.2. Concrete Mix Design

Concrete mix design is a composite and multistage process, to find the proper composition of ingredients to make concrete with required quality. The designer decides on the design mix ratios after analyzing the properties of each ingredient used. Design mix concrete can have very broad specifications that cannot meet by simple nominal mixes due to this conducting mix design through the advanced mix design methods is necessary(Ziolkowski & Niedostatkiewicz, 2019).There are different methods of mixed design; among them, the most common is the American Concrete Institute methods (ACI). ACI method of concrete mix design is based on the estimated weight of the concrete per unit volume. This method takes into consideration the requirements for consistency, workability, strength, and durability (Shraddhu, 2017). Accurate concrete mix design makes concrete construction more economical. Large constructions such as bridges and dams are required a large amount of concrete, as the reason, the correct amount makes the structure economical (Rahul, 2020).

2.2.3. Properties of Concrete

2.2.3.1. Workability of Concrete

Concrete workability is related to the relatively easy handling, pouring, compaction, and finishing of new concrete mixtures without separating components. If fresh concrete can be molded, compacted, and finished to its final shape and texture with minimal effort, and the components will not separate, then it is considered feasible. This process ability of fresh concrete is related to the mixture's consistency and cohesiveness, which are affected by cement content, aggregate quality, water content, and chemical additives (Daniel, 2006). The workability of concrete is determined through the slump test (Panesar, 2019).

2.2.3.2. Strength of Concrete

Strength of concrete is a fundamental property of concrete, which reflects the maximum load concrete can handle without failure. The structure of hardened cement paste is directly related to the strength of concrete, offering a complete picture of concrete quality (Mehta & Monteiro, 2014). Concrete strength is measured in three ways: flexural strength, compressive strength, and split tensile strength. Compressive strength is a measure of the failure of cubes under the compression, whereas flexural strength and tensile strength upon separation are measures of concrete's tensile strength. Although concrete has a significant compressive strength, it has somewhat lower tensile and flexural strengths. The tensile strength of concrete is 10% of its compressive strength, whereas the flexural strength is 15% of its compressive strength (Hailu, 2011).

Compressive strength is a widely used measure for assessing the performance of a concrete mixture. This element of concrete is crucial to consider because it is the fundamental determinant of how effectively concrete can bear loads that impact its size. It accurately reflects whether a specific blend is appropriate to meet the needs of a specific project. Concrete is particularly compressive load resistant (Gopal, 2014). Due to this reason it can is used to build arches, columns, dams, foundations, and tunnel linings. The compressive strength of concrete highly depends on the amount of cement and aggregate quality used. Besides it also affected by the ratio of water to cement, proper mixing, and pouring (Kurdowski, 2014). Furthermore, the degree of hydration and curing methods affect the compressive strength of concrete (Gagg, 2014).

2.2.3.3. Durability of Concrete

Durability is related to maintaining good performance throughout the service life associated with the intended use. The concrete that needs to be walked or driven has abrasion resistance to avoid abrasion. To withstand multiple freeze-thaw cycles, the concrete exposed on the structure's exterior must be weather-resistant. When subjected to repeated freeze-thaw cycles, the air entrained in the concrete can significantly affects its durability (Debieb et al., 2010). To protect the metal from corrosion, concrete with embedded steel bars must withstand excessive moisture absorption. Over time, natural wear and weathering cause certain changes in the appearance of concrete; however, durability includes maintaining both functional and aesthetic features. (Vijayalakshmi & Sekar, 2013).

2.2.4. Non-structural Concrete

According to the International Building Code non-structural concrete is an element made of plain or reinforced concrete that is not part of a structural system required to transfer either gravity or lateral loads to the ground (Ghosh, 2005). Non-structural concrete has low strength and is used when only minor compression or temporary loading is involved. It is used in 'blinding layers,' where a surface is covered in non-structural concrete to form a level and possibly more stable surface on which further work can be performed more easily (López-Uceda et al., 2016). According to ACI 318M (2014) target mean compressive strength of structural concrete shall not be less than 17MPa unless they are non-structural concrete. Therefore, concrete that has a target mean compressive strength of less than 17MPa is categorized under non-structural concrete. This non-structural concrete could be used to construct residential floors, sidewalks, and paving blocks that do not require high mechanical strength. Furthermore, drainage, small wall foundations, and concreted components with the large exposed surfaces are the main application area of non-structural concrete (Mas et al., 2012).

2.3. Cement

Cement is a broad term that refers binder materials. From the beginning, the builders used adhesives when combining them with rocks and stones to create safer buildings. Simple mud is used as a binder and it is still used in some parts of the world today (Gagg, 2014; Hewlett & Liska, 2019). The origins of hydraulic cement date back to Ancient Greece and Rome. Lime and volcanic ash are used as binder materials, which slowly react with it them in the presence of water to form a solid mass. It served as a binder for Roman mortars and concretes over 2000 years ago and subsequent construction work in Western Europe (Sismondo, 2011).

Cement is a fine gray powder that is used to form mortar or concrete when combined with water and other ingredients. When mixed with water, it forms a paste that hardens and sets due to hydration reactions and processes, allowing it to gain strength after hardening (demissew, 2020). Almost all types of cement produced globally are used in combination with sand, gravel, and water to make concrete and mortar (Gagg, 2014). It is a necessary substance for today's civilization because it is an important part of concrete, a necessary ingredient for the construction of homes and infrastructure (Cao et al., 2020).

The characteristics of cement used in construction are hydraulic or non-hydraulic. Hydraulic cement, such as Portland cement, harden due to hydration, whereas non-hydraulic cement will not set in moist or underwater environments. Instead, when dry, it solidifies and reacts with carbon dioxide in the air (Khatib & Bayomy, 1999). According to cement chemistry, hydration is the reaction of cement with water. Partial hydration of the cement can occur even in humid air, while for complete hydration cement must be with sufficient water be mixed (Beaudoin & Odler, 2019)

2.3.1. Types of Cement

There are different types of cement used in constructions; each types varies in its composition or production process. Some of the common cement types are: ordinary portland cement (OPC), portland pozzolana cement (PPC), rapid hardening cement (RHC), quick-setting cement (QSC), low-heat cement (LHC), sulfate-resisting cement (SRC), blast furnace slag cement (BFSC), high alumina cement (HAC), and air entraining cement(AEC) are used in a different types of construction works (Dunuweera & Rajapakse, 2018).

OPC, also known as basic Portland cement, is a high-quality cement that may be utilized in extensive concrete production with little exposure to sulfates in the soil or groundwater. Portland clinker is made of calcium silicate, which is obtained by heating a predefined homogenous mixture to a preliminary melting point, which contains 59-64% lime (CaO) and 19-24% silicon dioxide (SiO_2), 3-6% aluminum oxide (Al_2O_3), and 1-4% iron oxide (Fe_2O_3) (Ma et al., 2019). According to International standard code, OPC has 33, 43, and 53 grades based on its strength. The grades indicate the compressive strength of the mortar cube that will be attained after 28 days of setting (Banstola et al., 2021).

PPC is made by grinding clinker and pozzolana together or by combining portland cement with high-quality pozzolana. Depending on the weight of the cement, the percentage of pozzolana might range between 10 and 25%. PPC is appropriate for the following conditions: Suitable for waterfront or maritime buildings such as dams, piers, and substantial foundations with a high concrete content. It's also found in sanitary systems like sewers (Sangoju et al., 2015).

RHC has an equal chemical composition as Portland cement (PC), but has a higher lime content material than PC. The intention of the excessive lime content material is to harvest high heat within the early days (Dunuweera & Rajapakse, 2018). It is used in concrete when it is far vital to put off the formwork beforehand of time. Because cement hardens due to the formation of $CaCO_3$ as a result of the absorption of atmospheric CO_2 by CaO, the increased CaO concentration results in an increase in $CaCO_3$ formation even at an early stage, resulting in quick hardening. It is commonly utilized in road and bridge building where time is of the essence. Conversely, because its heat of hydration and self-contraction are quite low during the hardening process of concrete, LHC has gained a lot of attention for creating massive concrete structures (Mori et al., 2012). It is made by using enhancing the chemical makeup of OPC. In comparison to OPC, cement contains a large proportion of C_2S and a small amount of C_3S. Due to the slow rate of hydration and heat production of C_2S, this results in a low amount of heat, whereas hydration of C_3S is very rapid and results in a large amount of heat (Wang et al., 2018).

QSC is set very quickly and produced by adding a small amount of aluminum sulfate as an accelerator and reducing the amount of gypsum used in fine grinding (Qiyuan et al., 2012). It is used for aggressive foundation conditions. When pumps are required, or in submersible land areas and in some typical grouting work. Since ordinary portland cement is susceptible to sulfate erosion, SRC has been developed for use in places where the soil is affected by sulfate. Sulfate attack in OPC cement generates swelling and cracking in the concrete frame, which eventually fails. Many studies have shown that cement with low C_3A content is more effective in reducing sulfate attack. Sulfate-resistant cement has high silicate content and low C_3A and tetra calcium alumino-ferrite (C_4AF). According to reports, adding pozzolana additives such as fly ash can reduce the C_3A content of cement (Dunuweera & Rajapakse, 2018).

BFSC is produced by way of grinding the clinker with 60% slag. The properties of this cement are similar to PC. It is used for jobs where economic concerns are paramount (Liu et al., 2020). Portland slag cement can be used for any application that requires OPC. However, the former has certain advantages. It generates less heat and is more durable. On the opposite hand, HAC is acquired through melting a mixture of bauxite and lime and grinding the aggregate with a clinker. Due to its high aluminum oxide content, it is far a fast-placing cement with an initial and final setting time of approximately 3.5 and 5 hours, respectively. However, its use in hot weather is minimal due to increased porosity, reducing strength (Dunuweera & Rajapakse, 2018).

Using OPC cement clinker and adding power or liquid air-entraining agents manufactures AEC. Introducing air entertainers into other acids, including certain wetting agents such as animal and vegetable fats, oils, aluminum powder, and hydrogen peroxide, improves the frost resistance of hardened concrete. The addition of this cement to concrete increases its workability, segregation, and bleeding qualities (Riyazi et al., 2017).

2.3.2. Manufacture of Portland Cement

The production of cement consumes large amounts of non-renewable materials and energy. The production system is complicated, and includes a wide variety of raw materials, warmth remedy technologies, and different fuel sources. Cement manufacturing requires about 3.2 to 6.3 GJ of energy and 1.7 tons of raw materials with a ton of clinker manufacturing (Rahman et al., 2015).

The materials used to produce PC must include the appropriate proportions of lime, silica, alumina, and iron. The raw materials used should provide the main elements of cement (Alnawfleh et al., 2015). During manufacturing, analysis is frequently performed to ensure uniform and high-quality products. The ingredients are placed and blended in the favored proportions. After blending, the prepared combination is fed to a rotary kiln, where it is sintered or fired at a temperature of 1400-1650 °C (Marceau et al., 2006). The finished product is a bulk mixture of stable chemicals known as clinker. Clinker contains iron (Fe), aluminum (Al), silicon

(Si), and calcium (Ca) in four major compounds: Alite (Ca_3SiO_5), Belite (Ca_2SiO_4), known to geologists as larnite, Aluminate ($Ca_3A_{l2}O_6$), and Ferrite (Ca_2AlFeO_5) (Dalton et al., 2004).

2.3.3. Normal Consistency of Cement

A normal consistency of cement paste is defined as a percentage of water by weight of cement that allows a standard plunger of 10 mm diameter to penetrate up to a depth of 5 to 7 mm above the bottom of Vicat's mold. The Higher values of normal consistency of cement paste are observed when cement is old and when the cement is too fine that has a high specific surface area (Dinku, 2002). According to ASTM C187(2004),normal consistency is expressed as a percentage of dry cement weight and ranges from 22 to 30.

2.3.4. Setting Time of Cement

The cement paste setting time is the length of time it takes for the cement paste to lose its plasticity after it has been combined with water. Cement setting time is classified into two types: initial and final setting time. The time elapsed between adding water to the cement and the paste losing its flexibility and hardening is referred to as the initial setting time. While, final setting time is the time interval between when water is added to the cement and when the paste has completely lost its plasticity (Zhang et al., 2010). According to ASTM C150 (2010), the initial setting time should be no less than 45 minutes, and the final setting time should be no more than 375 minutes. According to Ethiopian standards, the initial setting time for cement should not be less than 45 minutes, and the final setting time should not be more than 600 minutes (Dinku, 2002).

2.3.5. Chemical Properties of the Cement

Lime, silica, alumina, and iron oxide are the main source of raw materials for PC production. These oxides carry out complex reactions in the kiln at high temperatures to form complex compounds. The chemical components of PC are reported in terms of oxides. The Chemical properties of cement are determined from the chemical analysis of these raw materials (Nawy, 2008). As demonstrated in Table 2.1, CaO accounted for 60 to 67% of cement oxide, while SiO_2 accounted for 17 to 25%. When compared to lime, alumina and ferric oxide contribute very little.

Table 2.1: Approximate oxide composition limits of ordinary Portland cement (Dalton et al., 2004; Dunuweera & Rajapakse, 2018).

Oxide	Common name of oxide	Weight by percent in Portland cement
CaO	Lime	60 to 67
SiO_2	Silica	17 to 25
Al_2O_3	Alumina	3 to 8
Fe_2O_3	Ferric oxide	0.5 to 6
MgO	Magnesia	0.1 to 0.4
K_2O, Na_2O	Alkali	0.4 to 1.3
SO_3	Sulphur trioxide	1.3 to 3

The rate of cooling of clinker, fineness of the particle, and the proportions of the oxide composition of cement mainly influence the properties of cement. The foremost compounds in PC are C_3S, C_2S, C_3A, and C_4AF. The compounds chargeable for the development of strength are C_2S and C_3S. These compounds represent approximately 70-80% of cement. C_3S are hydrates and harden very fast. In addition, it miles liable for the early strength of cement even as C_2S hardens slowly and is responsible for later strength improvement of concrete. Cement with excessive C_3S is better for cold climate concreting since it allows early strength improvement of concrete (Shetty, 2005).

C_3A hydrates very fast but contributes a little to the early strength development of concrete. Due to C_3A, reacting with water very fast water affects flash setting; however, with the aid of using which includes gypsum to the clinker at the time of grinding it may be prevented. The presence of C_3A can result in sturdiness problems of concretes, which are uncovered to sulfates. C_4AF hydrates rapidly but contributes little to the strength development of concrete. Comparatively, C_3A shows lower sulfate attack resistance than hydrated C_4AF (Dunuweera & Rajapakse, 2018).

2.3.6. Cement Hydration

Hydration is the term used to describe the chemical and physical processes that occur between cement and water. Cement hydration is critical because it is responsible for the setting and hardening of concrete. The chemical reaction converts the cement from a powder to a cohesive matrix with high strength that binds the aggregate particles together. The reaction between Portland cement and water is an exothermic chemical reaction (Richardson, 2000).

Both C_3S and C_2S react with water to form an amorphous calcium silicate hydrate known as C–S–H gel, which serves as the primary 'glue' that holds sand and coarse aggregate particles together in concrete. When water and Portland cement are combined, the constituent compounds of the cement and water undergo a chemical reaction that causes the concrete to harden. Each substance found in cement reacts with water at a different rate. The most reactive compounds are C_3S and C_3A, whereas C_2S reacts more slowly (Scrivener et al., 2019; Goshu, 2019). Approximately half of the C_3S present in typical cement will be hydrated by three days and 80% by 28 days. In contrast, the hydration of C_2S does not generally begin until about 14 days. The C_3S is hydrated to produce calcium silicate hydrates, lime, and heat, while the C_2S also hydrates to form calcium silicate hydrates and heat. Hydration of both are shown in equation 2.1 and equation 2.2 (Marchon & Flatt, 2016).

$$2C_3S + 6H \Rightarrow C_3S_2H_3 + 3CH \text{……………………………………..Equation 2.1}$$

$$C_2S + 4H \Rightarrow C_3S_2H_3 + CH \text{…………………………………...Equation 2.2}$$

Calcium silicate hydrate (C-S-H) is the most important product that determines the good properties of concrete. In reality, The C-S-H has a short-networked fiber structure, which contributes significantly to the cement glue's initial strength. A poorly crystalline material forms extremely small colloidal matter particles of less than one micrometer. C-S-H accounts for 50-60% of the hydrated cement paste (Scrivener et al., 2015). During the hydration reaction, C_3S produces less C-S-H and more $Ca(OH)_2$ than C_2S. Calcium hydroxide (CH) is an undesirable product in the concrete mass, particularly for hydraulic structures, because it is soluble in water and leaches out, making the concrete porous. It is recommended that cement with high percentages of C_2S be used to reduce the porosity of concrete for hydraulic structures (Shetty, 2005).

A variety of factors influence the rate and amount of heat of hydration. The most common of these are cement composition and fineness, water to cement ratio of the concrete, paste age, and ambient conditions. Portland cement hydration is more complicated than the individual compounds. This is because the different compounds have different products, reaction rates, and each compound consumes water. When cement is first mixed with water, some of the calcium sulfates added dissolve quickly. The purpose of adding calcium sulfate is to slow the hydration of C_3A, which results in flash set due to its high rate of reaction with water without calcium sulfate (Goshu, 2019). It is because C_3A is more reactive than any other compound in the cement and, if allowed, will absorb a large amount of water. $C_3A > C_3S > C_4AF > C_2S$ is the reaction sequence. However, the rate of hydration of these compounds varies from cement to cement depending on fineness, clinker-cooling rate, and other factors such as the presence of impurities and other cement compounds (Mindess et al., 2003).

2.3.7. Environmental Impact of Cement

Cement manufacturing is an environmentally unfriendly procedure because of the release of CO_2 gases into the atmosphere and natural useful resource degradations (Demissew et al., 2019). The cement sector is the arena's third-biggest industrial power consumer, accounting for 8% of industrial energy intake, and the second-biggest industrial emitter of CO_2, accounting for approximately 8% of the world's emissions (Akpenpuun et al., 2019). The manufacturing of Portland clinker is an energy-extensive procedure, in which raw substances are burned at 1450 °C. According to global cement manufacturing Statista, annual global cement production reached around 2.8 billion tons in 2015, but it will increase to 4.1 billion tons in 2019 (Aprianti et al., 2015). The cement industry faces demanding situations that include rising energy charges, insufficient necessities to reduce carbon dioxide emissions, and raw materials delivery.

Energy consumption is the largest environmental situation with cement and concrete production. Cement production is one of the most energy consumers when compared to others industrial manufacturing process. Including direct fuel use for mining and transporting uncooked materials, cement production takes about 1,758 kWh for every ton of cement. The cement industry is heavy reliance on coal results in specifically excessive emission stages of CO_2, nitrous oxide, and Sulphur, amongst different pollution. Consuming energy from fossil fuels such as oil and coal creates CO_2, the most important Greenhouse Gas causing climate change (Rodgers, 2018). Furthermore, the chemical process of producing clinker emits CO_2. Because of these two factors, the cement sector accounts for 8% of global manufactured CO_2 emissions, with the chemical process accounting for 50% and fuel combustion accounting for 37% (Lu et al., 2020).

Cement companies have a significant impact on the communities where they operate. The quarries and plants associated with cement production are major features of the local landscape and economy (Babor et al., 2009). The way companies evaluate and manage the social and economic impacts of assigning location and closure of sites affects the life of communities and reputation of the industry (Mehta, 2001). Different studies advocate the use of supplementary cementitious materials as a partial cement replacement to reduce the impact of cement manufacturing.

2.4. Supplementary Cementitious Materials

Supplementary Cementitious Materials (SCMs) are soluble siliceous, aluminosiliceous, or calcium aluminosiliceous powders used as partial replacements for clinker in cement or as partial replacements of portland cement in concrete combinations. It is used in conjunction with portland cement, portland limestone cement, or blended cement (Juenger et al., 2019). SCMs enhance the strength of concrete through pozzolanic reaction, improve the workability of concrete by decreasing permeability, and prolong the concrete's lifetime (Marchetti, 2020).

The use of SCMs in concrete as a cement replacement in relatively small amounts (5–20%) shows improvement in the long-term strength and durability of concrete while also lowering cement costs. The impact of replacing clinker partially with SCMs is frequently influenced by industry pressure to minimize CO_2 emissions from cement production (Juenger & Siddique, 2015). Many of the materials now employed as SCMs are byproducts of other industries. Fly ash, ground granulated blast furnace slag, silica fume, calcined clays, and natural pozzolans from coal-fired power plants are the most commonly used waste products. The process of converting these wastes for usage needs less energy than the energy required for cement manufacturing (Juenger et al., 2019).

2.4.1. Pozzolana

The term ‘pozzolana’ has distinct meanings. In its strictest definition, the term refers to pyroclastic (volcanic) ashes, located primarily close to the city of Pozzuoli (the historical Puteoli of the Roman times) (Massazza, 1998). More commonly, pozzolanic refers to inorganic minerals that harden in water when mixed with calcium hydroxide-releasing materials, such as Portland cement (Black, 2016). Pozzolans are siliceous substances that, by themselves, do not have cementitious properties, but when react with lime in the presence of water to form compounds with cementitious properties (Khan et al., 2017).

Materials that consist majorly of silica and alumina, able to combine and chemically react with calcium hydroxide in the presence of moisture at ordinary temperatures to form compounds possessing cementitious properties as a binding agent belongs to pozzolanic materials (Ojewumi et al., 2017). Pozzolanic materials are generally classified into natural and artificial materials primarily based on their source. Natural pozzolanic materials do not require any similar treatment aside from grinding, while artificial pozzolanic materials are created by chemical and/or structural improvements to materials that do not have or have only weak pozzolanic properties (Massazza, 1998).

2.4.1.1. Natural Pozzolana

Natural pozzolanas are materials from volcanic sources and sedimentary rocks with appropriate chemical and mineralogy compositions (Jackson, 1998). They are plentiful in certain locations and notably used as an addition to portland cement in countries that like Italy, Germany, and China. Volcanic ashes and pumices in large part composed of volcanic glass are typically used as deposits in which the volcanic glass has been altered to zeolites by reaction with alkaline water (McCarthy & Dyer, 2019).

2.4.1.2. Artificial Pozzolana

Artificial pozzolanas are thermally treated and activated clays and shales, air-cooled slags from lead, copper, zinc, and different merchandise from the Ferroalloys industry. Artificial pozzolanas shall now not increase the water demand of the cement appreciably, impair the resistance of the concrete or mortar to deterioration in any manner or reduce the corrosion protection there in reinforcement (Zhang et al., 2020). Artificial pozzolanas include fly ash, silica fume, rice husk ash, and met kaolin (Nwankwo et al., 2020).

2.4.2. Agricultural Waste Products as Supplementary Cementitious Materials

In recent years, the most critical worldwide issue taken into consideration is international environmental warming. As agricultural wastes affect the environment, the use of these waste substances by recycling will realize the numerous benefits in both maintaining environment and conserving natural resource (Ojewumi et al., 2017). As past studies, concrete made from agricultural waste has improved thermal properties, which can result in full-size points being won within the atmosphere and energy division of the leadership in the energy and environmental design (LEED) rating system (Aprianti et al., 2015). Furthermore, agricultural waste products (AWPs) used as SCMs in concrete manufacturing can help to improve the environmental friendliness and economic effectiveness of constructions around the world (Thomas et al., 2021).

Many studies on various AWPs as an SCM have been undertaken. Some of them, which are related to the current study, were reviewed. Previous scholars' works were reviewed for rice husk ash, teff straw ash, sugarcane bagasse ash, and African locust bean pod ash. Their physical and chemical properties, as well as their effects on the workability and compressive strength of concrete were discussed in the next sections.

2.4.2.1. Physical and Chemical Properties of Agricultural Waste Products

Rice husks are the hard protective coverings of rice grains that are removed during the milling process. Rice husk is a readily available waste material in all rice-producing countries, containing 30 to 50% organic carbon. Rice husk ash (RHA) is created by burning rice husk at a controlled temperature (Singh, 2018). Belay and Wondasenbet (2016) mentioned in their study that, after the husk was burned in the furnace, it turned a whitish-gray color. RHA had a specific gravity that was 35% lower than OPC's specific gravity and a bulk density that was roughly 33% that of OPC. The density of concrete decreases as the specific gravity and rough bulk density of RHA decrease. The mean particle size of RHA ranges from 5 to 10 μm, which is much larger than that of silica fume (Getahun et al., 2018; Shanmugavadivu et al., 2019).

Teff is an inherent and essential cereal crop grown for human consumption in Ethiopia. It is widely used in the preparation of injera. Teff's composition reveals that it contains many minerals and a lot of essential amino acids. The color of teff straw ranges from ivory to a dark reddish-brown purple. Teff straw has a non-uniform distribution, has a lower percentage of particles smaller than 1.20 mm, and contains finer particles. Teff straw sizes range from 0.6 to 1.18, with a dry density of 0.151 kg/cm^3 (Shantveerayya & Berrsa, 2020). The solid residue obtained from the Teff cereal is known as teff straw ash (TSA). Despite its widespread availability, teff Straw has received little attention. The surface area of the ash is less than that of the cement. As a result, brown teff straw ash (BTSA) has more fine particles than cement (Selamawit Woldemichael, 2020).

Bagasse is a by-product of the sugar industry that is burned to generate power for various factory activities. Bagasse waste has been used as a primary fuel source in cogeneration plants to generate electricity. When bagasse is burned as fuel, it produces a large amount of sugar cane bagasse ash (SCBA) (Bahurudeen et al., 2015). The specific gravity of SCBA is 2.16, which is much lower than the specific gravity of cement (3.15). Bagasse ash has a specific surface area of 4716 cm^2/g and a particle size of 40.10 μm on average (where 50% of the particle passes). Furthermore, it is in the form of powder and is black in color (Adero, 2019).

A Locust bean pod is an agricultural waste product derived from the African locust bean tree's fruit, which is called 'Parkiabiglobosa'. The pod is a necessary resource for the production of locust bean pod ash (Abubakar et al., 2020; Adama & Jimoh, 2012). Locust bean pod ash (LBPA) has a compacted bulk density of 660 kg/m^3 and is a lightweight material. The bulk density is determined by how densely the practices are packed. LBPA's specific gravity was determined to be 1.47, which is less than the specific gravity of cement (Saleh, 2014).

The chemical properties of SCMs are highly dependent on their chemical composition. SCMs' chemical reactions can be classified as pozzolanic, cementitious, or both. Pozzolanic reaction refers to the reaction that occurs between a pozzolanic SCM and calcium hydroxide. This reaction produces calcium silicate hydrate and calcium aluminate hydrate. Calcium hydroxide is formed during portland cement hydration in the presence of water (Juenger & Siddique, 2015). Cementitious or hydraulic activity is the direct reaction between SCM and water that produces products similar to portland cement hydration. Furthermore, the formation of calcium silicate hydrate and calcium aluminate hydrate are influenced by oxide composition of the SCM and portland cement. In addition, the consumption of calcium hydroxide also depends on the interaction of SCM and portland cement (Aprianti et al., 2015).

Since the chemical reaction is based on the oxide composition of SCMs, the oxide composition of some AWPs are presented in Table 2.2. All of the AWPs listed had a high SiO_2 content, ranging from 40.25 to 92.97 %. RHA is contains the most SiO_2 (92.97 %), whereas LPBA contains the least (40.25 %). For RHA and SCBA, the combination of SiO_2, Al_2O_3, and Fe_2O_3 is greater than 70%, making them pozzolanic materials of class F. However, their combined TSA and LBPA content is between 50 and 70%, classifying them as pozzolanic materials of class C.

Table 2.2: Oxide composition of different agricultural waste products

AWP	Oxide composition by weight percentage									Reference
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	LOI	
RHA	92.97	0.93	0.88	0.86	0.48	2.54	2.43	4.84	7.40	(Getahun et al., 2018)
	92.00	0.66	0.36	0.01	0.01	0.01	1.02	-	2.85	(Abebe Di, 2012)
TSA	52.22	1.54	9.74	17.66	1.98	3.92		4.10		(Wassie & Srivastava, 2017)
	56.18	7.80	1.14	6.04	0.10	16.8	0.01	-	7.24	(Selamawit 2020)
SCBA	65.58	5.87	4.32	1.78	1.23	6.41	1.02	-		(Abebe D. ,2012)
	61.04	6.12	3.52	1.36	2.56	5.92	1.08		10	(Goshu, 2019)
LBPA	40.25	13.15	9	12.50	2.03	5.62	1.21	1.5	6.5	(Akpenpuun et al., 2019)

2.4.2.2. Effect of AWPs on the Workability of the Concrete

Hence workability of concrete depends on slump value, effect of different AWPs on slump value of the concrete were reviewed below.

Several studies have been conducted to investigate the usage of RHA as SCMs. According to Gehatun's (2018) study, different mixes with partial replacement of cement by RHA caused a significant decrease in a slump compared to the control mix (without any replacement). As the replacement percentage of RHA increases, the slump decreases. RHA has a high specific surface area and a high-unburnt carbon content due to the absorptive properties of its cellular particles. RHA-containing concrete necessitates more water for a given consistency. The decrease in a will affect the ease with which concrete can be placed on the construction site, making it difficult to cast concrete (Belay & Woldesenbet, 2016)**.**

Shantveerayya & Berrsa (2020) investigated teff husk as a partial replacement of cement in concrete production. According to this investigation, the slump value rises as the percentage of teff husk increases due to the smooth surface and low specific surface area of the teff husk, which makes the concrete easy to work.

According to Abebe's (2012) and Adero's (2019) findings, the slump value of OPC- SCBA blended concrete decreases as the SCBA content increases. As the level of SCBA replacement increased, so did the demand for concrete water. This result could be attributed to the SCBA particles' higher specific surface area relative to cement, which was caused by the sugarcane bagasse ash particles' irregular and porous surfaces.

The workability of fresh concrete indicates that the incorporation of cement and LBPA in concrete results in a decrease in slump value, which depends on the replacement content. This slump reduction was caused by the LPBA particles absorbing some of the mixing water. Because of the large surface area, more water molecules were drawn to the surface of these particles. As a result, the amount of free water available for the concrete mix was reduced. Due to the fact stated above it reduces the workability of the concrete (Auta & Adebayo, 2020; Ali et al., 2019).

2.4.2.3. Effect of AWPs on the Compressive Strength of Concrete

The evolution of the mechanical properties of concrete depends on the composition and amount of portland cement, water-to-cementitious material ratio, air content, age, curing regime, and the type and amount of SCM used. The compressive strength of concrete is one of its most essential mechanical properties. The compressive strength of concrete with various AWPs was reviewed from previous works.

RHA increased the 7-day compressive strength of concrete by 12.0, 16.1, 22.4, and 20.5% at 5, 10, 15, and 20% replacement levels, respectively, when compared to the control mix. Similarly, compressive strength at 28 days also enhanced by 4.4, 10.8, 12.5, and 9.0% for each replacement percentage respectively. From the study, the author mentioned 15% of replacements enhanced compressive strength more than other replacement percentages (Abdul Rahim et al., 2014a). According to Belay and Woldesenbet (2016) study, concretes constructed with RHA substitution revealed a good early strength enhancement between the third and seventh days of the curing. However, as the replacement amount grew from 5% to 20%, the early strength development reduced because pozzolanic materials hydrated slowly after the release of $Ca(OH)_2$ during portland cement hydration.

Shantveyya and Berrsa (2020) discovered that when teff husk is replaced with concrete, the compressive strength increases somewhat, but the strength decreases at 10% later. This decrease in strength could be attributed to the teff husk's initial water absorption. According to Selamawit Woldemichael (2020) investigation, for a 28-day curing period, a brown teff straw ash mortar exhibits improvement at 10% replacement. The compressive strength of the mortar was enhanced by 12.94% when 10% brown teff straw ash was added.

According to Adero's (2019) findings, concrete samples blended with sugarcane bagasse ash has lower compressive strength than control samples on the7th day. However, the compressive strength of 5 and 10% replaced samples on the 28th and 56th days' shows improvement. The compressive strength of the concrete improved by 3.72 and 4.22% on the 28th day at 5 and 10% replacement respectively, and 4.83% and 7.82% on the 56th day. This improvement comes due to the high silica content of SCBA, which is more than the OPC contains. This implies the addition of bagasse ash up to 10% of the cement amount increased the compressive strength of the concrete.

Auta and Adebayo (2020) examined the substitute of cement accompanying until 50% LBPA at a break of 5% on the actual substance. They noticed that the compressive strength of concrete for 0 and 5% replacement at 28 days of curing was greater than 20 N/mm^2, indicating that LBPA incorporation as a binder in concrete mix afforded an advantage in compressive strength. In another study, the use of LBPA as partial cement replacement in concrete structures was studied, and observed that the cement replacement with LBPA led to a decrease in the concrete strength for grades 20, 25, and 30 with an increase in strengths as the curing days progressed (Ali et al., 2019).

2.5. Common Bean

The common bean (Phaseolus vulgaris) is an annual legume crop of the Fabaceae family. A vital legume is strong in protein, minerals, vitamins, and antioxidants. The common bean has up to 15% protein and provides 30% of the world's caloric requirements. It is also a good source of nutrients like iron, potassium, magnesium, zinc, and folic acid (Nadeem et al., 2021).

According to FAO statistics, total global common bean production in 2019 was 28.9 million tons gathered from 33.1 million hectares. Fifty percent of the world's common bean production was occupied by Asian countries and the top five world common bean producers are Myanmar, India, China, Brazil, and the United States from 2000 up to 2019 (Castro-Guerrero et al., 2019). This crop occupied more than 3.5 million hectares in sub-Saharan at some point of harvesting of 2018, Still, production is focused in the densely populated areas of East Africa and the highlands of southern Africa (Katungi et al., 2019).

The common bean is one of the most crucial and broadly cultivated species of ‘Phaseolus’ in Ethiopia. It is mostly known as ‘Boleqe’ in Ethiopia, and is also known as dry bean and haricot bean, in different parts of the world. It grows best in warm climate at 18 to 24^{o}C (Keba, 2021; Mohammed & Feleke, 2022). In Ethiopia, 514,000 tons of common bean harvested from 323,400 hectares with average productivity of 1.59 tons per hectare in 2015. Furthermore, this production increased to 797,331.88 tons from 311,583.58 hectares during harvesting season of 2020/2021 (CSA, 2021). Ethiopia grows a wide range of common bean varieties, including white, mottled, crimson, and black varieties (Bekele et al., 2019).

Figure 2.1: Common Bean during growing and harvested common bean

2.6. Research Gap

Previous studies on the use of CBSA as a partial replacement for cement in concrete have been explored. According to researcher-reviewed data, the use of CBSA for cement replacement has not been addressed. As an outcome, there is a gap in the use of CBSA for concrete work. Therefore, conducting an experimental study to cover the current gap about using CBSA as a partial replacement of cement to minimize the consumption of non-renewable materials and environmental pollution is crucial. To use CBSA as a partial cement replacement in concrete production, an initial investigation of the CBSA properties and its effect on the properties of fresh and hardened concrete should be needed. Due to this, the current study focused on the experimental investigation of CBSA properties and its effect on the workability, compressive strength, and water absorption of non-structural concrete.

3. MATERIALS AND METHODS

This chapter addressed the materials and procedures utilized to conduct this study based on required material specifications and various standards and methods.

3.1. Materials Used

Materials utilized in the laboratory for the current study were subjected to physical and chemical tests to assess the workability, compressive strength, durability, and microstructure of concrete using various percentages of common bean straw ash as a cement substitute.

3.1.1. Fine Aggregate

Fine aggregate is a granular material made up of small rock grains that is finer than gravel but coarser than silt. Fine aggregate is sand that passes through a sieve size of 4.75 mm and is retained at 150 μm. It should be free from lumps, organic material, silt, etc. Additionally, it should be robust and durable (Dinku, 2002). According to ASTM specification fine aggregate should be not absorb more than 5% of water. Fine aggregate for the current study was obtained based on the ASTM C33 (2003) standards requirements as mentioned in Figure 3.1(B).

3.1.2. Coarse Aggregate

In most cases, coarse aggregates are obtained by blasting in stone quarries or breaking them by hand or with crusher machines. It is a coarse aggregate with a size more than 4.75 mm or retrained on the IS Sieve of 4.75 mm. The coarse aggregate should be long lasting, strong, and hard enough to withstand crushing. They should not be covered in organic materials, clay, or dust since this will compromise the concrete's bonding strength (Nweke & Okogbue, 2021). Coarse aggregate, which meets ASTM C33(2003) was obtained to conduct this study as seen from Figure 3.1(C).

3.1.3. Water

Concrete's most important component is water. Water impurities and water content have a significant impact on concrete quality. As a result, the concrete water should be free of chemicals and other pollutants. The usage of potable water is normally safe; nevertheless, water that is unfit for drinking can be used to make concrete. Potable water, which meets ASTM C1602 (2006) standard was utilized for the current research.

3.1.4. Cement

Cement is a substance used in construction that sets, solidifies, and binds other materials together. For its rapid early strength in the first 28 days, locally available OPC cement was used in the current investigation. Furthermore, OPC cement manufacture uses a lot of limestone, which is a non-renewable resource, and since one goal of the current study is to eliminate non-renewable resources, OPC cement was chosen. The National OPC 42.5 N grade of cement was then chosen to match the specified specifications for the concrete, as shown in Figure 3.1(A). It was purchased from a supplier in Adama, Ethiopia, that met ASTM C150 (2016) specifications. The cement was stored in a dry place and away from moisture to ensure good condition during the experimental period.

3.1.5. Common Bean Straw Ash

Common bean straw for this research was sourced from Dole kebele in Negelle Arsi, Oromia state, Ethiopia, about 200 Km from the capital city Addis Ababa. The source location was chosen because of the high availability of common bean straw in the area and its closeness to the Adama, where the experimental work was carried out. The material is usually available as a waste product of agricultural processing of the common bean fruits during harvest season. To produce CBSA, the straw was incinerate in a furnace at the Ethiopia Defense University laboratory. CBSA was employed, which was similar in size to cement and passed a sieve opening of 150 mm. CBSA was utilized in this investigation, as shown in Figure 3.1(D).

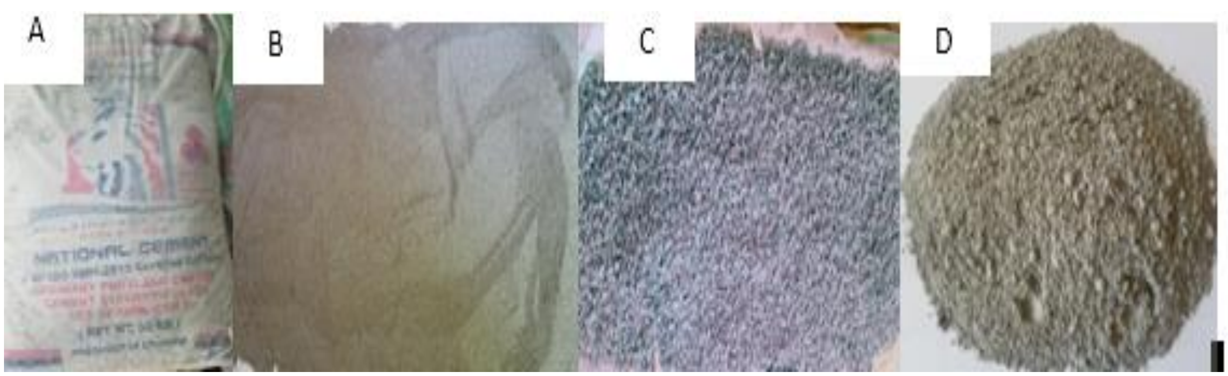

Figure 3.1: Materials used; A) National OPC cement, B) fine aggregate, C) coarse aggregate, and D) CBSA.

3.2. Methods

The current study employed an experimental method to achieve the aim of the research. The main purpose of the test method was to investigate the effect of common bean straw ash on concrete as a partial cement replacement. To achieve the aim of the current study, different laboratory tests were conducted according to different standard procedures. The outcomes of the tests were quantitatively and qualitatively analyzed based on the standard requirements or specifications. Origin, X'pert high score plus, Minitab Statistic, and Excel software were used to analyze results. Furthermore, analyzed data was presented through the table, figures, and chart. Figure 3.2 illustrated that the flow of experimental program of the current study.

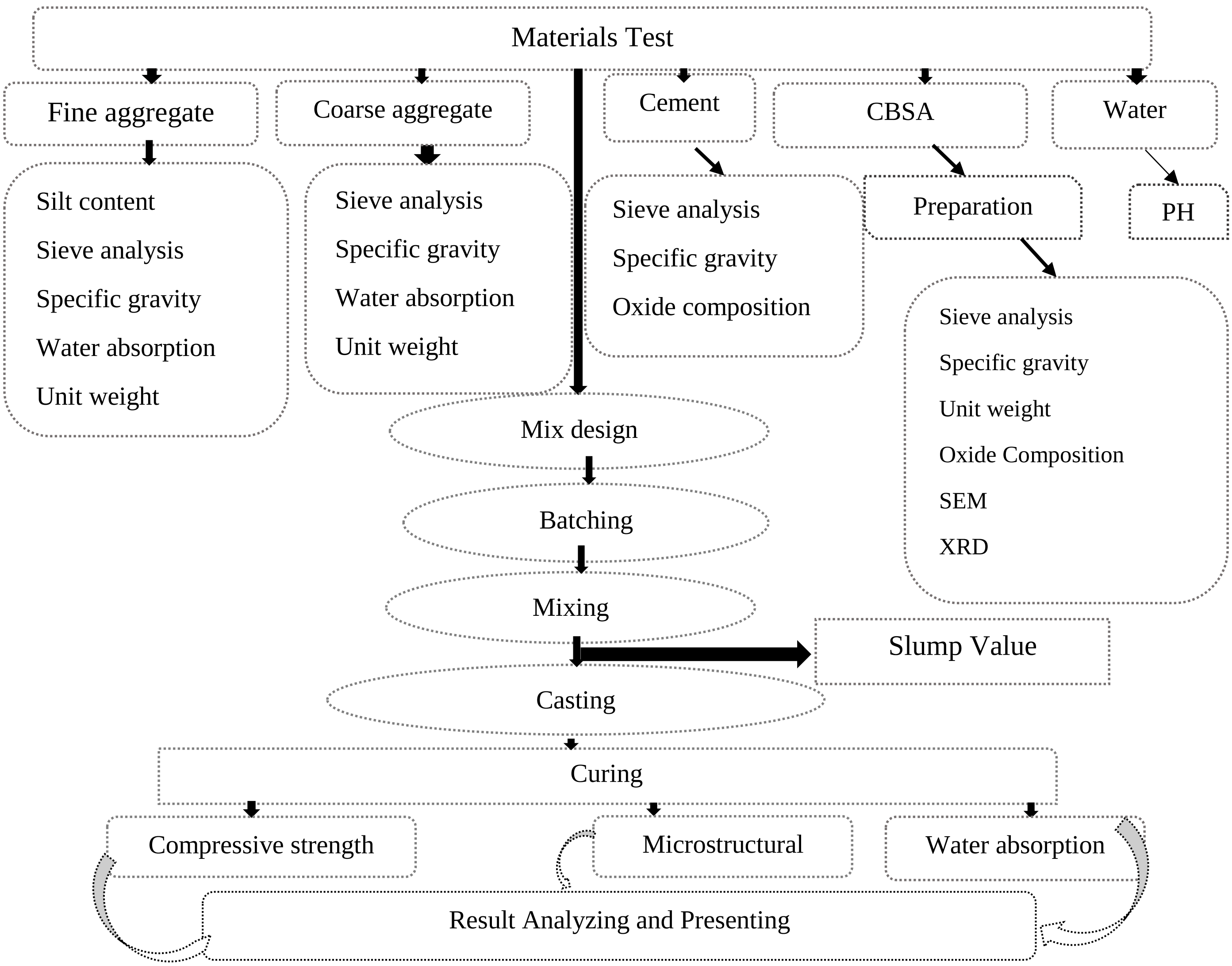

Figure 3.2: Flow chart of the current study experimental program.

3.2.1. Tests for Fine Aggregate

3.2.1.1. Silt Content

The objective of the test is to determine the silt (finer than sieve number 200) content in sand. Silt content is a fine material, which is less than 150 μm. It is unstable in the presence of water, which will reduce the strength and cause rework (Dinku, 2002). This test was carried out according to ASTM C117 (2013)standards. This test was undertaken by using apparatus such as: graduating cylinder, dish for taking sample of sand, small size spoon, sample sand, funnel, and clean water. According to the ASTM standard, fine aggregate with more than 5% of silt content should not be recommended for construction.

This test was carried out primarily with a graduating cylinder with a capacity of more than 1000 ml. The cylinder was then filled with 300 ml of fine aggregate and vigorously shaken for about a minute to mix the water and fine aggregate. The cylinder was then left for 24 hours to allow the silt to settle on the fine aggregate layer. Finally, the amount of finely produced separate layers on top of washed aggregate was measured. Silt content of fine aggregate was calculated according to equation 3.1.

$$\text{Silt content} = \left(\frac{\text{volume of separate layer}}{\text{volume of fine aggregate}}\right) * 100\% \quad \text{.........................Equation 3.1}$$

3.2.1.2. Sieve Analysis

The goal of sieve analysis is to determine the fine aggregates' particle size distribution and to check whether they are suitable for use in concrete mixing. Gradation is determined by weighing the material retained on each sieve as it passes through a series of sieves stacked with progressively smaller openings from top to bottom. From top to bottom, the IS sieves are 4.75 mm, 2.36 mm, 1.18 mm, 600 μm, 300 μm, 150 μm, and pan, respectively. A series of IS sieves, a pan, a shovel, a balance, a mechanical sieve shaker, and 1000 gm of fine aggregate were utilized for sieve analysis, as shown in Figure 3.3. The test was undertaken according to ASTM C136 (2006) standard.

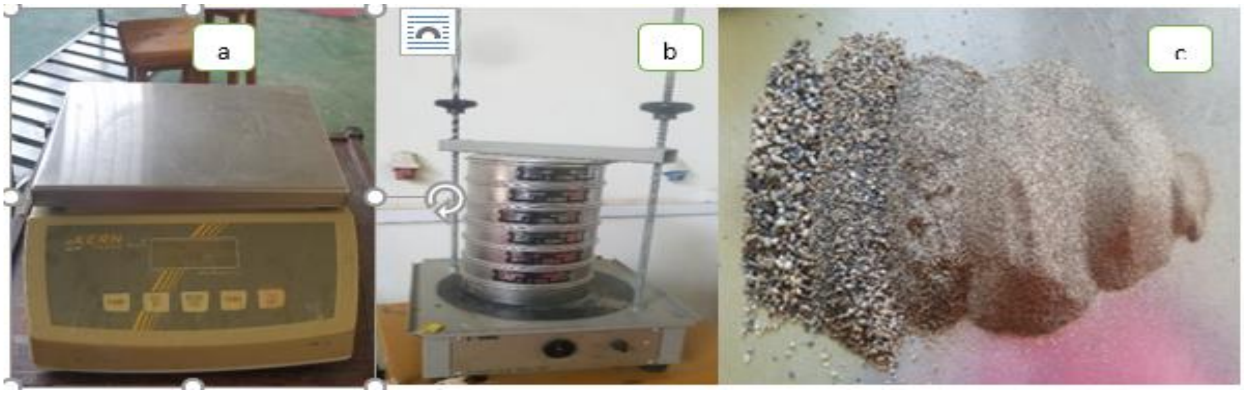

Figure 3.3: shows: a) electronic balance, b) sieves on the sieve shaker, and c) fine aggregate after sieved.

To undertake sieve analysis of fine aggregate, initially, 2 kg sample of fine aggregate was weighted and the sample was quartered by using a riffle box. Then 500 gm of fine aggregate was taken from quartered sample and empty sieves were weighted. After that, the pan was placed at the bottom of the sieve shaker and the other sieves were arranged according ascending of opening size of the sieves. Following that, 500 gm of fine aggregate was put on the top of sieve and shaken for 10 minutes in a sieve shaker. Lastly, the retained weight on each sieve was calculated and fineness modules was computed. Fineness modules of fine aggregate was computed by using equation 3.2.

$$Fineness\ modules\ = \sum\left(\frac{cummulative\ percent\ of\ retained}{100}\right) \text{…………. ...Equation 3.2}$$

3.2.1.3. Specific Gravity and Water Absorption Tests

The specific gravity test of fine aggregate is the ratio of a given volume of fine aggregate to the weight of an equal volume of water. The difference between the weight of the surface-dried saturated fine aggregate and the weight of the oven-dried aggregate at a given temperature is used to calculate the aggregate's water absorption. ASTM C128(2012) standard was followed to undertake specific gravity, and water absorption tests for fine aggregate. These experiments were carried out using a balance, pycnometer, pan, shovel, spoon, oven, cone, tamper, and 1000 g of fine aggregate sample.

Before the test, the specimen had to be prepared. At first, 1000 g of fine aggregate was obtained through a sample splitter and dried at 110°C for 24 hours before being allowed to cool. Then the sample was decanted with water to reduce fine loss, and the specimen was spread out on a flat non-absorbent surface. Following that, the sample was swirled repeatedly to ensure homogenous drying until it reached the saturated surface dry condition, and the surface moisture was measured using a cone test. The mold was held firmly on a smooth non-absorbent surface with a large diameter down, a portion of partially dried fine aggregate was placed loosely in the mold by filling it over and heaping additional materials above the top of the mold. Then the sand was lightly tamped into the mold with 25 light drops of tamper. Lastly, the surface was adjusted, loose sand was removed from the base, and the mold was lifted vertically. The fine aggregate reached saturated surface dry (S.S.D) when the sand slumped slightly as shown in Appendix D1.

To conduct the test, initially, 500 g of S.S.D sample was taken once the specimen was processed. The pycnometer was then half-filled with water and instantly filled with 500 g of S.S.D fine aggregate. After that, the pycnometer was filled with additional water to 90% capacity and rolled to eliminate all air bubbles. Following the removal of air bubbles, the water level was transmitted to the pycnometer calibrated capacity, and the total weight of the pycnometer, specimen, and water was calculated. The fine aggregate was then removed from the pycnometer, dried to constant weight at 110°C, cooled for one hour in the air at room temperature, and then weighed. Finally, the weight of filled pycnometer to its capacity was determined. Bulk specific gravity, apparent specific gravity and absorption capacity of fine aggregate were computed through 3.3 to 3.5 equations.

- Bulk specific gravity = A/ (A+S-C)……………………..Equation 3.3
- Apparent specific gravity = A/ (B+A-C)………………...Equation 3.4
- Absorption capacity = ((S-A)/A) * 100………..…………Equation 3.5

Where,

A: Weight of oven dry specimen in oven, (g).

B: Weight of pycnometer filled with water, (g).

S: Weight of saturated surface dry specimen, (g).

C: Weight of pycnometer with specimen and water to calibration mark, (g).

3.2.1.4. Unity Weight Test

The unit weight of fine aggregate is the weight of the sand that is required to fill a container of a specified unit volume. It depends on a variety of factors, including wet, dry, and loose conditions. The test was conducted by using a metal cylinder with a diameter of 100 mm and a height of 17 5 mm, a tamping rod, and balance. An empty cylinder was weighed and recorded to conduct this test. The cylinder was then filled with fine aggregate in three layers, each of which was tamped with 25 strokes by a tamping rod. The weight of the fine aggregate-filled cylinder was then measured and recorded. Finally, the unit weight of fine aggregate was calculated through equation 3.6 as illustrated in Appendix D4.

$$\text{Unit weight} = \frac{G-T}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Equation 3.6}$$

Where,

T = weight of empty cylinder (kg)

G = weight cylinder filled with fine aggregate (kg)

V = volume of cylinder ($V= \pi d^2 h/4$), while d is diameter and h denoted height of cylinder.

3.2.2. Test for Coarse Aggregate

3.2.2.1. Sieve Analysis

The main aim of coarse aggregate grading is to determine the fineness of the aggregate and to identify the category of aggregate use for the test. Gradation is determined by passing the material through a series of sieves stacked with progressively smaller openings from top to bottom and weighing the material retained on each sieve. From top to bottom, the IS sieves are 20 mm, 19 mm, 12.5 mm, 9.5 mm, 4.75 mm, and pan, respectively. Because the material that passed through the sieve opening 4.75mm was initially excluded, aggregates than 4.75 mm were not used. Sieve analysis apparatus used for the current study includes a set of IS sieves, a pan, shovel, balance, a mechanical sieve shaker, and a sample splitter. The test was undertaken according to ASTM C13 (2006) standard.

This test began with a 20 kg sample of coarse aggregate. Quartering was used to select the representative sample, and 2 kg of coarse aggregate was extracted from the quartered sample.

The weights of empty sieves were then recorded. After that, the pan was placed at the bottom of the sieve shaker, and the additional sieves were placed on the pan in order of increasing the sieve opening size. Then 2 kg of sample was placed on top of the sieve and shaken for 10 minutes. Lastly, the retained weight on each sieve were calculated and fineness modules was computed. Fineness modules of coarse aggregate computed by using equation 3.6.

$$fineness\ modules\ = \sum\left(\frac{cummulative\ percent\ of\ retained}{100}\right)$$ ……………...Equation 3.6

3.2.2.2. Specific Gravity and Water Absorption Tests

Specific gravity is the ratio of a given volume of aggregate to the weight of an equal volume of water. The water absorption test determines the water holding capacity of the coarse aggregates. It gives an idea of the internal structure of the aggregate and the strength of the aggregate. Apparatus used for sieve analysis is a series of the pan, shovel, balance, sample splitter, wire basket (20 cm diameter and 20 cm in height), absorbent cloth, and oven. Density, specific gravity and water absorption tests were done according to ASTM C127(2007)standard.

To carry out this test, sample was taken by using a sample splitter and sieved with 20 and 4.75 mm sieves to ignore materials retained on sieve opening 20 mm and passed through a sieve opening 4.75 mm. Then the sample was washed to remove dust particles and put in the oven at 110^{o}C for 24 hours. After that, the sample was allowed to cool after being removed from the oven and its weight was measured. The sample was submerged in the water for 24 hours. After the sample was removed from the water, it was rolled in a large absorbent cloth until all visible films of water were removed, and the required weight of the saturated surface dry sample was taken. After being weighted, immediately S.S.D sample was placed in the wire basket, and its weight in the water was determined. Finally, the sample dried to constant weight at a temperature of 110^{o}C, and cooled in the air for 2 hours. Overall calculations were done using equations 3.7 to 3.9.

- Bulk specific gravity = A/ (A+S-C)……………………………….…..Equation 3.7
- Apparent specific gravity = A/ (B+A-C)…………………………...Equation 3.8
- Absorption capacity = ((S-A)/A) * 100…………………………..…Equation 3.9

Where,

A: Weight of oven dry specimen in oven, (g)

B: Weight of wire basket with water, (g).

S: Weight of saturated surface dry specimen, (g).

C: Weight of wire basket with specimen in the water, (g).

3.2.2.3. Unit Weight Test

The unit weight of coarse aggregate is the weight of the coarse aggregate required to fill a container of a specified unit volume. This test was carried out in the same way that the procedure for determining the unit weight of fine aggregate was carried out in the previous section.

3.2.3. Test for Common Bean Straw Ash

3.2.3.1. Preparation of Common Bean Straw Ash

Primarily, common bean straw was collected from the source and packed for transportation. Then transported to the laboratory and placed around a clean area. After that, the common bean straw was washed to remove dust particles and dried under atmospheric conditions for two days. Then, burning of dried straw in the furnace took place. The sample was incinerate through a furnace for 2 hours at temperature of 500°C at the laboratory of Ethiopia Defense University, Bishoftu. Figure 3.4, shows the process of common bean straw ash preparation from common bean straw.

Figure 3.4: The process of common bean straw ash preparation.

3.2.3.2. Sieve Analysis

The main objective of sieve analysis is to determine the particle size distribution of common bean straw ash. Sieve analysis of the CBSA was undertaken, as the same as cement sieve analysis, since particle size distribution of CBSA should be similar to the cement.

3.2.3.3. Specific Gravity Test

Specific gravity is the ratio of the mass of a given volume of material to the mass of an equal volume of water. One method of determining the specific gravity of cement is to use a liquid that does not react with cement, such as water-free kerosene, by using a specific gravity pycnometer. A specific gravity pycnometer, in addition to hydraulic cement, can be used to determine the specific gravity of dust, sand, and other fine materials. Due to this reason, the specific gravity of CBSA is also determined by this method. The test was conducted according to ASTM C188 (2009) standard, the specific gravity of Portland cement ranges from 3.1 to 3.16 g/cc. Kerosene is used to determine the specific gravity because when water is used while testing it start reaction. This reaction may affect the experiment but kerosene does not react with cement and ash and not affect the test. The apparatus and kerosene used in this test are illustrated in Figure 3.5.

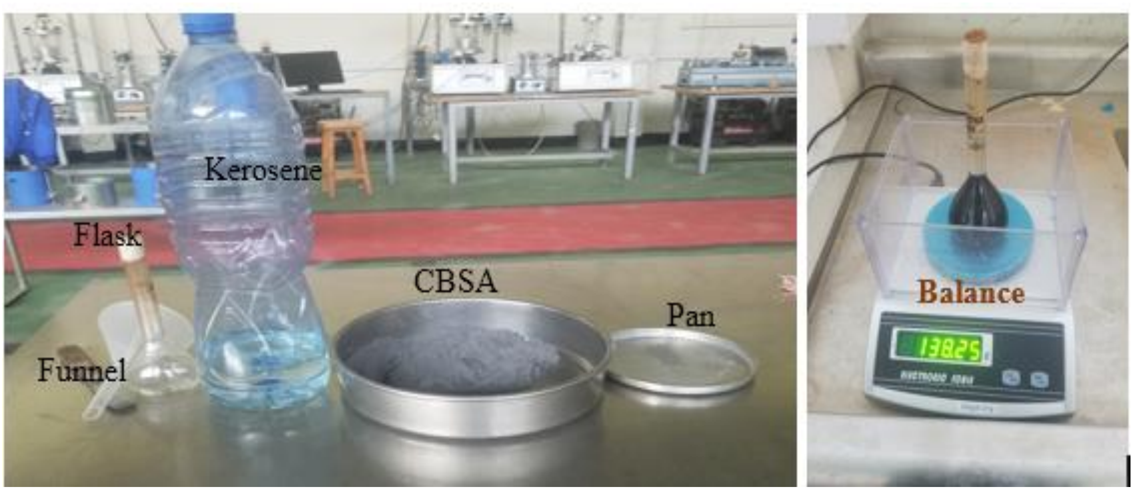

Figure 3.5: Apparatus and kerosene used to conduct specific gravity of the CBSA.

To conduct this test, initially, a specific gravity pycnometer was weighed and recorded. Then 25 g of CBSA was added to the pycnometer and measured. After that, kerosene was added up to the calibration point of the specific gravity pycnometer and weighted. Lastly, kerosene was poured into an empty pycnometer up to the calibration point and weighted. From obtained data, specific gravity of CBSA was calculated through equation 3.10.

$$S= \frac{(B-A)}{(B-A)-(C-D)*SK} \quad \text{.. Equation 3.10}$$

Where,

A= weight of specific gravity pycnometer (g)

B= weight of specific gravity pycnometer with CBSA (g)

C= weight of pycnometer with CBSA and kerosene (g)

D=weight of pycnometer with kerosene (g)

SK= specific gravity of kerosene (G)

SK= (weight of pycnometer with kerosene minus weight of pycnometer) divided to weight of pycnometer with distilled water minus weight of pycnometer).

3.2.3.4. Unit Weight Test

The density of CBSA is the weight of the ash that is required to fill a container of a specified unit volume. This test was done to determine the density of CBSA. The test was conducted by using a metal cylinder with a diameter of 100 mm and a height of 175 mm, a tamping rod, and balance. To undertake this test initial empty cylinder was weighted and recorded, then CBSA was filled into the cylinder through three layers, and each layer was rodded with 25 strokes by the tamping rod. After that, the weight of the filled cylinder with CBSA was measured and recorded. Finally, unit weight of CBSA was computed through equation 3.11.

$$\text{Unit weight} = \frac{F-C}{V} \quad \text{.......................................….Equation 3.11}$$

Where,

C = weight of empty cylinder (kg)

F = weight cylinder filled with CBSA (kg)

V = volume of cylinder ($V= \pi d^2 h/4$), while d is diameter and h denoted height of cylinder.

3.2.3.5. Chemical Composition Analysis

Chemical composition analysis is conducted for a wide range of purposes. The analysis provides valuable information about the elements of a test sample. Chemical composition analysis takes place to determine the amount of different oxides in the sample. This analysis can be done through different methods. For this research, a complete silica analysis was conducted at the laboratory of the Ethiopia Geological Survey.

3.2.3.6. Microstructural Test of CBSA

Scanning Electron Microscope (SEM) and X-Ray Diffraction (XRD) tests were used to determine the microstructure of the CBSA. The shape and size of CBSA particles were determined using SEM, while the amorphous and crystalline structures of CBSA particles were examined using XRD. To conduct SEM analysis of CBSA, initially sample was prepared by taking the ash that passed through sieve opening 150 μm. Then the prepared sample was taken to SEM laboratory and analysis was conducted. Finally, the displayed morphological image of CBSA was analyzed qualitatively through observation of the image. While to perform the XRD analysis of CBSA, at first sample was prepared as the same for SEM analysis and taken to XRD laboratory. Following the analysis, the peaks were generated on the Origin Software using the collected XRD data in terms of intensity and 2-theta scale. Finally, the peaks were interpreted using the X'pert High Score plus software.

3.2.4. Test for Water

Water is one of the most important components of concrete. As a result, water quality testing is required. The PH value determines the quality of the water used in concrete production. Therefore, determining the PH value of the water is crucial. The PH value of the water was measured using a PH meter in this study. To carry out this test initial water sample was prepared from water used for drinking function at Adama Science and Technology University. The electrode was then placed in the buffer. The electrode was then inserted into the water sample that had been prepared. Finally, the PH vale of water was readied from a PH meter as shown in the picture presented in Appendix D3.

3.2.5. Normal Consistency and Setting Time Test

3.2.5.1. Normal Consistency Test

Normal or standard consistency is the optimum percentage of water content required for a cement paste. The normal consistency test is used to determine the amount of water needed for the paste. The test was conducted according to ASTM C187(2016) standard to determine the normal consistency of hydraulic cement. To carry out this test Vicat apparatus has a plunger that weighs 500 g is needed. The test was done for four different percentages of pastes i.e. 0, 5, 10, and 15 % of common bean straw ash.

According to Juenger (2019), the use of SCM as a cement replacement is typically between 5 and 20%. Furthermore, Abdul Rahim (2014), Adero (2019), Belay (2016), and Hadiza(2019) carried out their research by replacing cement at 5% intervals with agricultural waste products. As a result, due to a lack of resources and time to conduct a pilot study to determine the appropriate replacement interval, 5% was chosen for the current study as the interval based on the references provided.

To begin this test, 650 g of cement and water were mixed together to make cement paste. The amount of replacement in the blended paste was subtracted from the total amount of cement in each replacement percentage. Next, the paste was placed on the ring of the Vicat apparatus, and excess paste was removed with the help trowel. After that, the plunger was attached to the moveable rod of the Vicat apparatus, and the movable indicator was seated initial reading could be taken. The rod was released after 30 seconds of paste formed, and the paste shall be of normal consistency when the rod settles to a pint 10 mm below the original surface 30 seconds after being released. Lastly, after the trial was made the normal consistency result was obtained. According to ASTM C187 (2004) the percentage of the water to be added to obtain the normal consistency is about 22-30% of the amount of cement. Appendix D5 shows experimental works during the normal consistency and setting time tests.

3.2.5.2. Setting Time Test

ASTM C 595 (2018) recommends the use of ASTM C 191 (2004) method for measuring setting time of hydraulic cements. The initial setting time of the paste was determined by the duration of 25 mm penetration of vicat needle into the paste in 30 seconds after it has been released while the final setting time was determined by measuring the time related to zero penetration of the needle into the paste.

Initially, 650 g of cement and 5, 10, and 15 % CBSA by weight of cement were used in the setting time test. Then, using the water content determined during the normal consistency test, cement, and blended CBSA paste were prepared. The time since water was added to the cement was recorded after the paste was placed on the Vicat ring. The specimen was allowed to sit for 30 minutes in the moist cabinet after molding without being disturbed. Until the penetration was reached 25 mm, the penetration of 1mm needle was determined for every ten minutes. . The initial reading was obtained by lowering the needle of the Vicat apparatus until it met the surface of the cement paste and tightening the screw. After that, the screw was released, and the needle was allowed to settle for 30 seconds to read the penetration. However, the final setting time is computed when the needles do not visibly sink into the paste.

3.2.6. Concrete Mix Design

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. In this study, ACI method was used to design mix proportion for C-15 grade of non-structural concrete. It involves designing a basic mixture containing only cement as a binder and incorporating CBSA in required percentage to produce final batches by adjustment of material quantities per unit volume. Target mean or average compressive strength of C-15 concrete is the sum of characteristic compressive strength at 28 days in N/mm² and concrete grade factor.

According to ACI 211.1-91 (2002), the first step for mix design is computing required average compressive strength from the given characteristic strength of 15 MPa.

$$f'ck = fck + X \quad \text{...Equation 3.12}$$

Where,

- fck - Characteristic compressive strength at 28 days in N/mm².
- f ’ck - Target mean compressive strength at 28 days in N/mm².
- X- Factor based on the grade of concrete.

Concrete that has less than 21 MPa concrete grade their factor is seven from Appendix A1. Therefore, target mean compressive strength for C-15 was:

15 MPa + 7 MPa = 22 MPa

Secondly, Minimum cement content was specified and slump value was selected. From durability considerations, cement content should not be reduced below 300 Kg/m^3 for concrete. IS 456 (2000) recommends higher cement contents for more severe conditions of exposure of weathering agents to the concrete. The average slump value chosen for trial mix was 30 mm, which is found between 20 to 80 mm for pavement and slabs from Appendix A2. The selected maximum and nominal size of aggregates was 20 mm and 19 mm respectively with non-air entrained concrete. The amount of water selected was 185 Kg/m^3 with entrapped air of 2%, based on slump value and maximum size of aggregate from Appendix A3.

The water–cement ratio is the ratio of the weight of water to the weight of cement used in a concrete mix. A lower ratio leads to higher strength and durability, but may make the mix difficult to work with and form. Water cement ratio (w/c) for average compressive strength of 22 MPa was 0.658 from Appendix A4, through interpolation. Then by having this ration, the amount of cement calculated as follows.

$$\text{Cement content} = \frac{\text{water content}}{\text{w/c}} \text{.......................................Equation 3.13}$$

$$\text{Cement content} = \frac{185}{0.658} = 281.16 \text{ kg/m}^3$$

The computed cement content was less than the specified minimum cement content, which is 300 kg/m$^{3.}$ Therefore, 300 kg/m^3 was used for the mix design for this study.

In this study, the specific gravity of CBSA was 1.78, which is less than the cement 3.13. Therefore, water to cementitious material ratio for different percentage of replacement were different. Water to cementitious material was computed as follows via equation 3.14.

$$\text{WCM}= \frac{3.13(\frac{w}{c})}{3.13(1-A)+sg(A)} \text{....................................... Equation 3.14}$$

Where,

- WCM: water to cementitious material ratio.
- W/c: water to cement ratio for control mix.
- A: replacement percentage.
- Sg: specific gravity of cementitious material (1.78)
- 3.13: specific gravity of cement.

Based on above equation the WCM for all replacement percentage were determined:

- For 5 % replacement= (3.13*0.658) / (3.13(1-0.05) + (1.78*0.05)) = 0.672
- For 10 % replacement= (3.13*0.658) / (3.13(1-0.1) + (1.78*0.1)) = 0.687
- For 5 % replacement= (3.13*0.658) / (3.13(1-0.15) + (1.78*0.15)) = 0.703

From the above calculation as the percentage of replacement increased the amount WCM also increased. Hence, all results were greater than water to cement ratio of control mix minimum specified cement content was used for all mixes.

ACI 211.1-91 (2002) recommends coarse aggregate content based on the fineness modulus of the fine aggregate and maximum size of coarse aggregate. For this study, the fineness modulus of fine aggregate was 2.81 and the maximum aggregate size was 20 mm. Then based on this value the oven-dry rodded coarse aggregate per unit volume of concrete was obtained 0.62 from Appendix A5**.** Weight coarse aggregate was computed by multiplying dry rodded density of coarse aggregate, and volume of oven dry rodded coarse aggregate per unit volume of concrete. The weight of coarse aggregate was 1043.86 kg/m^3, where obtained bulk density of coarse aggregate was 1683.64 kg/m^3. Solid volume of coarse aggregate was computed by dividing weight of coarse aggregate to specific gravity of coarse aggregate. Thus, solid volume of coarse aggregate was 388.05 l/m^3, while computed specific gravity was 2.69.

Solid volume of cement was 95.24 l/m^3 that obtained through division of minimum cement content to specific gravity of cement (300/3.13). Volume of water and air content were 185 and 20 l/m^3 respectively. Solid volume of fine aggregate was computed by deduction of volume of coarse aggregate, cement, water, and air from 1000. Then solid volume of fine aggregate was 311.71 l/m^3. Weight of fine aggregate was multiplication of its solid volume and specific gravity, which are 311.71 l /m^3 and 2.6 respectively and the obtained result, was 810.45 kg/m^3. Table 3.1 indicated the mix design for production of one cubic meter concrete before adjustment. The results in Table 3.1 were not directly used for mix; rather they adjusted based on the absorption capacity. The amount of water absorbed by coarse aggregate was computed by multiply weight of coarse aggregate and its moisture content, which is 0.018. Also the amount of water supplied by fine aggregate was computed by multiply weight of fine aggregate and its moisture content, which is 0.029. Then their result were 19.1 and 26.57 kg/m^3 respectively.

Table 3.1: Summary of mix design before adjustment on water absorption for one cubic meter of concrete.

Ingredients	Volume (l)	Weight (kg)
Cement	95.24	300
Fine aggregate	311.71	810.45
Coarse aggregate	388.05	1043.86
Water	185	185
Air	20	-
Total	1000	2,339.31

The above result were not directly used for mix; rather they adjusted based on the absorption capacity. The amount of water absorbed by coarse aggregate was computed by multiply weight of coarse aggregate and its moisture content, which is 0.018. Also the amount of water supplied by fine aggregate was computed by multiply weight of fine aggregate and its moisture content, which is 0.029. Then their result were 19.1 and 26.57 kg/m^3 respectively.

Adjusted water amount was calculated by sum up of absorbed water and deduct of supplied water to original water amount.

- Adjusted fine aggregate = original fine aggregate amount plus supplied capacity
- Adjusted coarse aggregate= original coarse aggregate amount minus absorbed capacity

Adjusted amount of all concrete ingredients for this study mix design presented in Table 3.2.

Table 3.2: Adjusted amount of concrete ingredients for production of one cubic meter concrete.

Ingredients	Weight in kg per m^3
Cement	300
Fine aggregate	787.11
Coarse aggregate	1024.76
Water	180.76

Since specific gravity of cement and CBSA was not equal, 1kg of cement is equal to 0.565 kg of CBSA. Therefore, 1 kg of cement was replaced by 0.565 kg of CBSA. The mix design for one cubic meter concrete production was summarized as Table 3.3. Amount of cement is depend on amount replacement. While the content of fine and aggregate are the same through all mixes.

Table 3.3: Summary of mix design for production of one cubic meter concrete.

Mix code	Cement content ($kg/m^{3)}$)	CBSA content ($kg/m^{3)}$)	Fine aggregate content ($kg/m^{3)}$)	Coarse aggregate content ($kg/m^{3)}$)	Water content ($kg/m^{3)}$)	Water to binder ratio
CBSA0	300	0	787.11	1024.76	180.76	0.658
CBSA5	285	8.48	787.11	1024.76	180.76	0.673
CBSA10	270	16.96	787.11	1024.76	180.76	0.688
CBSA15	255	25.43	787.11	1024.76	180.76	0.704

The ration of concrete mix design was computed by dividing quantity of fine and coarse aggregate to quantity of cement. From Table 3.4, the mix ration of concrete ingredients is 1: 2.62: 3.42.

Table 3.4: Mix design ratio

Ingredients	Cement(kg)	Fine aggregate (kg)	Coarse aggregate(kg)
Quantity	300	787.11	1024.76
Ratio	300/300	787.11/300	1024.76/300
	1	2.62	3.42

3.2.7. Batching and Mixing

Batching is the process in which the quantity or proportion of materials like cement, fine and coarse aggregates, water, etc. are measured based on either weight or volume to prepare the concrete mix. In this study, the weight batching method was employed, and Ordinary Portland cement was replaced partially by the weight at different percentage by CBSA. In addition to that, 0 % replacement was used as a control test for the study. The dry mix was carried out by mixing aggregate and cement before the wet mix. While for blended concrete, first CBSA was mixed with cement, and then mixed with other ingredients except for water. After that, water was added to the mix and mixed for 3 minutes. To mix the concrete small size automatic mixer was used. Concrete mix was carried out at room temperature. Concrete ingredients were batched as shown in Figure 3.6(A), dry mix of ingredients carried out as illustrated in Figure 3.6(B), and Figure 3.6(C) shows wet mixing.

Figure 3.6: Pictures shows batching and mixing procedure: A) batched ingredients, B) dry mixing, and C) wet mixing:.

3.2.8. Test for Fresh Concrete

The concrete slump test measures the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete. The slump cone test can be used as an indicator of an improperly mixed batch. If the concrete cannot flow because the consistency or slump is too low, there are potential problems with proper consolidation. If the concrete will not stop flowing because the slump is too high, there are potential problems with mortar loss through the formwork, excessive formwork pressure, finishing delays, and segregation. The test was done with accordance of ASTM C143 (2010) standard. To undertake this test slump cone (which has the shape of a frustum of a cone having dimensions, base diameter 200 mm, top diameter 10 mm, and height 300 mm), tamper rod (16 mm in diameter and 600 mm in length), Ruler, flat pan and tools were used.

The slump cone was first washed with water and placed on the flat pan to conduct the test. Fresh concrete was then poured into the cone in three levels, each layer accounting for around one-third of the cone's capacity and compacted with 25 tamper rod strokes. Strokes were evenly dispersed across the cone's cross-section. The cone was gently lifted once filling and compaction was completed, and the slump value was recorded using a ruler. The test was conducted through three trials to get the reliable result and the mean value computed for each mix codes. The slump test process and slump value are shown in Appendix D6.

3.2.9. Casting of Samples and Curing

Concrete was cast in cubes size (150*150*150) mm to investigate the compressive strength of the concrete. Different mixes are prepared at different percentage replacement cement by CBSA. The concrete was mixed, placed, and compacted in three layers. The specimens were stored in moist air for 24 hours as seen in Appendix D7 and the specimens were removed from the mold after 24 hours. Then submerged in clear freshwater at room temperature until the specimens are taken out from the curing tank just before the test, the concrete was surface dried for one hour in the moist condition before conducting the test.

Three samples were cast for each percentage of replacement at 7, 14, and 28 days of curing for the compressive strength test. Due to concrete gains maximum strength at 28 days and 65 % of the target strength by the time of 7 days, those curing periods were chosen. In addition, until 14 days concrete shows up to 90 % of the target strength (Gopal M., 2014). The minimum number of samples specified by ASTM C39 is three. To acquire a reliable value, three samples were prepared for each test in the current study. On other hand, (70*70*70) mm cube sized specimens were cast to carry out water absorption test. Three specimens were cast for each percentage of replacement at 7 and 28 days of the curing period. Due to the early hydration process of OPC, ASTM C140 recommends that water absorption concrete should be tested after 28 days of curing. In addition, a test at 7 days of curing was carried out to investigate the effect of curing age on water absorption. As shown in Table 3.5, 36 and 24 specimens were casted for compressive strength and water absorption tests respectively. Appendix D8 shows samples in the curing tank during curing periods.

Table 3.5: Number specimens casted for compressive strength and water absorption tests.

Mix Code	Number of specimens				
	For Compressive strength test			For water absorption test	
	7 days	14 days	28 days	7 days	28 days
CBSA0	3	3	3	3	3
CBSA5	3	3	3	3	3
CBSA10	3	3	3	3	3
CBSA15	3	3	3	3	3
Sub total	12	12	12	12	12
Grand total	**36**			**24**	

3.2.10. Test for Hardened Concrete

Testing of hardened concrete plays an important role in controlling and confirming the quality of cement concrete works. Systematic testing of raw materials, fresh concrete, and hardened concrete are an inseparable part of any quality control program for concrete, which helps to achieve higher efficiency of the material used and greater assurance of the performance of the concrete regarding both strength and durability. The test methods should be simple, direct, and convenient to apply.

3.2.10.1. Compressive Strength Test

The compressive strength is the ability of hardened concrete to withstand axial loads without cracking or deflection. This test aims to determine the compressive strength of hardened concrete by replacing cement with a different percentage of CBSA for 7, 14, and 28 days of the curing period. Compression tests are performed on cubic or cylindrical specimens. For this study, (150*150*150) mm cube-sized specimens were used. The test was carried out through an automatic compressive machine that has capacity of 3000KN at Adama Science and Technology University in accordance with ASTM C192 (2016)standard. The Load was applied gradually at the rate of 14 N/mm^2 per minute until the specimen failed. The compressive strength of concrete is a division of load at the failure to the area of the specimen. Some pictures showing the procedure of the test are attached in Appendix D9. Compressive strength of concrete is calculated according to equation 3.15.

$$CS = \frac{F}{A} \text{ ……………………………………………………………Equation 3.15}$$

Where,

- CS- Compressive strength in N/mm^2
- F- Force or load at point of failure in N
- Initial cross-sectional surface area in mm^2

3.2.10.2. Durability Test for Hardened Concrete

The ability of concrete to withstand weathering, chemical attack, water absorption, and abrasion while maintaining its desired engineering properties is called its durability. Concrete's durability can be determined in a variety of ways. A water absorption test was used to determine the concrete's durability for the current study. This test was conducted after the specimen cured for 7 and 28 days for all replacement percentages. The ASTM C140 (2013)standard was used to conduct this test. The specimens were first dried for 24 hours at 110°C, and their weight was recorded as dry weight. Then they were submerged in water for 72 hours, and their weight was recorded as submerged weight. For both the 7 and 28-day tests, the same procedure was followed. Appendix D10 shows procedures followed while conducting this test. Percent of water absorption was calculated based on equation 3.16.

$$\%\, water\ absorption = \left(\frac{immersed\ weight - Dry\ weight}{Dry\ wieght}\right) * 100\% \text{ …………….Equation 3.16}$$

3.2.10.3. Microstructural Test for Hardened Concrete

The concrete microstructural analysis is a methods used for determining the morphological characteristics of the concrete. The study of concrete microstructure has greatly benefited from microscope examination and X-ray microanalysis. SEM and XRD techniques are developed to image the complex microstructure of concrete and provide images with sub-micrometer resolution. The SEM uses a focused beam of electrons to scan the specimen and measures any of the signals produced by the beam's interaction with the specimen. The size, shape, surface roughness, and fracture of a surface are all investigated using topography images. Quantitative spot chemical analysis and element distribution maps are provided by X-ray microanalysis (Stutzman, 2000).

After 28 days of curing, samples were taken from the control mix and 5% replacement to conduct SEM analysis of the concrete. Initially, the samples were prepared by cutting a portion from the cured specimen and reducing them to the required size. Then the prepared samples were taken to the SEM laboratory. Finally, after the analysis was conducted, the displayed morphological images of the samples were analyzed qualitatively through the observation of the images.

To perform XRD analysis on the concrete, portions of the concrete were extracted from the control, and 5% replacement specimens were cured for 28 days. The portions were taken from the top, middle, and bottom of the specimens. Then the portions were ground to powder and taken to the XRD laboratory. Following the analysis, the peaks were generated on the Origin Software using the collected XRD data in terms of intensity and degree of diffraction. Finally, the peaks were interpreted using the X'pert High Score plus software.

3.2.11. Environmental and Economic Implication Exploration

The environmental and economic implications of using common bean straw ash as a partial cement replacement in concrete were explored in terms of raw materials usage, energy usage, CO_2 emissions, and economic implications. To investigate raw material usage, raw material consumption for the production of one cubic meter of concrete without and with CBSA was calculated and compared. The difference in incineration temperatures of cement clinker and CBS was employed as a parameter to investigate the energy usage and coal consumption of concrete without and with CBSA. To determine CO_2 emissions during the manufacturing of 1 kg of CBSA and compare them to cement CO_2 emissions, coal consumption and the difference in incineration temperature were used as a parameter due to the CO_2 emission of cement highly depends on coal consumption. Lastly, the cost of one cubic meter of concrete without and with 5% of CBSA was computed to explore cost implications. The current market price of materials and the cost of CBSA production were used to calculate the concrete cost.

4. RESULTS AND DISCUSSION

4.1. Introduction

This section presented and analyzed the results of various experimental tests. The chemical analysis of CBSA was mentioned, including the properties of the materials used in this study. Blended paste consistency and setting time were also observed. Workability, compressive strength, water absorption, and microstructure of the concrete were also discussed. Finally, the environmental and economic implications of using CBSA as a partial replacement of cement in concrete production were explored and presented.

4.2. Materials Properties

4.2.1. Fine Aggregate

4.2.1.1. Silt Content

Before using fine aggregate for concrete production, it was necessary to determine the silt content in the laboratory. According to Ethiopian standards, silt content should not be greater than 6% (Dinku, 2002)**.** As shown in Table 4.1, the average of the three-trail test of silt content of fine aggregate used for this study was 3.11%. The result shows that using this fine aggregate for construction purposes is permissible. However, for better quality of concrete fine aggregate used for the study was washed as seen in the Appendix D2.

Table 4.1: Silt content test result of fine aggregate

Trail	Volume of separated layer (ml)	Amount of fine aggregate (ml)	Silt content (%)
1	11	300	(11/300)* 100 =3.67
2	8	300	(8/300)* 100= 2.67
3	9	300	(9/300)* 100= 3.00
Average	**9.33**	**300**	**(9.33/300)* 100 =3.11**

4.2.1.2. Sieve Analysis

The laboratory test was carried out to identify the physical properties of the original sand sample was meeting the grading requirement to determine the fineness modulus of the fine aggregate.

Table 4.2 shows the fine aggregate grading requirements according to ASTM C136 (2006)and the fine aggregate grain size distribution. The calculation shows that the fineness modulus of sand is 2.81.

Table 4.2: Sieve analysis results and standard for fine aggregate.

Sieve size (mm)	Wt. of size (g)	Wt. of size and retained (g)	Wt. of retained (g)	Percent of retained (%)	Cumulative percent retained (%)	Percent finer (%)	Range (ASTM)
4.75	444	444	0	0	0	100	95-100
2.36	406	456	50	10	10	90	80-100
1.18	458	453	95	19	29	71	50-85
0.60	331	454	123	24.6	53.6	46.4	25-60
0.30	327	474	177	35.4	89	11	5-30
0.15	279	329	50	10	99	1	0-10
Pan	252	257	5	1	-	-	
Total Weight					280.6		

Fineness modules= $\frac{10+29+53.6+89+99}{100}$= 2.81

Fineness modules value in range the specified by ASTM C33 (2003) which is from 2.3 to 3.1. The gradation curve of used fine aggregate was laid between ASTM lower and upper limit as seen from Figure 4.1. So the used fine aggregate was meted the ASTM C136 (2006) requirement.

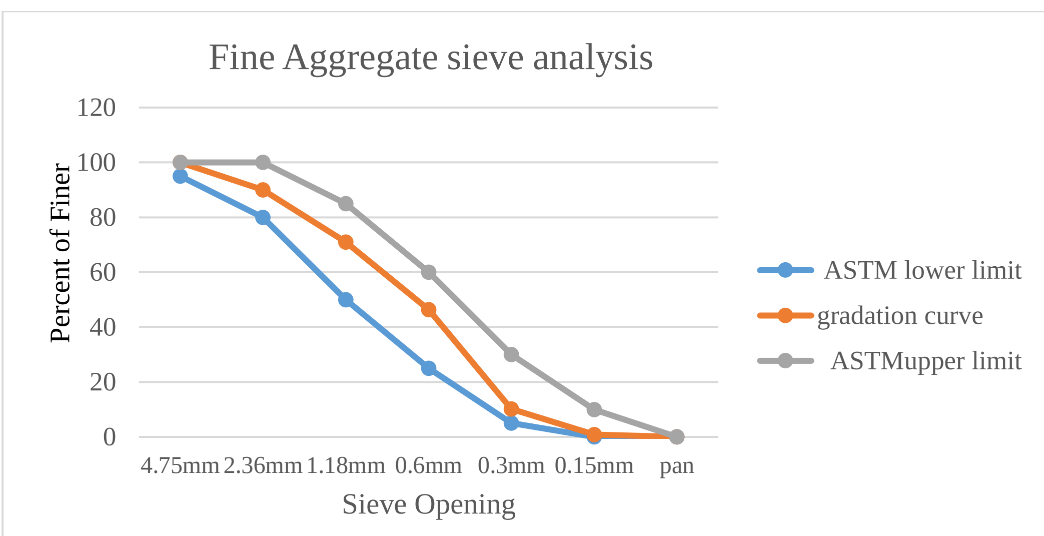

Figure 4.1: The result shows gradation curve of fine aggregate and ASTM lower and upper limit.

4.2.1.3. Specific Gravity and Water Absorption

Specific gravity and water absorption of fine aggregate were computed through obtained test results:

- Weight of oven dry specimen in oven (A) was 486 gram.
- Weight of pycnometer filled with water (B) was 1464 gram.
- Weight of saturated surface dry specimen (C) was 500 gram.
- Weight of pycnometer with specimen and water to calibration mark(S) was 1763 gram.

From the calculation in Table 4.3, bulk and apparent specific gravity of fine aggregate were 2.48 and 2.6 respectively. While obtained water absorption of fine aggregate result is 2.88 %. The obtained result, for specific gravity of fine aggregate was between limit (2.5 to 3.0) that specified by ASTM C127.

Table 4.3: Result of specific gravity and absorption capacity of fine aggregate.

	Formula	Calculation	Result
Bulk specific gravity(BSG)	BSG= S/(B+S-C)	500/(1464+500-1763)	2.48
Apparent specific gravity (ASG)	ASG= A/(A+B-C)	486/(486+1464-1763)	2.6
Water absorption (WA) in %	WA=((S-A)/A)*100	((500-486)/486)*100	2.88%

4.2.1.4. Unit Weight

Unit weight of fine aggregate was computed through the obtained test results:

- Weight of empty cylinder (T) was 4.734 kg
- Volume of the cylinder was (V) 0.001375 m^3
- Weight of the fine aggregate plus the cylinder (G) was 6.694 kg

Unit weight = (G-T)/ V

= (6.694-4.734) kg / 0.001375 m^3 = **1,425.45 kg/m^3**

Therefore, the computed unit weight of fine aggregate was within the range (1200 to 1750) kg/m^3 that specified by ASTM C29.

4.2.2. Coarse aggregate

4.2.2.1. Sieve Analysis

The laboratory test was carried out to identify the physical properties of the coarse aggregate was meeting the grading requirement ASTM C136. the grain size distribution of the coarse aggregate and the grading requirement for coarse aggregate according to ASTM C136(2006) is as show in Table 4.4.

Table 4.4: Result of sieve analysis of coarse aggregate.

Sieve size (mm)	Wt. of size (g)	Wt. of size and retained (g)	Wt. of retained (g)	Percent of retained (%)	Cumulative percent retained (%)	Percent finer (%)	Range [ASTM C136]
20	1381	1381	0	0	0	100	100
19	433	470	37	1.85	1.85	98.15	95-100
12.5	440	1160	720	36	37.85	62.15	40-80
9.5	443	1173	730	36.5	74.35	25.65	20-55
4.75	444	957	513	25.65	100	0	0-10
Pan	252	252	0	0	-	0	-

The gradation curve of the employed coarse aggregate was within the ASTM lower and higher limits, as shown in Figure 4.2. As a result, the fine aggregate used met the requirements.

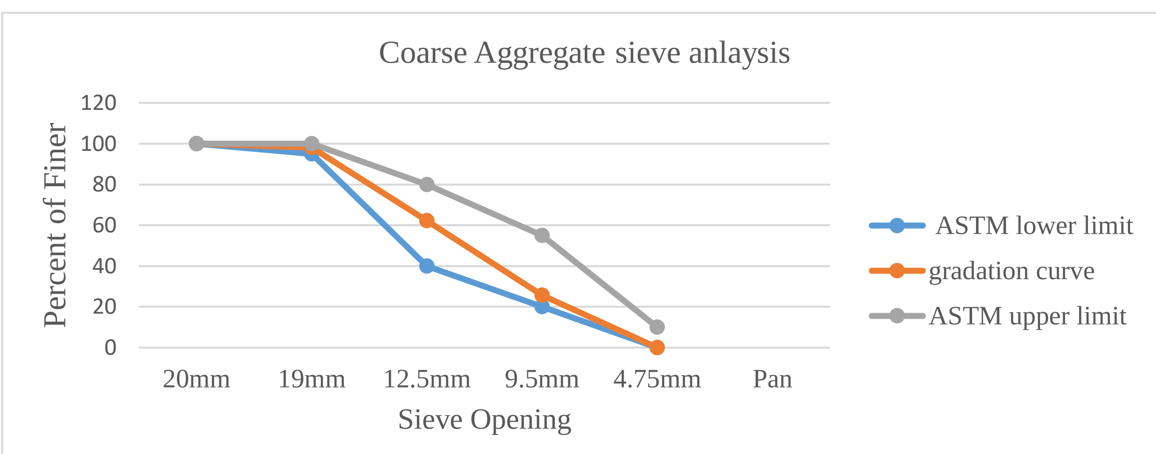

Figure 4.2: Chart shows the gradation curve of coarse aggregate and ASTM lower and upper limit.

4.2.2.2. Specific Gravity and Water Absorption

Specific gravity and water absorption of coarse aggregate were computed through obtained test results:

- Weight of oven dry specimen in oven (A) was 2946 gram.
- Weight of saturated surface dry specimen (B) was 3000 gram.
- Weight of specimen in the water with the wire basket (C) was 1763 gram.

From the calculation in Table 4.5, bulk and apparent specific gravity of coarse aggregate were 2.61 and 2.69 correspondingly. While obtained water absorption of coarse aggregate result is 1.83 in percent. The obtained result, for specific gravity of coarse aggregate was between limit (2.5 to 3.0) that specified by ASTM C128. In addition, water absorption of coarse aggregate was less than the specified maximum value (2%).

Table 4.5: Result of specific gravity and absorption capacity of Coarse aggregate.

	Formula	Calculation	Result
Bulk specific gravity(BSG)	BSG= B/(B-C)	3000/(3000-1852)	2.61
Apparent specific gravity (ASG)	ASG= A/(A-C)	2946/(2946-1852)	2.69
Water absorption (WA) in %	WA=((B-A)/A)*100	((3000-2946)/2946)*100	1.83%

4.2.2.3. Unit Weight

Unit weight of coarse aggregate was computed through obtained test results:

- Weight of empty cylinder (T) was 4.734 kg
- Volume of the cylinder was (V) 0.001375 m^3
- Weight of the coarse aggregate plus the cylinder (G) was 7.049 kg

Unit weight = (G-T)/ V

= (7.049 - 4.734) kg / 0.001375 m^3 = **1,683.64 kg/m^3**

The result shows that, the unit weight of coarse aggregate was laid between the ranges (1200 to 1750) kg/m^3 that specified by ASTM C29. Therefore the coarse aggregate used for the current study was fulfilled the requirements in terms of unit weight. The summary of fine and coarse aggregate test results were summarized in Table 4.6.

Table 4.6: Summary of test results of fine and coarse aggregate.

Test description		Fine aggregate	Coarse aggregate
Silt content (%)		3.11	-
Max size (mm)		4.75	20
Unit weight (kg/m^3)		1,425.45	1,683.64
Water absorption (%)		2.88	1.83
Fineness modulus		2.81	-
Specific gravity	Bulk	2.48	2.61
	Apparent	2.6	2.69

4.2.3. Water

To check the quality of the water used for the concrete production PH measuring test was conducted. According to the obtained result, the PH value of water found at Adama Science and Technology University is 7.56. The acquired result is between the range(6 to 8.5) that specified by ASTM(2006) standard. So, the water used for mixing concrete in the current study is fulfilled the requirements.

4.2.4. Common Bean Straw Ash

4.2.4.1. Sieve Analysis of Common Bean Straw Ash and Cement

This test was carried out to determine the percentage of fine particles of CBSA and cement that pass through a sieve opening of 75 μm. As shown in Table 4.7, 86% of CBSA was passed through sieve opening of 75 μm, whereas 76% cement passed. As a result, CBSA is finer than cement, implying that CBSA has a larger specific surface area than cement. This is because as particle size decreases, the surface area of substances increases (Selamawit W, 2020). This implies a reduction in particle size utilized to fill the gap between aggregates. However, an increase in the surface area leads to incremental water needs, which leads to compressive strength reduction and durability degradation when the CBSA is employed in large amounts.

Table 4.7: Particle size of cement and CBSA

Sieve size (μm)	Wt. of size (g)	Cement			Common bean straw ash		
		Wt. of size and retained (g)	Wt. of retained (g)	Percent finer (%)	Wt. of size and retained (g)	Wt. of retained (g)	Percent of retained (%)
150	279	279	0	100	279	0	100
75	273	285	12	76	280	7	86
Pan	253	291	38	0	296	43	0
Total			50			50	

4.2.4.2. Specific Gravity of Cement and CBSA

The specific gravity of cement and CBSA were 3.13 and 1.78 respectively. As shown in Table 4.8, the specific gravity of CBSA is smaller than that of cement. This implies CBSA was lighter than cement. Besides, computed specific gravity of cement is within a range of ASTM C188(2009) standard, which ranges (from 3.1 to 3.16). Low specific gravity of CBSA is causes reduction in unit weight of concrete.

Table 4.8: The result of specific gravity of cement and CBSA

Particulars	Denotation		Samples in gram			
			1	2	3	Mean
Weight of empty flask (g)	A	Cement	46.81	46.81	46.81	46.81
		CBSA	46.81	46.81	46.81	46.81
Weight of pycnometer with CBSA (g)	B	Cement	71.65	71.73	71.80	71.73
		CBSA	71.75	71.81	71.85	71.80
Weight of pycnometer with CBSA and kerosene (g)	C	Cement	146.02	146.35	141.25	146.21
		CBSA	138.25	139.1	137.95	138.28
Weight of pcynometer with kerosene (g)	D	Cement	124.75	124.76	124.74	124.75
		CBSA	124.75	124.98	123.98	124.57
Specific gravity	S	Cement				3.13
		CBSA				1.78

Specific gravity of CBSA and cement were calculated by using Equation 3.10, where specific gravity of kerosene was 0.79.

4.2.4.3. Unit Weight of CBSA

Unit weight of CBSA was calculated through obtained test results:

- Weight of empty cylinder (C) was 4.740 kg
- Volume of the cylinder was (V) 0.001375 m^3
- Weight of the cylinder filled with CBSA (F) was 5.845 kg

Unit weight = (F-C)/ V

$$= (5.845 - 4.740)\ kg / 0.001375\ m^3 = \mathbf{803.6\ kg/m^3}$$

As the result, unit weight of CBSA was lower than the cement that is 1440 kg/m^3 that indicates concrete with CBSA was lighter than concrete without CBSA.

4.2.4.4. Chemical Composition of CBSA and National OPC Cement

The chemical composition of CBSA and National OPC cement was determined through complete silica analysis at laboratory of the Ethiopian Geological Survey and presented in Table 4.9. The results show that CBSA was reach in SiO_2 content (47.88%) and it has high LOI content. The reason for occurrence of high LOI in CBSA is presence of carbon in the ash due to low combustion temperature. According to Barrack and Sylvester (2021), the value of LOI increases when compounds are burned at a low temperature. The SCBA has LOI value of 11.07%, which is lower than ASTM C618's maximum value of 12%. The combined oxide composition: SiO_2 + Al_2O_3 + Fe_2O_3 = 51.07% which is greater than 50%. So according to ASTM standards CBSA shows the pozzolanic property and belonged to class C pozzolanic materials.

CBSA has lower SiO_2 content than rice husk ash, teff straw ash, and sugarcane bagasse, according to the reviewed literature in (section 2.3.2.1), Table 2.2. However, when compared to locust bean pod ash, CBSA has slightly more SiO_2 content. The CaO content of CBSA was higher than that of other AWPs. Furthermore, the CBSA was discovered to contain a high alkali content, such as K_2O (10.06%), signaling a high potential for the alkali-silica reaction when utilized in concrete with silica reach aggregate. As a result, combining CBSA with silica reach aggregate has a negative impact on the long-term durability of concrete. It is recommended to handle this problem with a silica-free aggregate.

Table 4.9: Oxide composition of CBSA and National OPC cement

Oxide Composition (%)	National OPC Cement [Appendix C1]	CBSA [Appendix C2]
SiO_2	26.02	47.88
Al_2O_3	5.09	2.33
Fe_2O_3	3.48	0.86
CaO	60.40	20.92
MgO	1.76	4.78
Na_2O	0.34	1.30
K_2O	0.56	10.06
LOI	1.89	11.07
$SiO_2 + Al_2O_3 + Fe_2O_3$	34.59	51.07

4.2.4.5. Microstructure of CBSA

The morphology of the CBSA particles was studied using scanning electron microscopy (SEM). The results of the SEM for CBSA at 20µm and 10µm grid sizes were shown in the Figures 4.3. Figure 4.3 (a) shows micrographs that depict a qualitative description of the phases seen in CBSA. The CBSA particles were discovered to have irregular shapes. In the microstructure, higher magnifications revealed irregularly shaped particles. The irregular shapes evidence the presence of silica in the ash. Fibers on the surface of CBSA are depicted in Figure 4.3(b). Low combustion temperature may cause a fibrous surface. Additionally, distinct textures can be observed due to the morphology of the straw. There are also porous and fine particles visible. As seen in the magnified image of CBSA, Figure 4.3 (b), small cavities on the surface indicate the presence of an interconnected porous network.

The crystallographic characteristics of CBSA were investigated using an XRD diffractometer set to 24 mA, 40 Kv, and 2θ scans between 10° and 80°. Diffraction patterns were detected using XRD data and X'pert High score plus software to determine the crystallographic phases of the CBSA. Figure 4.4 shows CBSA's X-ray diffraction pattern. Quartz (SiO_2) was found along the steep peaks at 2θ values of 29.2° and 27°, whereas CaO was found at 2θ values of 34° and K_2O was found at 2θ value of 45.2°. Furthermore, CBSA qualitative examination indicated silica's amorphous structure. The intensity of the phase diffraction peaks is directly proportional to the concentration of the crystallographic component that forms it and the difference in the concentration of the components is marked by the difference in peak intensities (Memon et al., 2021). The diffraction patterns reveal the slight amount of amorphous silica in CBSA. Because of its more reactive nature, amorphous silica is more desirable than crystalline silica, which aids in the acceleration of the pozzolanic reaction.

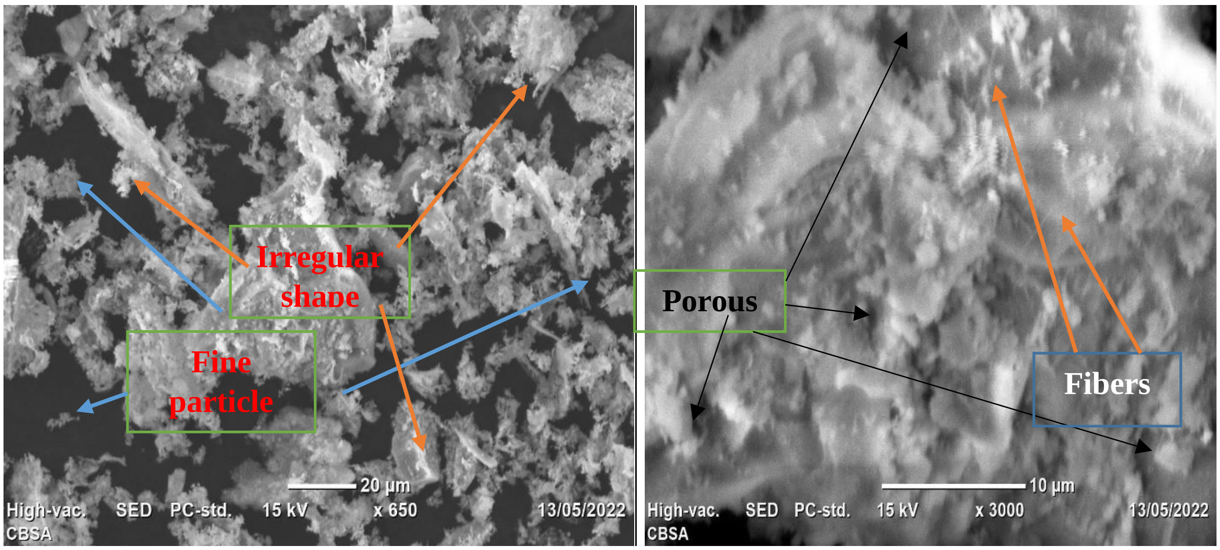

Figure 4.3: SEM image of CBSA at a) 1000 and b) 2000 magnification.

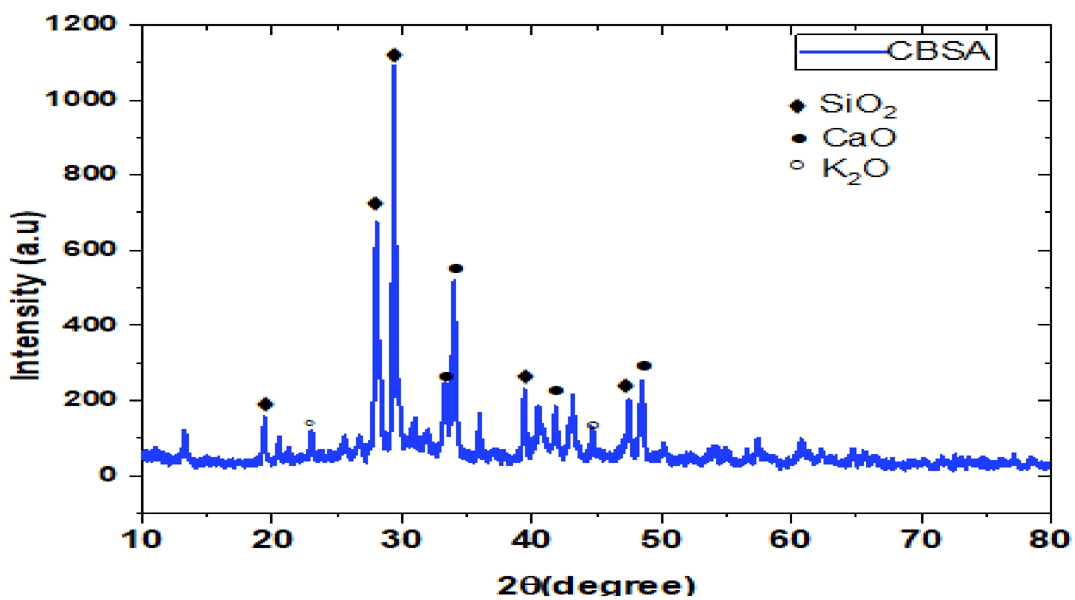

Figure 4.4: XRD analysis of CBSA

4.2.5. Normal Consistency and Setting Time of Blended Paste

The normal consistency of the control paste was 26%. The usual consistency of all blended pastes was greater than the control paste, as shown in Table 4.10. At 5, 10, and 15% of replacement, normal consistency of blended pastes was attained at 28, 29, and 31%, respectively. According to ASTM C187 **(**2016) range, normal consistency of blended paste at 5% and 10% replacements were in ranges (22-30 %). Whereas at 15% of replacement it was beyond specified range. Based on the current investigation, blended paste with 5% CBSA was chosen over other replacement percentages excluding control paste.

Table 4.10: Result of normal consistency and setting time of blended paste with common bean straw ash

Mix code	Normal consistency (%) (ASTM C187)	Initial setting time (minutes)	Final setting time (minutes)
CBSA0	26	123	289
CBSA5	28	145	330
CBSA10	29	153	352
CBSA15	31	172	368

Figure 4.5 indicates that the normal consistency rose as the replacement percentage increased. The greater fineness and porosity of CBSA compared to cement resulted in an incremental in normal consistency.

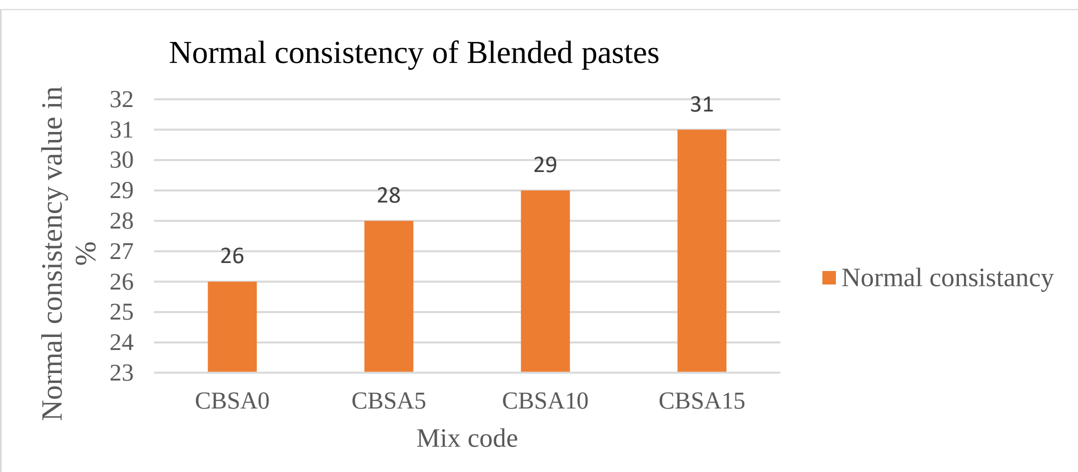

Figure 4.5: Chart of normal consistency of blended paste

The results for setting time in Table 4.10 and illustrated in Figure 4.6 indicated that the addition of CBSA retarded both the initial and final settings of the paste. The initial setting time of blended paste was retarded from the control paste by 17.88%, 24.39%, and 39.84% at 5%, 10%, and 15% replacement respectively. While the final setting was retarded by 14.18%, 21.80%, and 27.34% respectively. However, this retardation was within the limit as specified by ASTM standards. The reason for retardation could be a high demand of water by surface area of CBSA and late hydration of pozzolanic materials. In addition, reduction of calcium hydroxides and the development of silica gel film around cement grains may have caused the retardation of setting time **(**Ajay et al., 2009**)**. As a result, in hot climates where delayed hydration is essential, CBSA as a partial replacement for cement is advised. Detail time and date of the experiments were presented in Appendix B1.

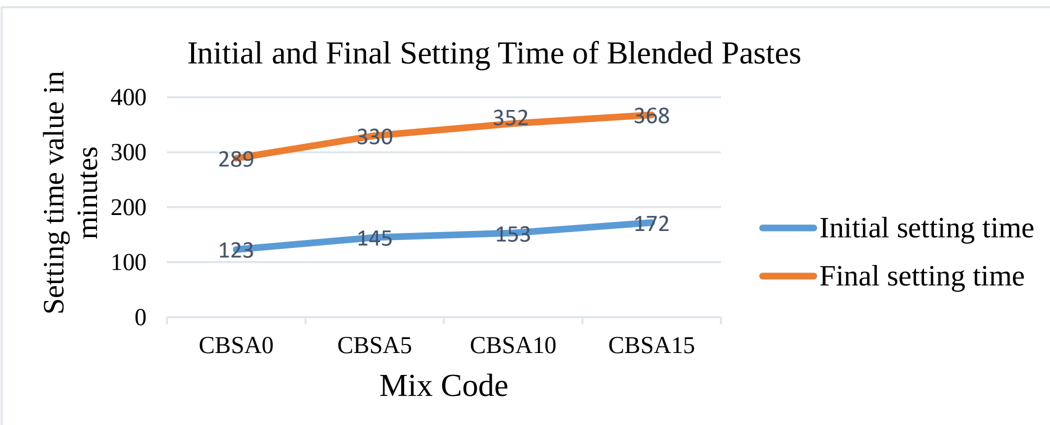

Figure 4.6: Initial and final setting time of blended paste with CBSA

4.3. Workability of the Concrete

Table 4.11 shows the results of the CBSA concrete's fresh concrete properties, which show a flow of slumps between 19 and 25 mm. The least slump value was obtained at the 15% replacement, while the control mix had the highest slump value. The slump value of concrete with 15% CBSA was outside of the range used for mix design, whereas the slump value of concrete with 5% and 10% replacement was within the range. Workability of concrete decreases as the percentage of replacement increases. The obtained result indicated that adding more content of CBSA to the concrete decrease the workability is similar to the properties of other AWPs discussed in the literature part. Detail result for each samples attached in Appendix B2.

Table 4.11: Result of mean slump value of fresh concrete.

No.	Mix Code	Percent replaced	Slump result in mm
1	CBSA0	0	25
2	CBSA5	5	24
3	CBSA10	10	21
4	CBSA15	15	19

As shown in Figure 4.7, the slump values of samples CBSA5, CBSA10, and CBSA15 dropped by 4%, 12%, and 24%, respectively, when compared to the control slump value. The porous structure of CBSA could cause a decrease in a slump as its content increases. The presence of macro and mesoporous inside and on the surface of the material resulted in a significant specific surface area which leads material to high water absorbent (Akpenpuun et al., 2019). The CBSA was absorbed some amount of water due to its surface during mixing which would be cause a subsequent reduction in free water and a lower slump value Therefore, concrete with high content of CBSA is unworkable. In general, the addition of mixing water can aid in simple mixing and workability, but it generates increased porosity, which results in strength and durability degradation (Kim et al., 2014). In the current study, concrete with 5% of CBSA showed better workability when compared to other replacement percentages except the control mix.

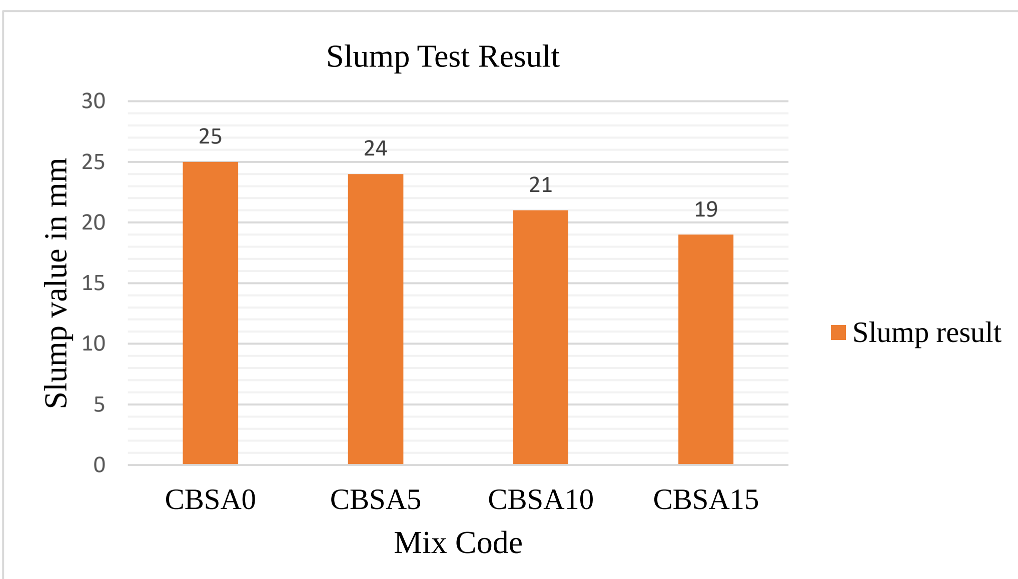

Figure 4.7: Chart shows slump value of concrete at different percentage of replacement.

4.4. Properties of the Hardened Concrete

4.4.1. Unit Weight

The results for the average weight and volume of cube-sized (150*150*150) mm are presented in Table 4.12. The highest value was obtained for the unit weight of concrete with 0% replacement at 7 days, while the lowest value was obtained for the unit weight of concrete with 15% replacement at 28 days.

Table 4.12: Unit weight of concrete blended with CBSA.

Curing period in days	Mix code	Mean mass in kg	Volume in m^3	Unit wt. in kg/m^3	Reduction in %
7	CBSA0	7.60	0.003375	2,251.85	0.00
	CBSA5	7.55	0.003375	2,237.04	0.66
	CBSA10	7.51	0.003375	2,225.19	1.19
	CBSA15	7.40	0.003375	2,192.59	2.63
14	CBSA0	7.56	0.003375	2,240.00	0.00
	CBSA5	7.51	0.003375	2,225.49	0.65
	CBSA10	7.49	0.003375	2219.26	0.93
	CBSA15	7.38	0.003375	2,186.67	2.40
28	CBSA0	7.49	0.003375	2,219.26	0.00
	CBSA5	7.46	0.003375	2,210.37	0.41
	CBSA10	7.43	0.003375	2,201.48	0.80
	CBSA15	7.36	0.003375	2,180.74	1.73

The biggest reduction in a unit weight of 2.63% was obtained when 15% of the cement was replaced by CBSA during the 7-day curing period. As illustrated in Figure 4.8, the unit weight of concrete decreases as the percentage of replacement of CBSA increases. While the percent of the reduction in unit weight decreased as the curing period increased. The reduction in the unit weight of concrete is due to the specific gravity of CBSA. The low specific gravity of the CBSA, 1.78, as compared to 3.13 for that of OPC resulted in a reduction of unit weights of the blended concretes. Specific gravity of materials and their unit weight have direct relationship (Goshu, 2019). Therefore, replacing cement at specified percentage of CBSA is preferred for the production of lightweight concrete, especially for non-structural concretes and light structures. Figure 4.8 shows that, the reduction in unit weight as CBSA content increases.

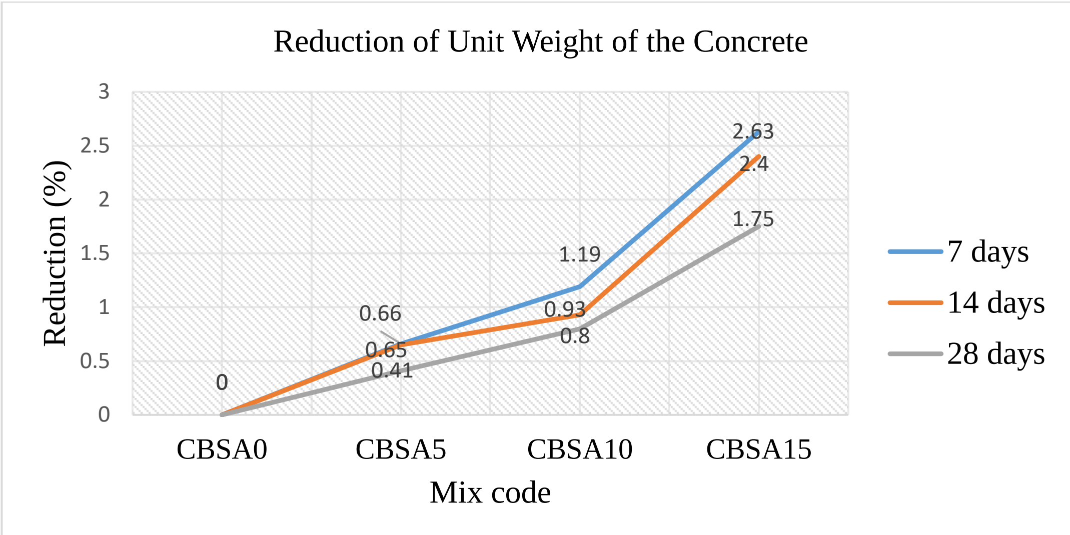

Figure 4.8: Chart shows percent of reduction in unit weight of concrete.

4.4.2. Compressive Strength

The most popular test for hardened concrete is the compressive strength test. Many codes and design manuals are based on this characteristic. Other properties of concrete are dependent on compressive strength, and it is easy to detect the concrete property when compared to other tests. Concrete's compressive strength was tested using cubes measuring 150 x 150 x 150 mm that were placed under a 3000 KN compression machine. Three cube samples were examined for each mix codes and curing days, and the average values were used to determine the compressive strength of concretes. The detail results of compressive strength test are presented in Appendix B3, and average compressive strength results are summarized in the Table 4.13.

According to data presented in Table 4.13, at 7 days, the compressive strength of the control (CBSA0) mix was recorded as the highest value (13.54 N/mm^2) due to concrete with pozzolanic materials does not achieve early strength when compared to normal concrete due to slow hydration and slower setting. While the compressive strength of the CBSA5 mix was 17.94 N/mm^2 and 18.98 N/mm^2 at 14 and 28 days, respectively, they were the highest values for their respective curing days. As an outcome, in the current investigation, concrete with 5% CBSA maintains maximal compressive strength.

Table 4.13: Average compressive strength of the concrete with different replacement percentage at 7, 14, and 28 day's age.

No.	Mix code	Average compressive strength result in N/mm^2			Improvement (%) at 28 day
		7^{th} day	14^{th} day	28^{th} day	
1	CBSA0	13.54	16.42	18.31	0
2	CBSA5	13.18	17.94	18.98	+ 3.65
3	CBSA10	12.45	15.95	17.85	- 2.51
4	CBSA15	11.70	14.89	17.04	- 6.93

Figure 4.9 shows that the compressive strength of concrete with 5% CBSA replacement improves by 3.65% when compared to concrete without CBSA. This enhancement is due to CBSA's pozzolanic properties. A pozzolanic reaction occurs between CBSA and CH, resulting in the formation of additional C-S-H in most of the voids surrounding hydrated cement particles. This additional C-S-H not only enhances the compressive strength of the concrete. However, it creates a much denser matrix, mostly in areas that would have remained as small voids susceptible to the entrance of harmful materials (Akpenpuun et al., 2019). Concrete with more than 5% of CBSA shows a reduction in compressive strength. The reason for reduction could be the finer particles and porous surface of CBSA that leads to incremental in water requirement. The compressive strength of concrete decreases when the amount of water increases Additionally, Silica with a slight amorphous structure has low reactivity and could be used as a filler. Because of this, the compressive strength of concrete falls as the percentage of replacement increase. Moreover, the compressive strength of concrete with CBSA up to 15% replacement was greater than the characteristics compressive strength of C-15 non-structural concrete, which has 15 N/mm^2.

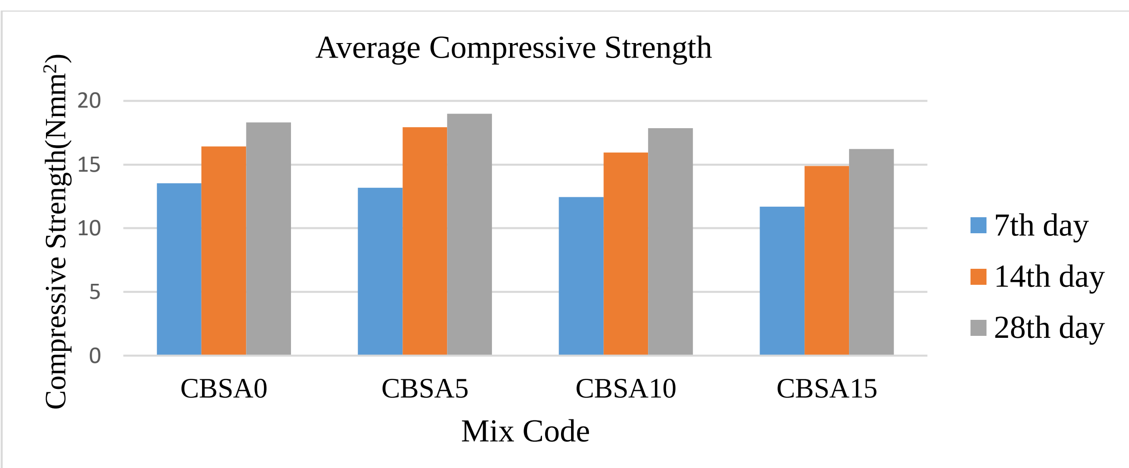

Figure 4.9: Average compressive strength of the concrete.

As illustrated in Table 4.13 and Figure 4.10, concrete with 5% of CBSA only shows positive improvement while concrete with 10 and 15% of CBSA shows negative improvement (reduction) by 2.51 and 6.93% respectively.

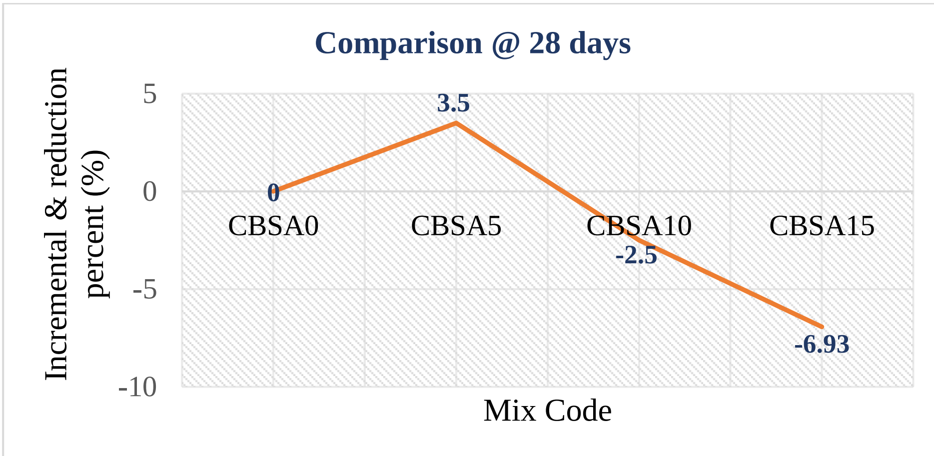

Figure 4.10: CBSA0 mix code compressive strength compression to other mix codes.

The minimum compressive strength value obtained from three samples of the CBSA0 mix is 17.28 N/mm^2, which is larger than the lower limit of 16.75 N/mm^2 that is limited based on the mean value and standard deviation. As a result, the obtained results meet the requirement and are reliable. Furthermore, the lower limit of compressive strength of the CBSA5 mix was 17.89 N/mm^2 based on the samples' mean value and standard deviation. However, the minimum compressive strength of concrete containing 5% of CBSA obtained from three samples was 18.31 N/mm^2, which is larger than the lower limit, as shown in Figure 4.11 and Appendix B3. Therefore, the results validate the tests' reliability.

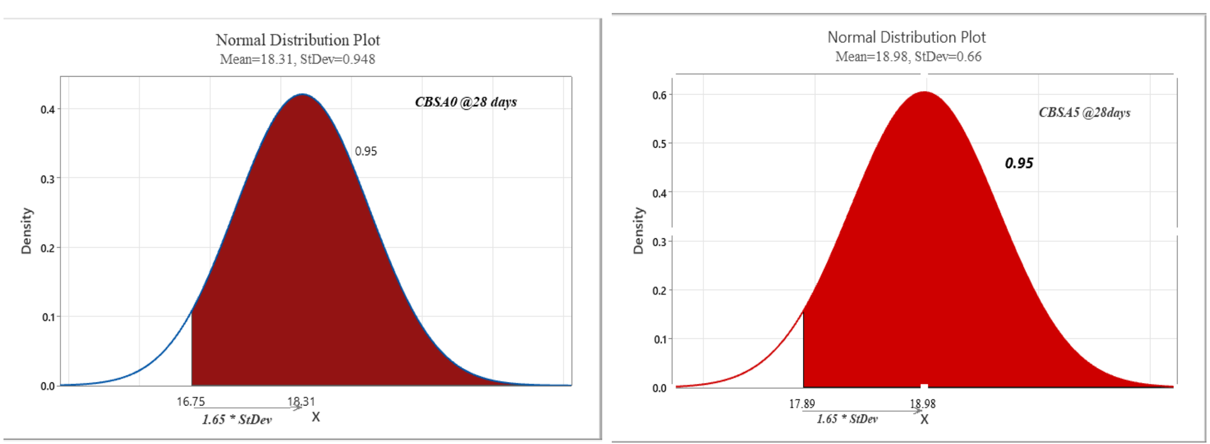

Figure 4.11: Normal distribution plot of compressive strength results.

4.4.3. Water Absorption

Water absorption is used to determine the amount of water absorbed under specified conditions. A water absorption test was conducted to measure the durability of the concrete. As presented in Table 4.14, the average water absorptions of CBSA concrete were 8.3%, 10.1%, 10.9%, and 11.1% for sample with; 0%, 5%, 10%, and 15% of replacement respectively after a 7-day curing period. While; 8%, 9.6%, 10.1%, and 10.9% were obtained at 28-day curing period for each respective replacement percentage. The lowest water absorption occurred at control mix and the highest occurred at 15% replacement for both 7 and 28 days. Detailed results for all samples are presented in Appendix B4.

Table 4.14: Average water absorption of concrete at 7 days and 28 days in percentage.

Mix code	Average of water absorption percentage					
	At 7^{th} day			At 28^{th} day		
	O (g)	S (kg)	%	O (kg)	S (kg)	%
CBSA0	0.726	0.786	8.3	0.735	0.794	8.0
CBSA5	0.695	0.765	10.1	0.708	0.776	9.6
CBSA10	0.690	0.765	10.9	0.696	0.766	10.1
CBSA15	0.675	0.750	11.1	0.689	0.764	10.9

Where, O denotes for weight of oven dry sample and S for submerged sample.

Figure 4.12 shows that when the percentage of replacement increased, water absorption of concrete at 7 and 28 days also increased. A higher amount of water absorption concrete with CBSA is due to the porous surface, which leads to high specific surface area. As the result the surface of CBSA was, absorb more water. However, water absorption concrete decreased as curing ages increased as the result of late hydration of concrete with pozzolanic materials. Furthermore, pore structures formed during hydration and porosity often reduce with age in curing conditions (Kim et al., 2014). Water absorption of concrete without CBSA and with 5% of CBSA were less than the maximum water absorption specified by ASTM C642(2013) which is 10% at 28 days. While concrete with 10% and 15% of CBSA has water absorption greater than the specified maximum value. From the current study finding using concrete with 5%, replacement is acceptable rather than the other replacement percentages in terms of water absorption of the concrete. The surface water absorption simply reduced the cover concrete's compressive strength. The surface and inner structures of concrete determine the overall strength. As a result, surface water absorption cannot be utilized only to determine concrete strength (Zhang & Zong, 2014). This could explain why the compressive strength was higher at 5% replacement as compared to the control mix, which had reduced water absorption capabilities. .

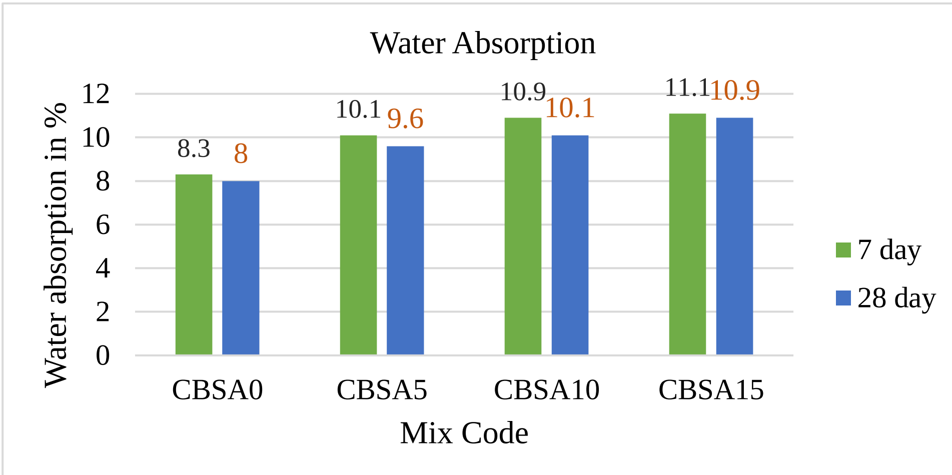

Figure 4.12: Shows water absorption concrete at 7 and 28 days.

4.4.4. Microstructure of the Concrete

Microstructural observation of mixes without CBSA and with 5% CBSA through SEM analysis can be seen in the Figure 4.13. CBSA0 and CBSA5 mixes were investigated using SEM due to the maximum compressive strength, better workability, and lower water absorption observed at 5% replacement versus other replacement percentages. SEM images are taken after a prolonged curing period of 28 days. Each mix was explored under (x650) magnification to investigate the microstructure of the concrete. Calcium hydroxide is identified by its relative brightness and hexagonal habits in the concrete (Stutzman, 2000). In the control mix, a narrow and bright structure with crystalline formation was observed that could be CH, as shown in the Figure 4.13(a). While CBSA's pore structure is becoming more refined, it is still dense at 5% replacement, as shown in Figure 4.13(b). The mix with 5% CBSA replacement could be seen, as could reduced voids on the surface due to improved hydration and a high occurrence of calcium silica hydrate (C-S-H) gels on the surface, as short noted by the networked fiber structure. This could account for the maximum compressive strength achieved at this mixed level. The formation of amorphous C-S-H gel is primarily due to secondary hydration caused by CBSA's pozzolanic properties (Akpenpuun et al., 2019). The reduction in CH content caused by the pozzolanic reaction of ash particles is the most significant difference between concrete without CBSA and concrete with 5% of CBSA.

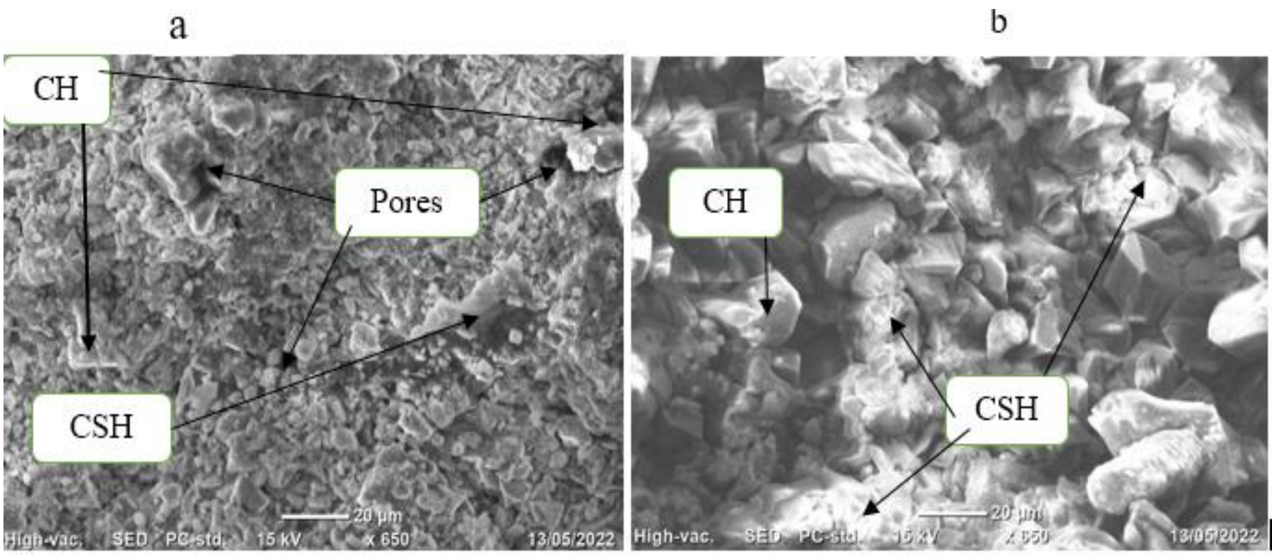

Figure 4.13: SEM images of at 650 magnification: a) CBSA0 and b) CBSA5.

The X-ray energy level is represented as a set of peaks on a continuous background, with the number of counts at each energy interval. Peak positions and relative intensities are used to identify elements because peak positions and relative intensities are unique to each element. Peaks were determined using XRD data and the X'pert High score Plus software. Figure 4.14 shows the X-ray diffraction pattern of concrete without CBSA and with 5% CBSA. According to the findings, CH in the concrete with CBSA has high peaks at 2θ values of 28°.

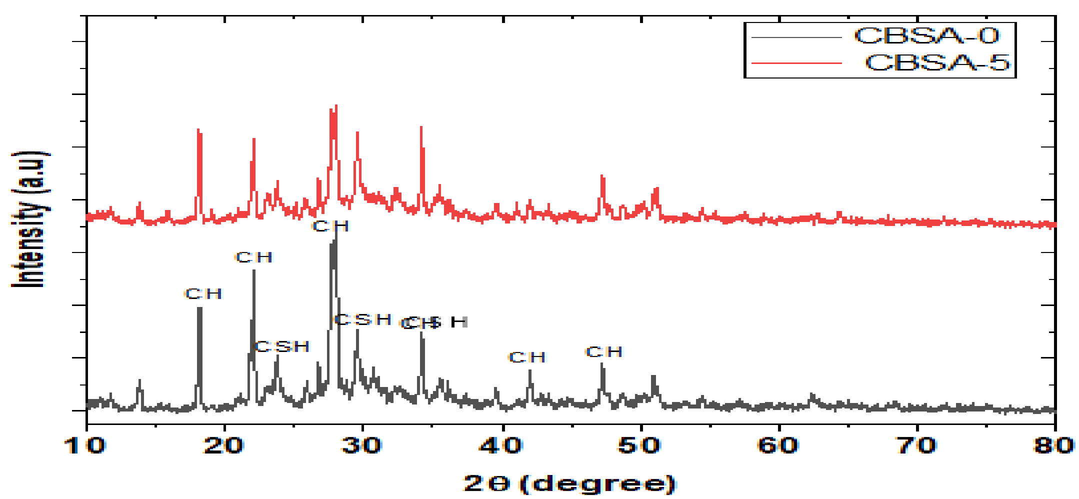

Figure 4.14: XRD analysis of CBSA0 and CBSA5 concrete specimens.

The intensity of the CH peaks in the CBSA5 mix appears to decrease when compared to the CBSA0 mix, demonstrating CBSA's pozzolanic properties. The pozzolanic reaction that takes place between the active elements of pozzolanic materials, lime, and water causes the reduction of free lime in the concrete by increasing soluble silica, resulting in the formation of C-S-H gel (Ojewumi et al., 2017). Due this reason, the intensity of the C-S-H peaks of the CBSA5 mix appears to increase during the second hydration of CH and silica in the CBSA. This formation of additional C-S-H gel improves the strength of concrete. That the main reason for observation of compressive strength at 5% replacement.

Pozzolanic reaction between ordinary Portland cement and CBSA

$CaO + H_2O \Rightarrow Ca(OH)_2$

$Ca(OH)_2$ + Silica (in the CBSA) ⇨ Calcium Silica Hydrate (C-S-H)

4.5. Environmental and Economic Implications of Using CBSA

The environmental and economic benefits of using agricultural waste products in concrete are partly motivated by the fact that they are frequently waste items. The problem today is not only to progress construction material technology but also to choose the best materials while balancing cost, environmental impact, and long-term performance. Using agricultural waste products greatly reduces the impact of waste on both humans and the environment.

4.5.1. Raw Materials Savings

Limestone, clay, chalk, and other raw materials are the principal raw materials used in cement manufacture, and large quantities of each are regularly quarried to meet demand (Abebe Demissew, 2020). For manufacture of one ton of OPC cement 1.52 tons of raw materials are required (Demissew et al., 2019)**.** Those raw materials are non-renewable, which causes natural resource degradation. However, using CBSA, which is waste, and recycled material as a partial cement replacement in concrete production has a high contribution to saving raw material requirements for the manufacture of cement.

As tabulated in Table 4.15, the usage of CBSA as a cement replacement saves the use of raw materials for the production of concrete. For instance, the 5 % replacement saved about 1.01 % of raw materials required to produce one cubic meter of concrete. This is directly related to the minimization of raw materials requirements for cement manufacturing. Raw materials used to produce 300 kg of cement are reduced from the control by 22.80, 45.60, and 68.40 kg at 5, 10, and 15 % of replacement respectively. At 15 % replacement, 45 kg of cement per a meter cube of concrete when compared to the control concrete that is nearly one bag of cement per one-meter cubic of concrete is saved.

Table 4.15: Raw material used for one cubic meter of concrete and amount of raw materials saved.

Mix code	CBSA0	CBSA5	CBSA10	CBSA15
Raw material of OPC (kg/m^3)	456.00	433.20	410.40	387.60
Fine aggregate (kg/m^3)	787.11	787.11	787.11	787.11
Coarse aggregate (kg/m^3)	1024.76	1024.76	1024.76	1024.76
Total of virgin materials (kg/m^3)	2,267.87	2,245.07	2,222.27	2,199.47
CBSA(kg/m^3)	0	8.48	19.96	25.43
Saving of raw materials for production 300 kg of cement (kg)	0	22.80	45.60	68.40
Saving (%) in 1m^3 of concrete (%)	0	1.01	2.01	3.02

NB: amount of cement used for this study is 300 kg/m^3, when it converted to raw material it was 456 kg/m^3 (300*1.52).

4.5.2. Energy Saving

Cement manufacturing is an energy-intensive process. The manufacturing of Portland clinker is an energy-extensive procedure, in which raw substances are burned at 1450°C **(**Akpenpuun et al., 2019). While the formation of CBSA in the current study needs only 500^{o}C, which is leads to reduction of 950^{o}C (65.52%) of temperature required for formation of clinker. This plays a great role in addressing global warming and energy cost. On another hand, to produce one ton of clinker, 0.164 ton of coals and 43,223.8 KJ of energy per one kilogram of clinker is required (Demissew et al., 2019).

Table 4.16 shows that the production of one ton of CBSA consumes 0.056 tons of coal while cement consumes 0.164 tons. The energy required for CBSA is 14,912.21 kJ, which is less than one of the cement, which is 43,223.80 kJ. The consumption of coal and the requirement of energy of CBSA is reduced by 0.108 tons and 28,311.59 kJ respectively. Therefore, the usage of CBSA as a partial cement replacement in concrete has great benefits in terms of reducing the consumption of coal by 65.85% and the requirement of energy by 65.48%, which highly reduces the cost of the cement.

Table 4.16: Energy requirement for production of cement and CBSA per ton.

	Required temperature (^{o}C)	Ratio of required temperature for CBSA to cement	Required coal (ton)	Required Energy(kJ)
Cement	1450		0.164	43,223.8
CBSA	500	(500/1450) = 0.345	(0.164*0.345) = 0.056	(43,223.8*0.345) = 14,912.21
Reduction	950		0.108	28,311.59

NB: amount of required coal and energy for production of CBSA were calculated by multiplying the ratio of required temperature for production of CBSA to cement and the amount of coal and energy required for cement production.

Additionally, embodied energy of one cubic concrete of concrete was computed as presented in Table 4.17. Calculating the embodied energy of concrete materials is crucial for choosing the optimal choice for decreasing a structure's entire energy consumption and environmental influence. Taffese's (2019) studies employed Senegal embodied energy coefficient due to a lack of research in Ethiopia. By summing the embodied energy of concrete materials, the embodied energy of concrete can be calculated. As a result, embodied energy is the product of the quantity of each material and its embodied energy coefficient. According to the results in Table 4.17, the embodied energy of cement is the highest, accounting for 996 MJ. As a result, reducing the cement content has a significant role in lowering the embodied energy of concrete.

Table 4.17: Embodied energy of one cubic meter concrete

Materials	Quantity of materials (Kg)	Embodied energy coefficient (MJ/Kg) (Taffese, 2019)	Embodied energy (MJ)
Cement	300	3.32	996
Fine aggregate	781.11	0.06	46.87
Coarse aggregate	1,024.76	0.16	163.96
Total embodied energy			**1,206.83**

4.5.3. Reduction of CO_2 Emissions

One of the challenges is the sustainable development of the cement and construction industries in terms of environmental impact. One ton of Portland cement emits approximately one ton of CO_2 into the atmosphere during the manufacturing process. The cement industry accounts for approximately 8% of total global CO_2 emissions (Akpenpuun et al., 2019). The majority of CO_2 emissions and energy use in the cement industry are related to clinker production; 63% of CO_2 emitted during cement production comes from the calcination process, with the remainder (37%) produced during the combustion of fossil fuels to feed the calcination process. The weighted average globally is approximately 0.83 kg of CO_2 per kg of cement (Moya et al., 2010). Therefore, emission per kg of cement comes from fossil fuel (coal) consumption is 0.31 kg of CO_2 (37%*0.83) as illustrated in Table 4.18. While when the ratio of CBSA to cement is 0.341 in terms of the required coal and the CO_2 emission of cement per kg due to coal is 0.31, the CO_2 emission due to coal per kg of CBSA is 0.106 kg (0.341*0.31). When compared to cement, the use of CBSA reduced CO_2 emissions by 0.204 kg of CO_2 per kg. In general, using CBSA as a partial cement replacement will help to minimize CO_2 emissions and costs associated with coal consumption.

Table 4.18: CO_2 emission due to coal consumption of cement and CBSA.

	Required coal per kg (kg)	Ratio of required coal for CBSA to cement	Emission (kg of CO_2)
Cement	0.164		0.310
CBSA	0.056	(0.056 / 0.164) = 0.341	(0.341*0.310) = 0.106
Reduction	0.108		0.204

4.5.4. Economic Implication

The exploration of the economic implications of using CBSA as a partial replacement of cement in non-structural concrete was evaluated in terms of estimated materials costs for the production of concrete without and with CBSA. The calculation of costs is based on the current market price of materials surveyed on May 20, 2022.

According to current market prices of construction materials, one quantal of OPC National cement costs approximately 1,100 ETB. It was about 11 ETB per kg when converted. Fine aggregate costs 1,050 ETB per cubic meter, whereas coarse aggregate costs 1,200 ETB. Furthermore, the cost of water per cubic meter is 25 ETB. The estimated total cost of materials for producing one cubic meter of concrete without CBSA was 4,045.50 ETB, as presented in the Table 4.19.

Table 4.19:Estimated total cost of materials for production of one cubic meter concrete without CBSA based on the current market price (at the day of May 20, 2022).

Materials Item	Unit	Quantity	Rate	Amount (ETB)
Cement	kg	300	11	3,300.00
Fine aggregate	M^3	0.30	1,050	315.00
Coarse aggregate	M^3	0.38	1,200	456.00
Water	M^3	0.18	25	4.50
Total				**4,045.50**

Costs incurred during CBSA production

CBSA cost was exclusively calculated in terms of labor costs during material collection and burning of common bean straw. To produce CBSA initially, one employee was employed as a collector on one day and worked for two hours during the CBS collection. The collector's hourly rate was 30 ETB, and the total labor cost for the CBSA collection was 60 ETB. While one lab assistant worked three hours every day for two days to complete CBSA production. The assistant's hourly rate was 40 ETB, and the total cost was 240 ETB. The total cost of producing 5 kg of CBSA was 300 ETB. Table 4.20 illustrates costs incurred during production of CBSA.

Table 4.20: Total cost incurred for production of 5kg of CBSA

Item	Quantity	Working day	Working hour	Rate per hour	Amount (ETB)
During collection	1	1	2	30	60.00
During production	1	2	3	40	240.00
Total					**300.00 ETB**

The rate of CBSA per kg was 60 ETB based on the production cost of 5kg of CBSA, which was higher than the rate of cement per kg. As a result, the estimated total cost of one cubic meter of concrete with 5% CBSA increases by 373.80 ETB when compared to concrete without CBSA. However, if the CBSA is mass-produced like cement, its cost could be less than that of the cement. Furthermore, the benefits of saving non-renewable materials and energy and reducing CO_2 emissions outweigh the cost implications of utilizing CBSA as a cement replacement in concrete production. Table 4.21 shows the estimated total cost of materials for the production of one cubic meter of concrete with 5% of CBSA.

Table 4.21: Estimated total cost of materials for production of concrete with 5% of CBSA

Materials Item	Unit	Quantity	Rate	Amount (ETB)
Cement	Kg	285	11	3,135.00
Fine aggregate	m^3	0.30	1,050	315.00
Coarse aggregate	m^3	0.38	1,200	456.00
Water	m^3	0.18	25	4.50
CBSA	Kg	8.48	60	508.80
Total				**4,419.30 ETB**

Additionally, cement manufacturing is an energy-intensive process that is dependent on the presence of raw materials near the cement-manufacturing environment. Clinker burning is the most energy-intensive process, accounting for approximately more than 90% of the fuel consumed. Fuel costs account for a large portion of the cement industry's manufacturing costs, causing cement plants to consume a lot of energy(Rahman et al., 2015). Therefore, the production of CBSA reduce the fuel consumption by 65.85% that implies the cost fuel is reduced by 65.85% as compared to cement production.

In general, using CBSA as a partial cement replacement in non-structural concrete reduces the use of non-renewable materials, which helps to preserve natural resources. In addition, it reduces the consumption of coal and energy in cement production along with CO_2 emissions reduction. Furthermore, when coal consumption decreases, so does the cost of cement. The use of CBSA in concrete production has both environmental and economic benefits.

5. CONCLUSIONS AND RECOMMENDATIONS

The findings of various experimental results and the overall outcomes of this study were used to draw conclusions and make recommendations.

5.1. Conclusions

The use of CBSA as a cement substitute material in the production of C-15 non-structural concrete was investigated in this study. From the complete silica analysis result, the chemical composition of CBSA can be classified as class C pozzolana as specified by ASTM (SiO_2 + Al_2O_3 + Fe_2O_3 is greater than 50%). The normal consistency of blended paste varied from mix to mix, which is the main issue with by-product materials. Adding more CBSA to the paste resulted in a higher normal consistency, which required more water and caused retardation of the setting. However, due to the increased water requirement of the ash, the workability of concrete containing CBSA decreases as the amount of CBSA increases. Moreover, the compressive strength of the concrete with 5% of CBSA shows an improvement of 3.65% as compared to concrete without CBSA due to the formation of additional C-S-H gel during the second reaction of CH and silica. However, as the percentage of replacement increased to 10% and 15%, the compressive strength of the concrete reduced by 2.51% and 6.93%, respectively, due to a lower cement content and the slow hydration process. This finding shows that 5% of replacement is the percentage that reached maximum compressive strength but not the optimal. Likewise, the water absorption of CBSA containing concrete increases as the ash content increases due to the ash's high water-absorbent property and slow hydration. However, it reduces as the concrete ages because of the late hydration of pozzolanic materials. Furthermore, the microstructure of the concrete with 5% of CBSA on day 28 shows the formation of additional C-S-H gel in the concrete due to the higher silica content of the ash. Lastly, using CBSA as a partial cement replacement in non-structural concrete reduces the consumption of non-renewable materials, saves energy, minimizes CO_2 emissions, and reduces the cost incurred for cement.

5.2. Recommendations

According to the findings of this study, CBSA is one of the agricultural waste products that can be used to replace cement in the production of non-structural concrete. Cement industries, government institutions, and research communities should be made aware of the possibility of using CBSA for partial cement replacement by encouraging standardized production and use. According to the current investigation, the maximum compressive strength was obtained at 5% cement replacement by CBSA, but this is not the optimum replacement percentage. Therefore, the researcher forwarded the following recommendations for future study.

- Optimizing the use of CBSA as a cement replacement should be done by testing additional concrete properties such as tensile strength, flexural strength, and modulus of elasticity.
- The water absorption test was only conducted to determine the durability of concrete in this study, whereas permeability, chloride attack, and sulfur acid attack resistance tests should be conducted to determine the long-term durability of concrete.
- Since CBSA has a high alkali content, the petrographic analysis should be performed before use to examine the aggregate's alkali-silica characteristic.
- CBSA is recommended for partial cement replacement in low-grade concrete works such as lean concrete, bedding for structural concrete, and walkway pavements.

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APPENDIX

Appendix A: Tables for ACI concrete mix design

Appendix A1: Factor based on the grade of concrete

Specified characteristic compressive strength (fck, MPa)	Required average compressive strength in (f'ck , MPa
<21	f'ck + 7
21-35	f'ck + 8.5
>35	1.1*f'ck + 5

Appendix A2: Recommended slumps for various types of constructions

Types of constructions	Slump (cm)	
	Minimum	Maximum
Reinforced foundations, walls, and footings	2	8
Plain footings, cassoins ,and substructure walls	2	8
Beams and reinforced walls	2	10
Building columns	2	10
Pavements and slabs	2	8
Heavy mass concrete	2	8

Appendix A3: Approximate mixing water requirements for different slumps and maximum sizes of aggregates.

Slump (cm)	Water kg/m3 of concrete for indicated max. sizes of aggregate in mm							
	10	12.5	20	25	40	50	70	150
Non-air entrained concrete								
3-10	205	200	185	180	160	155	145	125
8-10	225	215	200	195	175	170	160	140
15-18	240	230	210	205	185	180	170	-
Approx. amount of entrapped air in non-entrained concrete (%)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air entrained concrete								
3-5	180	175	165	160	145	140	135	120
8-10	215	206	190	185	170	165	160	-
Recommended average total air content (%)	8	7	6	5	4.5	4	3.5	3

Appendix A4: Estimated water cement ration for average compressive strength concrete

Compressive strength at 28 days (MPa)	Water cement ratio by mass	
	Non-air entrained	Air entrained
45	0.38	-
40	0.42	-
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.71

Appendix A5: Volume of coarse Aggregate per unit Volume of concrete

Maximum size of aggregate	Volume of dry rodded coarse aggregate per unit volume of concrete for different fineness modulus		
	2.6	2.8	3.0
10	0.50	0.46	0.44
12.5	0.59	0.55	0.53
20	0.66	0.62	0.60
25	0.71	0.67	0.65
40	0.76	0.72	0.70
50	0.78	0.74	0.72
70	0.81	0.77	0.75

Appendix II: Different Test Results

Appendix B1: Initial and final setting time result with detail experiment time and date.

Mix code	Time of starting the experiment	Time at taking initial setting reading	Time at taking final setting reading	Initial setting time (min)	Final setting time (min)	Date of experiment
CBSA0	8:00am	10:03am	12:49am	123	289	15/03/22
CBSA5	1:00pm	3:45pm	6:30pm	145	330	15/03/22
CBSA10	8:30am	11:03am	2:52pm	153	352	16/03/22
CBSA15	8:30am	11:22am	2:38pm	172	368	17/07/22

Appendix B2: Detail slump value for fresh concrete that blended with CBSA for each mix code three trail was tested.

No.	Mix Code	Percent replaced in %	Trail	Slump result in mm	Average in mm
1	CBSA0	0	1	24	25
			2	26	
			3	25	
2	CBSA5	5	1	25	24
			2	23	
			3	24	
3	CBSA10	10	1	23	21
			2	21	
			3	19	
4	CBSA15	15	1	22	19
			2	17	
			3	18	

Appendix B3: Detail result of compressive strength for different mix code at different curing periods.

No.	**Mix code**	**Sample**	**Compressive strength result in N/mm^2**					
			7th day		**14th day**		**28th day**	
			Load(KN)	**Strength**	**Load**	**Strength**	**Load**	**Strength**
1	CBSA0	1	283	12.58	339	15.06	389	17.28
		2	312	13.86	402	17.88	431	19.15
		3	319	14.25	368	16.35	416	18.49
		Average	**305**	**13.54**	**369**	**16.42**	**412**	**18.31**
2	CBSA5	1	286	12.73	404	17.95	476	19.02
		2	298	13.25	395	17.56	412	18.31
		3	305	13.56	412	18.32	442	19.64
		Average	**296**	**13.18**	**404**	**17.94**	**444**	**18.98**
3	CBSA10	1	303	13.35	372	16.52	402	18.25
		2	282	12.66	360	15.98	411	17.85
		3	255	11.34	348	15.45	393	17.45
		Average	**280**	**12.45**	**359**	**15.95**	**402**	**17.85**
4	CBSA15	1	253	11.25	328	14.56	379	16.88
		2	270	12.01	343	15.23	382	16.98
		3	267	11.85	335	14.89	388	17.25
		Average	**263**	**11.70**	**335**	**14.89**	**383**	**17.04**

Appendix B4: Water absorption result for each sample at different mix code and curing days.

Mix code		**Water absorption by percentage**					
	Sample	At 7th day			At 28th day		
		O (kg)	S (kg)	%	O (kg)	S (kg)	%
CBSA0	1	0.728	0.792	8.8	0.726	0.784	8
	2	0.738	0.805	9.1	0.745	0.810	8.7
	3	0.712	0.761	6.9	0.734	0.788	7.4
	Average	**0.726**	**0.786**	**8.3**	**0.735**	**0.794**	**8.0**
CBSA5	1	0.699	0.768	9.9	0.704	0.764	8.5
	2	0.702	0.782	11.4	0.714	0.793	11.1
	3	0.684	0.745	8.9	0.706	0.771	9.2
	Average	**0.695**	**0.765**	**10.1**	**0.708**	**0.776**	**9.6**
CBSA10	1	0.691	0.753	9	0.693	0.754	8.8
	2	0.689	0.761	10.4	0.696	0.768	10.3
	3	0.690	0.772	11.9	0.696	0.776	11.5
	Average	**0.690**	**0.765**	**10.9**	**0.696**	**0.766**	**10.1**
CBSA15	1	0.671	0.742	10.6	0.675	0.745	10.4
	2	0.683	0.765	12	0.699	0.782	11.9
	3	0.671	0.743	10.7	0.693	0.765	10.4
	Average	**0.675**	**0.750**	**11.1**	**0.689**	**0.764**	**10.9**

Appendix C: oxide composition of OPC National cement and CBSA

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

Issue Date:- 17/05/2022
Request No:- GLD/RO/965/22
Report No:- GLD/RN/450/22
Sample Preparation: - 200 Mesh
Number of Sample:- One (01)

Customer Name:- Adem Bedaso

Sample type :- OPC-NC
Date Submitted:-14/04/2022
Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.
Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS.

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	Weight of Sample
1	26.02	5.09	3.48	60.40	1.76	0.34	0.56	0.04	0.1	0.16	0.19	1.89	800.00gm

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

Analysts
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Lidet Endeshaw
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Quality Control
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Appendix C1: Oxide composition of OPC National cement

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

Issue Date:- 17/05/2022
Request No:- GLD/RO/962/22
Report No:- GLD/RN/449/22
Sample Preparation: - 200 Mesh
Number of Sample:- One (01)

Customer Name:- Adem Bedaso

Sample type :- CBSA/Ash
Date Submitted:-14/04/2022
Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.
Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS.

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	Weight of Sample
1	47.88	2.33	0.86	20.92	4.78	1.30	10.06	<0.01	1.31	<0.01	0.91	11.07	100.00gm

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

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Appendix C2: Oxide composition of CBSA

Appendix D: Pictures taken during experimental works.

Appendix D1: Pictures taken during preparation of saturated surface dry sample for fine aggregate test.

Appendix D2: Pictures taken during fine and coarse aggregate washing and drying.

Appendix D3: Picture taken while measuring PH of the water.

Appendix D4: Pictures captured during conducting unit weight test for fine aggregate and coarse aggregate.

Appendix D5: Picture taken during normal consistency and setting time test.

Appendix D6: Pictures captured during slump test.

Appendix D7: Pictures shows casted samples: (150*150*150) mm sized cube for compressive strength test and (70*70*70) mm sized cube for water absorption test.

Appendix D8: Pictures taken during curing of different concrete samples in the curing tank.

Appendix D9: Pictures shows sample preparation for compressive test and during conducting the test.

Appendix D10: Pictures shows samples during oven drying, weighting oven dried sample, and submerged samples in the water.