Addis Ababa University

Addis Ababa Institute of Technology

School of Chemical and Bio Engineering

Sugarcane Bagasse Ash as Partial Replacement of Cement in Concrete Production

A Thesis Submitted to The School of Chemical and Bio Engineering Presented in partial fulfillment of the requirement for the Degree of Master of Science in Chemical and Bio Engineering (Process Engineering Stream)

By: Tsigehana G/micael

Advisor: Prof. Dr. Eng Belay Woldeyes

Addis Ababa, Ethiopia

July 2019

DECLARATION

I declare that this thesis entitled "Sugarcane Bagasse Ash as Partial Replacement of Cement in Concrete Production " has not been submitted in any form for another degree, diploma or an award at any university or other institution of the tertiary education. Whenever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature and discussions. Information taken from published and unpublished work of others has been acknowledged in the text and a list of references is given. The work was under the guidance of instructor **Prof. Dr. Eng Belay Woldeyes** in Addis Ababa University, School of Chemical and Bio Engineering.

Name: Tsigehana G/micael

Signature: ______________________

Addis Ababa University

Addis Ababa Institute of Technology

School of Chemical and Bio Engineering

This is to certify that the thesis prepared by *Tsigehana G/micael*, entitled: *sugarcane bagasse ash as partial replacement of cement in concrete production and* submitted in partial fulfillment of the requirement for the degree of Master of Science in Chemical Engineering under Process Engineering Stream complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Prof.Dr.Eng Belay Woldeyes

Advisor	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date
School or Center of Chair Person	Signature	Date

ABSTRACT

Sugarcane bagasse ash is a byproduct from cogeneration boilers of sugar industries found after the extraction of all economical sugar from sugar cane. The disposal of this agricultural waste causes environmental problems around the sugar industries. Cement industry also creates environmental problem by emission of carbon dioxide during manufacturing of cement and consumes lot of raw materials. Therefore, this research deals sugarcane bagasse ash as partial replacement of cement in concrete production. First the sugarcane bagasse ash samples were collected from Wonji sugar factory. Sugarcane bagasse ash was sieved with 250μm sieve size. M25 grade strength of concrete were deign with five different proportions of concrete mixes. Sugarcane bagasse ash ranging from 5% to 20% by weight of cement including the control mix was prepared with a water cement ratio of 0.45. For each substitution ratio, 3 sets (a total of 12) concrete specimens were prepared for compressive strength test conducted at the age of 7, 14, 21 and 28 days. For this experimental work a total of 60 cubic concrete specimens for compressive strength test and 15 cylindrical concrete specimens for water absorption test were casted. Sugar cane bagasse ash has shown low density and higher surface area as compared to cement. The chemical composition of bagasse ash, combined value of SiO_2*,* Al_2O_3*, and* Fe_2O_3*, investigated in this study was 87.68 which is higher than the standard, value 70%, and qualifies to be a Class N Pozzolan. The results of the compressive strength of concrete work have shown that up to 5% replacement of the ordinary Portland cement by bagasse ash is possible. In addition, higher compressive strength at all test ages, 7, 14, 21 and 28 days, were observed. The 21and 28 day compressive strength value of concrete with 5% sugarcane bagasse ash replacement was showing a strength enhancement of about 8% and 6%, respectively. The Water absorption of concrete increases with increasing the sugarcane bagasse ash content of concrete with the exception of water absorption for the concrete with 5% sugarcane bagasse ash. 5% partial replacement of cement by sugarcane bagasse ash in concrete production results in a similar concrete properties and higher replacement could also be used with a slight reduction in the performance of the concrete.*

Keywords- *Sugarcane bagasse Ash, Cement, Concrete, water absorption & Compressive Strength.*

ACKNOWLEDGEMENTS

Above every one, I praise to my Almighty God for his blessing, always being with me in all my activities and for giving me the strength to carry out this study and the postgraduate studies in general. I would like to convey my honest gratitude to my advisor Prof. Dr. Eng. Belay Woldeyes for his useful comments, suggestions, kind support, and guidance to supervise my research work. My acknowledgment is also extended to Dr. Beteley Tekola, for giving the idea of this title and support some information's about this thesis at the staring of this work. Special gratitude goes to Department of Chemical and Bio Engineering laboratory staff for their help throughout the experimental work, provided support in conducting tests that this research was in need of. I am very grateful for the kind of cooperation and support provided by the Civil Engineering Department and staffs from Civil Engineering Department Material laboratory of Addis Ababa Institute of Technology. Special appreciations to Adigrat University for sponsoring me to accomplish post graduate program at Addis Ababa Institute of Technology. In addition, I am extremely thankful to Wonji/Shoa sugar factory for providing me the research material sugarcane bagasse ash and for their support. Finally, I would like to acknowledge my families for their endless encouragement, patience and friends who have shared all the pain in coming up with this study. I also acknowledge everybody who helped me in one or another way during my study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONOYMS

ASTM	American Society for Testing Materials
AASHTO	American Association of State Highway and Transportation Officials
Al_2O_3	Alumina
BA	Bagasse Ash
CA	Course aggregate
$CaCO_3$	Calcium Carbonate
$CaSO_4$	Calcium Sulfite
C_3S	Tricalcium Silicate
C_2S	Dicalcium Silicate
C_3A	Tricalcium Aluminate
CO_2	Carbon dioxide
CaO	Calcium Oxide
$Ca(OH)_2$	Calcium Hydroxide
C–S–H	Calcium Silicate Hydrate
CSH_2	Calcium Sulfate dehydrate
ES	Ethiopian Standard
FA	Fine aggregate
Fig	Figure
Fe_2O_3	Ferrite
ITZ	Interfacial transition zone
GHG	Green house gases

L.O.I	Loss on Ignition
MPa	Mega Pascal
MgO	Magnesium Oxide
OPC	Ordinary Portland Cement
PPC	Portland Pozzolana Cement
SBA	Sugarcane bagasse ash
SiO_2	Silicon dioxide
SO_3	Sulfur Trioxide
SSD	Saturated Surface Dry
W/C	Water to cement ratio
W/B	Water to Binder ratio
W/C+BA	Water to cement plus bagasse ash ratio

1. INTRODUCTION

1.1 Background

Cement is the most widely consumable material in the infrastructure development works. It is considered as a durable material of construction. Manufacturing of Portland cement is a resource exhausting, energy intensive process that releases large amount of the greenhouse gas, CO_2 into the atmosphere. Production of 1 ton of Portland cement requires about 2.8 tons of raw materials, including fuel and other materials(Xiaolu, Huisheng &Warren, 2010). The cement industry has been pointed out as one of the major contributors of anthropogenic CO_2 emissions with about 5% globally. Several research activities have been directed towards partial or total substitution of Portland cement by pozzolanic binders, eg. Lime, fly ash, bagasse ash, rice straw ash and natural Pozzolan among others.

In sugar industry bagasse ash is a residue resulting from the burning of sugarcane bagasse in boilers for power generation. A limited amount of bagasse ash has been used as soil amendment while the rest of the BA is useless causing serious environmental impacts. It has a very high silica concentration and contains aluminum, iron, alkalis and alkaline earth oxides in smaller amounts. However, BA can utilize to possible addition of bagasse ash as supplementary cementious material. Unlike other pozzolanic materials, the concrete incorporating the BA shows excellent strength development (Balakrishnan,&Batra,2011).

The pozzolanic property of SBA came from the silicate content of the ash. The silicate content in the ash may vary from ash to ash depending on the burning and other properties of the raw materials like the soil on which the sugar cane is grown.(Gowda, 2015)

The silica content of pozzolans reacts with free lime released during the hydration of cement and forms additional calcium silicate hydrate (CSH) as new hydration products which improves the mechanical properties of concrete formation.(Amin, 2015)

Concrete is the most commonly used construction material in the world. It is basically composed of two components: paste and aggregate. The paste contains cement and water and sometimes other cementious and chemical admixtures, whereas the aggregate contains sand and gravel or crushed stone. The paste binds the aggregates together. The aggregates are relatively inert filler materials which occupy 70% to 80% of the concrete and can therefore be expected to have influence on its properties (Hailu, Unsw, & Tekle, 2016).

The proportion of these components, the paste and the aggregate is controlled by the strength and durability of the desired concrete, the workability of the fresh concrete and the cost of the concrete. Concrete has high compressive strength, corrosion and weathering effect is minimal. However, concrete has low tensile strength and can easily crack due its characteristic which is brittle.

In this study, SBA is used as a partial replacement for ordinary Portland cement in concrete. The aggregates, cement and bagasse ash were mixed and the effects of SBA with various amounts of cement replacement on properties concrete were investigated by conducting workability test, water absorption test and compressive strength.

1.2 Problem Statement

Sugarcane bagasse is an industrial waste which is used worldwide as fuel in sugar industry. Sugarcane bagasse ash, which is a byproduct of sugar factories found after burning sugarcane bagasse which in turn is found after the extraction of all economical sugar from sugarcane (Gowda, 2015). The generation of energy by using bagasse as fuel also creates a great deal of waste material known as SBA which results in waste disposal problem and environmental pollution which is the case in most sugar factories. The bagasse ash is about 8-10 % of the bagasse and contains unburned matter, silica and alumina (Hailu et al., 2016). The consumption of Portland cement is increasing rapidly because of the rapid growth in construction worldwide. Cement production consumes lot of raw materials from natural resources. The production of cement is one of the most environmental unfriendly processes due to the release of CO_2 gases to the atmosphere. It is believed that one ton of Portland cement clinker production creates about one ton of CO_2 and other greenhouse gases. In addition to its negative environmental impact, cement is also one of the most expensive materials when compared to the other constituents of concrete. In this century, environmental issues play a leading role in the sustainable development of cement and concrete industry(Naik & Moriconi ,2006).

This study was carried out in order to promote the utilization of Sugarcane bagasse ash generated in Ethiopian sugar factories and to improve concrete properties such as workability, compressive strength, and water absorption with partial replacement of Portland cement by Sugarcane bagasse ash in concrete production. Therefore, utilization of Sugarcane bagasse ash reduces cost of cement, amount of CO_2 emitted and bagasse ash disposal around sugar factory.

1.3 Objectives

1.3.1 Main objective

The general objective of this study is to utilize sugarcane bagasse ash as partial replacement of cement in concrete production.

1.3.2 Specific objectives

- Investigation of the physical properties (density, fineness and particle size) of Sugarcane bagasse ash.
- Investigation of the chemical compositions of Sugarcane bagasse ash.
- Evaluating the performance of concrete made of Sugarcane bagasse ash as partial replacement of cement by conducting workability test on fresh concrete and compressive strength and water absorption test on hardened concrete.

1.4 Significance of the study

Sugarcane bagasse ash is a fibrous ash collected after the burning of bagasse in boilers during the cogeneration process in sugar factory. This fibrous waste material is found to have characteristics of a supplementary cementious material because it is rich in amorphous SiO_2. It also contains small amounts of aluminum, iron; alkalis and alkaline earth oxides are also present. 8-10% of the bagasse burned during the cogeneration process gets converted to bagasse ash (Ganesan, Rajagopal, & Thangavel, 2007). Disposal of this ash is a critical issue for sugar industries due to environmental constraints and land requirement. Rapid implementation of new cogeneration plants in sugar industries are further expected to increase bagasse ash generation significantly. Utilization of BA as supplementary cementious material in concrete production to achieve durable as well as sustainable concrete and can reduce the disposal problem significantly. Cement industry also creates environmental problem by emission of carbon dioxide during manufacturing of cement and consumes lot of raw materials.

Therefore, this research deals SBA as partial replacement of cement in concrete production to reduce the environmental pollutions created in cement industries by emission of carbon dioxide and to minimize the environmental pollutions by disposal of BA around sugar industries. The results of this experimental work have concealed that cement could advantageously be replaced with bagasse ash up to 5%. This replacement results in high concrete properties to that of the control concrete. Higher replacement percentages can also be used with a slight reduction in the performance of the concrete.

2. LITERATURE REVIEW

2.1 Introduction

Concrete is one of the most widely used construction materials in the world. However, the production of Portland cement, an essential constituent of concrete, leads to the release of significant amount of CO_2, a greenhouse gas. One ton of Portland cement clinker production creates one ton of CO_2 and other greenhouse gases. Many developed and developing countries had regularized use of pozzolanic materials in Portland cement on account of achieving control on environmental issues and also improving quality of concrete mainly the durability aspect(McDonough, 1992). Utilization of agricultural, industrial and agro- industrial byproducts in concrete production has become an attractive area to the researchers worldwide. Utilization of such wastes as cement replacement materials also as mineral admixture can reduce the cost of concrete and also minimize the negative environmental effects associated with the disposal of these wastes(Mulay, Vesmawala, Patil, & Gholap, 2017). BA is one of these byproduct materials found from sugar factories. Recently it has been studied for its feasibility as a cement replacing material in some parts of the world and has been found to improve some of the properties of mortar and concrete. The performance of mortar and concrete is assessed by different tests on both the fresh and hardened concrete. These include workability, strength and permeability(Hailu et al., 2016).Today use of SBA as cement replacement reduce the cost of manufactured Portland cement, and make concrete more durable, as well as reduce GHG emissions.

2.2 Concrete

The word concrete comes from a Latin word concretus which means to grow together, which implies that it is a composite of different materials. It is composed of coarse granular material called aggregate or filler which is embedded in a hard matrix of material (cement or binder with water) binding the aggregates together and filling the space formed between them. When the constituents are mixed with water the concrete solidifies and hardens due to a chemical reaction between the water and the cement called hydration, which finally forms a stone like material by binding the aggregates together(Hailu et al., 2016).

Concrete is mainly composed of cement, aggregate and water. Cementious materials, pozzolanic materials, filler materials, chemical admixtures, and some other additives may also be the constituents of concrete depending on the need and their availability. All the constituents have their own purpose in the concrete. Cement with water acts as a binding medium in which the aggregates which accounts 70% to 80% of the concrete are bound together to form the concrete. Economy, dimensional stability and wear resistance are the main reasons behind using aggregates. Different types of admixtures are used to modify the properties of ordinary concrete so as to make it suitable for any situation. If a concrete is to be suitable for a particular purpose, it is necessary to select the constituent materials and combine them in such a manner as to develop the special qualities required as economical as possible. Therefore the selection of constituents of concrete depends on the quality and economy of the particular concrete required(Hailu et al., 2016).

Concrete is a mixture of aggregates and cement water paste. The cement water paste has its role to bind the aggregates to form a strong rock like mass after hardening has a consequence of the chemical reaction between cement and water. Aggregates are classified in to fine aggregate and coarse aggregate. Fine aggregate consist of sand whose particular size does not exceed 4.75mm coarse aggregate consist of gravel, crush stone etc. of practical size more than 4.75mm. When the materials are mixed together so has to form a workable concrete, it can be moulded into beams, slabs etc. After few hours of mixing, the material undergoes a chemical combination and consequently the mixture solidifies and hardens, attaining greater strength with age. Concrete possess a high compressive strength and has a poor tensile strength. It also develops shrinkage stresses(Denamo A., 2005).

2.2.1 Properties of concrete

A hardened concrete must possess the following properties:

Strength: Strength is defined as the resistance of the hardened concrete to rupture under different loadings and is accordingly designated in different tensile strength, compressive strength, flexural strength, etc. Strength of concrete is commonly considered the most valuable property, although in many practical cases other characteristics, such as durability and permeability, may in fact be more important. Nevertheless, strength usually gives an overall picture of the quality of concrete because it is directly related to the structure of the hardened cement paste. The strength of concrete is dependent on many things. The hydration reaction, water to Cement ratio, aggregate type, amount and size, water content, cement content, curing condition, cement type, compaction method used etc. have an effect on the strength of concrete. Strength at any w/c ratio depends on the degree of hydration of the cement and its physical and chemical properties. The decrease in the water content of the concrete results in a higher strength of the concrete. The water required for the hydration reaction is less than that of the mixing water; the extra water provided is used to make the concrete more workable. Different pozzolanic materials have different effect on strength. But most of them including BA have been found to improve the strength of concrete especially at latter days due to the secondary reaction(Hailu et al., 2016).

Workability: Workability is the measure of how easy or difficult it is to place, consolidate and finish concrete. It can also be defined in terms of the amount of mechanical work, or energy required producing full compaction of the concrete without segregation. This property of concrete is affected by a number of factors like: water content of the mix, mix proportions, aggregate properties, time, temperature, characteristics of the cement and admixtures. Water content is the most important factor affecting the workability of concrete. Increasing the amount of water will increase the workability of the concrete. However the increase in water content of the mix will decrease the strength and also result in segregation and bleeding. When considering the effect of aggregate the amount of aggregate, the proportion of coarse and fine aggregate and the shape and texture of the aggregate particles affect the workability of concrete. Keeping the water content and cement content constant increasing the amount of aggregate reduces the workability of concrete. Spherical and smooth aggregate result in more workable mix, whereas flat, elongated and rough aggregate particles will result in reduction of workability. The cement content and cement replacing materials also affect the workability. Higher cement content reduces workability. The effect of cement replacing materials depends on their nature. Finer materials result in reduction of workability while spherical materials increase it.

Permeability: The movement of fluid through a porous medium due to a pressure head difference is called permeability. Thus ability of the concrete to transmit fluids through it caused by pressure head difference is called permeability of concrete. This term applies to both gases and liquids. This property of concrete plays a great role in the durability of the concrete because it controls the entry of moistures which may contain aggressive chemicals and the movement of water during heating and freezing. Durability of concrete refers to the ability of concrete to resist weathering actions, chemical attacks, abrasions or any processes of deteriorations. The w/c ratio of concrete has major influence on the permeability of concrete. As the w/c ratio decreases the porosity of the paste decrease and the concrete becomes more impermeable. This variation of permeability with w/c ratio is largely due to large capillary porosity rather than gel pores. Most pozzolanic materials were found to decrease the permeability of concrete due to the pozzolanic reaction and their higher fineness. The pozzolanic reaction consumes the free lime in the concrete and the higher fineness of the pozzolan fills pores in the concrete both resulting in a lower permeability.

Impermeability: The impermeability of hardened concrete may be defined as the property to resist entry of water. This property is achieved by using extra quantity of cement in concrete mix. A concrete in hardened state must be impermeable.

Shrinkage: A hardened concrete should experience least shrinkage. This property is guided by w/c ratio. Shrinkage is less if w/c ratio is less.

2.3 Cement

Cement is a finely ground, non-metallic, inorganic powder when mixed with water forms a paste that sets and hardens. This hydraulic hardening is primarily due to the formation of calcium silicate hydrates as a result of the reaction between mixing water and the constituents of the cement. In the case of aluminous cements hydraulic hardening involves the formation of calcium aluminate hydrates. Cement is a basic material for building and civil engineering construction. In Europe the use of cement and concrete (a mixture of cement, aggregates, sand and water) in large civil works can be traced back to antiquity. Portland cement is the most widely used cement in concrete construction. Output from the cement industry is directly related to the state of the construction business in general and therefore tracks the overall economic situation closely(Commission, 2001).

2.3.1 Manufacture of cement

The following operations are key in the manufacture of cement.

Raw Mealing: This is the process of making raw meal. The materials are quarried and pre-determined quantities of raw materials are mixed together and ground into fine powder known as raw meal. After this, the raw meal is led to a silo where it is homogenized through mixing. Homogenization is important in that it enhances the combination of oxides during burning.

Regular tests are employed as quality control measures in the chemical composition and fineness of the raw meal (Osore & Kwena, 2016).

Clinkering: This is the process of burning raw meal to produce clinker. The raw meal is fed into a preheating chamber where hot air is blown over it to dry it and make it easy to burn. The raw meal is then led into a rotary kiln with temperature ranging from 900^oC at the inlet to 1450^oC at the hottest end. The kiln is inclined downwards at about 5^oC and rotated so that raw meal moves slowly towards the hotter end. Powdered coal and industrial oil are the major fuels used to provide heat. Between the temperature ranges of 900^oC-950^oC, the calcium carbonate in limestone or chalk breaks down to Calcium Oxide and Carbon Dioxide by the equation shown below:

$CaCO_3 \xrightarrow{heat} CaO + CO_2$ {calcining}..Equation 2.1

It is noteworthy to mention that this process of calcining is a big contributor to the carbon dioxide that forms a key pollutant in the cement manufacturing process. Between 1250^oC and 1450^oC, the oxides combine and fuse into hard pellets known as clinkers. The clinker is then cooled by blowing cold air over it and is then led into a shed for storage. The air used to cool the clinker heats up and is used to preheat the raw meal before burning.

Grinding and Packaging: This is the process of crushing clinker to produce cement. The chemical composition and fineness of cement is closely monitored at all times during the grinding process. Grinding of the clinker to fine particles greatly helps in enhancing the strength of concrete. Homogenizing of the raw meal can be done by mixing in water (wet process) or by mixing in dry conditions (dry process). The wet process usually requires additional energy to dry the raw meal before burning, but reduces dust emissions. Modern technology however incorporates efficient dust arrestors making the wet process obsolete. The cement is then packaged in 25kg and 50kg bags(Osore& Kwena, 2016).

Naik T. et al reported that in 2000, the worldwide cement clinker production was approximately 1.6 billion tons mixed with water and aggregates the resulting concrete is second only to water as the most consumed substance on Earth. The consumption of cement correlates to the economic development of a country as a base for new building, factories and infrastructures which are the root of development. As a result of this, cement manufacturing has increased sharply in those developing countries.

2.3.2 Types of cement

Cement can be used for mortar and plaster production. It is used in all types of structural concrete like walls, floors, bridges, tunnels, etc. It is further used in all types of masonry works like foundations, footings, dams, retaining walls, and pavements. When Portland cement is mixed with sand and lime, it serves as mortar for laying brick and stone; and when it is mixed with coarse aggregate and fine aggregate (sand) together with enough water, to ensure a good consistency. There are different types of cement depending on their composition, method of manufacturing (grinding, burning, etc.) and also the relative proportion of the different compounds. One of these types and the most commonly used one is Portland cement, which in turn is divided into many types. The other common type of cement is Portland pozzolana cement which contains some amount of pozzolanic materials.

1, Portland cement: Portland cement is one of the most widely used cement and is the most important hydraulic cement. The origin of the name “Portland cement" is usually attributed to Joseph Aspdin, a brick mason in England who in 1824 took out a patent for making a powder made from mixed and ground hard limestone and finely divided clay. This forms into slurry and then is calcined in a furnace till the CO_2 was expelled. He called the resulting material Portland cement because when the mortar made with it hardened it produced a material resembling the stone which was quarried near Portland, England. The method of making cement has been improved upon since that time but the basic process has remained the same. Modern Portland cement is made from materials which must contain the proper proportions of lime (CaO), silica (SiO_2), alumina (Al_2O_3), iron (Fe_2O_3) with minor amounts of magnesia and sulfur trioxide. A typical composition of general purpose Ordinary Portland cement is shown in the Table 2.1 below.

Table 2.1 Typical composition of ordinary Portland cement(Sidney, Francis, David, 2003)

Chemical Name	Chemical formula	Shorthand Notation	Weight percentage
Tricalcium silicate	$3CaO{\cdot}SiO_2$	C_3S	55
Dicalcium silicate	$2CaO{\cdot}SiO_2$	C_2S	18
Tricalcium aluminate	$3CaO{\cdot}Al_2O_3$	C_3A	10
Tetracalcium aluminoferrite	$4CaO{\cdot}Al_2O_3{\cdot}FeO_3$	C_4AF	8
Calcium sulfate dehydrate (gypsum)	$CaSO_4{\cdot}2H_2O$	CSH_2	6

Of these compounds, C_3S and C_3A are mainly responsible for early strength of concrete. High percentages of C_3S (low C_2S) results in high early strength but also high heat generation as the concrete sets. The reverse combination, that is, low C_3S and high C_2S develops strength more slowly and generates less heat. C_3A causes undesirable heat and rapid reacting properties, which can be prevented by adding $CaSO_4$ to the final product. The most common classification of Portland cement is that of ASTM. It classifies Portland cement mainly into five groups (non-air entrained) differing only on the relative amount of the compounds and the degree of fineness.

ASTM type I cement is a general purpose Portland cement used when there is no special property required by the concrete.

ASTM type II cement is Moderate Portland cement. It is also a general-purpose cement to be used when moderate sulphate resistance or moderate heat of hydration is desired.

ASTM type III cement is High early strength Portland cement which is used when high early strength is desired, usually less than one week, it is usually used when a structure must be put into service as quickly as possible.

ASTM type IV cement is Low -Heat of Hydration Portland cement which is used, when heat of hydration is low required, like in mass concrete.

Finally, ASTM type V is Sulphate resisting Portland cement which is used when high sulphate resistance is desired.

2, Portland Pozzolana cement: Portland pozzolana cement (PPC) is manufactured by the intergrinding of OPC clinker with 15 to 35 % of pozzolanic materials. Pozzolanic materials are siliceous or aluminous materials which by themselves possess little or no cementious properties. But in the presence of water they react with calcium hydroxide which is liberated from the hydration of cement to form a compound possessing cementious property. The reaction of the pozzolanic materials with calcium hydroxide results in many advantages of PPC over OPC. If these pozzolanic materials were not reacted with the calcium hydroxide, free calcium hydroxide would have been present in the concrete resulting in higher permeability of the concrete and susceptibility to other attacks. The pozzolanic reaction reduces the porosity of the concrete by producing cementious compound. It also reduces the heat of hydration since its reaction is slower than that of OPC, which implies that it has slower rate of strength than OPC, making it suitable for mass concrete construction. In addition to these cement types there are also other types of cement which are produced by either adding other materials to the clinker or by forming other compounds during burning. They are collectively called modified Portland cements. Expansive cement, calcium sulfoaluminate cement, masonry cement, oil well cement, white cement etc. can be an example for this. There are also non-Portland inorganic cements which are used to some extent.

2.3.3 Hydration of cement

When water and Portland cement are mixed, the constituent compounds of the cement and the water undergo a chemical reaction resulting in hardening of the concrete. This chemical reaction of the cement and the water is called hydration, and it results in new compounds called hydration products. Both C_3S and C_2S react with water to produce an amorphous calcium silicate hydrate known as C–S–H gel which is the main glue which binds the sand and coarse aggregate particles together in concrete. Each of the compounds found in the cement react with water, but the rate at which they react is different. C_3S and C_3A are the most reactive compounds, whereas C_2S reacts much more slowly. Approximately half of the C_3S present in typical cement will be hydrated by 3 days and 80 % by 28 days, in contrast, the hydration of C_2S does not normally proceed to a significant extent until approximately 14 days. Gypsum is added to lower the hydration rate of C_3A.

The hydration of C_3S and C_2S are shown in Eq.2.1 and Eq.2.2:

$C_3S + 4.3H \longrightarrow C_{1.7}SH3 + 1.3CH$……………………………………Eq 2.1

$C_2S + 3.3H \longrightarrow C_{1.7}SH + 0.3CH$…………………………………….Eq 2.2

After a rapid initial reaction C_3S will pass through a dormant stage which has a practical significance because it allows concrete to be placed and compacted before setting and hardening commences.

The rate and amount of heat of hydration are affected by various factors. Among these cement composition and fineness, water to cement ratio of the concrete, age of the paste and ambient conditions are the most common ones. Varying the cement composition affects the rate of reaction because the different compounds present in the cement have different speed of hydration. The hydration of Portland cement as a whole is more complex than the individual compounds. This is because of the different compounds have different products, reaction rate, and each of the compounds consumes water. When cement is first mixed with water some of the added calcium sulfate dissolves rapidly. The purpose of adding calcium sulfate is in order to retard the hydration of C_3A, which BA as a cement replacing material. Without calcium sulfate results in flash set due its high rate of reaction with water. This is because C_3A is more reactive than any of the compounds in the cement and if allowed will take much of the water. The order of reaction is $C_3A > C_3S > C_4AF > C_2S$. But the rate of hydration of these compounds differs from cement to cement depending on the fineness, the rate of cooling of the clinker and other factors like presence of impurities and other cement compounds.

2.3.4 Physical properties of cement

Specifications for cement place limits on its physical properties. An understanding of the significance of some of the physical properties is helpful in interpreting results of cement tests. Tests of the physical properties of the cements should be used to evaluate the properties of the cement, rather than the concrete.

Fineness: The fineness of cement affects many of its properties. The heat released and the rates of hydration are the main properties which are affected by the fineness of cement. These properties of the cement in turn affect many other properties, like normal consistency, setting time, strength, etc. Fineness of cement can be measured mainly by specific surface area method and particle size distribution. The specific surface area is the summation of the surface area of all of the particles in 1 gm or 1 kg of cement. Most of the time, it is a general practice to describe fineness by a single parameter, specific surface area. Although it is possible to measure the particle size distribution of cement, there is still no agreement on what would contribute a best grading curve for cement. Due to this and other factors the specific surface area is preferred over the particle size distribution. The surface area is measured by the Blaine air-permeability test (ASTM C 204 or AASHTO T 153) that indirectly measures the surface area of the cement particle per unit mass. According to the Ethiopian standard ordinary Portland cement shall have a specific surface area of not less than 2250 cm^2/g, whereas the ASTM C 150 standard recommends a minimum of 2800 cm^2/g.

Consistency of cement paste: Many of the properties of concrete are affected by its water content. The physical requirements of cement paste like setting and soundness depends on the water content of the neat cement paste. Therefore it is necessary to define and study the water content at which to do these tests. This is defined in terms of the normal consistency of the paste which is measured according to ASTM C 187. The amount of water required to achieve a normal consistency as defined by a penetration of 10 ± 1 mm of the Vicat plunger (ASTM C 187) is expressed as a percentage by weight of the dry cement, the usual range being about 26% to 33%. The test is very sensitive to the conditions under which it is being carried out, particularly the temperature and the way the cement is compacted into the mold. The test does not correlate to the quality of the cement; it only measures the plasticity of cement paste.

Setting time: Setting is a process in which cementious mixtures of plastic consistency is converted into a set material which has lost its deformability and crumbles under the effect of sufficiently great external force. It is preceded by a stiffening of the paste in which the apparent viscosity of the material increases without losing its plastic character. There are two types of setting time i.e. initial and final setting times. The initial setting time indicates the time at which the paste begins to stiffen considerably and can no longer be molded; while the final setting time indicates the time at which the paste has hardened to the point at which it can sustain some load. Like normal consistency these tests are also used for quality control. Ethiopian standard recommends that the initial setting time for cement not to be less than 45 minutes and the final setting time not to exceed 10 hours.

2.3.5 Cement production in Ethiopia

In Ethiopia, Dire dawa cement factory was the first cement factory established by Italians in 1936 during the five years fascist occupation of the Country. The cement production has been growing since then and in 2008 there were four cement plants with a combined production capacity of about 2.85 million metric tons per year as reported by Ethiopian investment agency. However the per capita production as of 2009 as calculated from Table 2.2 is about 33 kilograms which is among the lowest in the world and well below the levels found in china, which is about 800 kilograms and India about 125 kilograms per capita (Hailu et al., 2016).

Table 2.2 Cement production in Ethiopia

Plant name	Mixed capacity	2009 Capacity		
		PPC	OPC	Total
Mugher Cement	900,000	777,500	89,000	864,000
Messebo Cement	900,000	845,000		845,000
National Cement	300,000	300,000		300,000
Jemma Cement	240,000		200,000	200,000
Abyssinia Cement	150,000		100,000	100,000
Midroc Dejen	90,000		90,000	90,000
Red Fox Intl	150,000			150,000
CGOCC Cement	150,000	100,000	150,000	100,000
Total	**2,880,000**	**2,020,000**	**629,000**	**2,649,000**

Despite the rising supply, the cement demand in the country has been increasing even more than the supply due to large-scale public sector infrastructure projects (roads, power plants) and private sector construction activity for residential housing, industry, and real estate developments Due to this low supply and rising demand in the country, cement price has been increasing for quite some time. This high cost of cement makes its affordability under question mark in the country. There is a huge difference between the Ex-factory selling price and the retail selling price (Hailu et al., 2016). This shows that there is high profit margin on the selling price of cement which is caused by the demand supply gap. The increase in cement price calls for some form of cement replacing materials with a lower price.

2.4 Bagasse ash

Sugarcane is a member of the grass family. Sugarcane is a tree-free renewable resource and one of the most important agricultural plants that grown in hot regions. Sugarcane is “carbon neutral” (i.e. emissions are equal to energy generated) and is the product of choice in the manufacture of bio-fuels due to its high energy conversion rate. Bagasse is lateral production of sugarcane that after treatment of sugarcane in the form of light yellow color particles is produced. The chemical composition of this product are cellulous fibers, water and some soil soluble material such as cube sugar, by passing time cube sugars converted alcohol also the evaporation of bagasse fiber produces the methane gas which can cause fire in some circumstance. Bagasse is composed of fiber and pith, the fiber is thick walled and relatively long. Bagasse is a major by-product of sugar industry which finds a very useful utilization in the same industry as an energy source. Sugarcane consists of 25-30% bagasse whereas sugar recovered by the industry is about 10%. Bagasse is also used as a raw material for paper making due to its fibrous content(Agunsoye & Aigbodion, 2015). SBA is obtained in abundant quantities from sugar industries. After crushing of sugarcane in sugar mills and extraction of juice from processed cane by milling, the discarded fibrous matter is called bagasse. Bagasse is used as fuel in the cogeneration boiler to generate steam for the production of sugar as well as electricity. Bagasse is burnt at around 500°C in a controlled process to use its maximum fuel value. The residue after burning, namely, BA, is collected using a bag-house filter and directly disposed to the nearest land as slurry. When bagasse is burnt in the boiler of cogeneration plant under controlled conditions, reactive amorphous silica is formed due to the combustion process and is present in the residual ashes. This amorphous silica content makes BA a useful cement replacement material in concrete. Use of supplementary cementious materials significantly enhances the microstructure of concrete and helps to attain less permeable concrete. When pozzolanic materials are used, reactive silica present in these materials reacts with calcium hydroxide and produce additional C–S–H gel. Permeability of concrete is considerably reduced because of pore refinement as well as additional C–S–H formation (Bahurudeen & Santhanam, 2014).The use of different cement replacing materials has become a common practice in the construction industry. Most of these cement replacement materials are byproducts of different industries and agricultural wastes. Blast furnace slag, silica fume, fly ash and rice husk can be cited as an example. SBA has also been found to have such pozzolanic property(Hailu et al., 2016).

BA is a cellulose fiber remaining after the extraction of the sugar-bearing juice from sugarcane. BA is one of the biomass sources and valuable byproducts in sugar milling that often uses bagasse as a primary fuel source to supply all the needs of energy to move the plants. Burning bagasse as an energy source yields its ash, considered as a waste causing disposal problems.(Worathanakul, Payubnop, & Muangpet, 2018)

2.4.1 Pozzolanic property of bagasse ash

Pozzolans are siliceous or siliceous and aluminous materials which alone possess little or no cementious value but which will, in finely divided form in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementious properties. Pozzolanic materials can be divided into two groups: natural pozzolana and artificial pozzolana. Clay and shales, opalinc chert, diatomaceous earth, and volcanic ash are an example of natural pozzolans while fly ash, blast furnace slag, silica fume, rice husk ash, and metakaoline are example of artificial pozzolans. Most of the pozzolans in use today are mainly byproduct materials that are widely available. Pozzolan as silica material or alumina-silica that has not any cohesive characteristics itself but in the form of fine powder in adjacent of moisture and normal heat reacted with calcium hydroxide and make a composition with cementious characteristics. Using Pozzolan in concrete as cement replacement will enhance the workability, followability, mechanical strength and concrete durability.

Because of the diversity of pozzolans their chemical composition also varies. Therefore, classifying pozzolans only depending on their chemical composition would be difficult. For this reason, ASTM C 618 classifies pozzolans depending on performance basis. ASTM C 618 chemical composition for natural (N), fly ash (F) and silica fume (S) pozzolans is as shown in Table 2.3.

Table 2.3: ASTM C 618 chemical requirement for Pozzolan (Hailu et al., 2016)

Chemicals	Pozzolan Class		
	N	F	S
SiO_2+Al_2O_3+Fe_2O_3 (min %)	70.0	70.0	70.0
MgO (max %)	5.0	-	5.0
SO_3 (max %)	4.0	5.0	4.0
Moisture content (max %)	3.0	3.0	3.0
Loss on ignition (max %)	10.0	12.0	10.0
Available alkalis as Na_2O (max %)	-	1.5	1.5

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

BA was also tested to have such property. It acts as a pozzolanic material when added to cement because of its silica (SiO_2) content which reacts with free lime released during the hydration of the cement and forms additional calcium silicate hydrate (CSH) as a new hydration product. This additional CSH improves the mechanical strength of the cement concrete. The capacity of pozzolonic material of enhancing the strength of concrete is more closer associated with physical than chemical effects(Jagadesh, Ramachandramurthy, & Murugesan, 2018).

The silica content of the ash depends on the type of soil and harvesting. It is also found that it depends on the burning temperature of the bagasse. High temperature helps eliminate impurities in bagasse ash as well. In addition to this it was found that the holding time in the furnace has also some effect on the content of the silica. A research conducted on the burning of sugarcane bagasse at 400, 500, 600, 700, and 800^{o}c for 3, 5, 6 and 8 hours respectively, identified the suitable burning and residence time to be 600^{o}c for 5 hours. The higher temperatures will give higher amount of silica content, but the resulting silica is in crystalline form which is not in active state(Ajay & Anwar ., 2007).

2.4.2 Potential of sugarcane BA as supplementary cementious material in concrete

Material characterization and performance evaluation are needed to evaluate new alternative supplementary cementious materials for use in concrete. This process includes chemical, physical, mineralogical and micro structural characterization. Chemical characterization is imperative to find major, minor, and trace elements in the alternative materials. Special attention is needed for the compounds which influence the hydration of cement or properties of the concrete. If such compounds are present, then suitable test should be carried out to find the availability of these compounds to participate in hydration reactions. Characterization and performance evaluation of SBA in the previous research studies have been reviewed and presented in this section.

Raw bagasse ash is composed mainly of SiO_2 (60-75 %), CaO, K_2O and other minor oxides including Al_2O_3, Fe_2O_3, and SO_3. The amount of silica present in the residual ashes is directly related to the burning temperature of bagasse in the boiler. Due to the presence of unburned particles, the loss on ignition of raw bagasse is reported to be higher than the permissible limits in the standard for use as pozzolanic material. Many ways were suggested to increase the compliance of the industry to the demand of sustainable development. Increased use of supplementary cementitious materials, increased reliance on recycled materials, improved sustainability, mechanical property and reuse of wash water are some of the methods.

The reduction of Portland cement in concrete can be achieved by replacing it with different supplementary cementious materials which are a byproduct of another industry. Fly ash, silica fume, ground granulated blast furnace slag, and etc have been used for this purpose successfully.

SBA as described before contains silica which is the most important component of cement replacing materials. It is also found in large amount as a byproduct in sugar factories. Despite this abundance and silica content, relatively little has been done to examine the potential of this material for concrete production. Even though little, the conducted researches confirm the suitability of this material for concrete production by replacing cement in some percentage.

The water consistency and setting time of the blended cements increased with the increase of SBA because of dilution effect. Water requirement of the bagasse ash blended mix was more than the control mix due to the presence of large fibrous particles. Compressive strength, water absorption, and chloride diffusion in concrete were investigated. Samples with SCBA better performance compared to control specimens. The raw bagasse ash performance was not evaluated before processing. Most of the previous research studies directly processed bagasse ash to cement fineness and used as mineral admixture in concrete. .

U.R. Kawade et al., had studied on "Effect of use of Bagasse ash on Strength of Concrete" they had chemically and physically characterized and partial replaced in the ratio of 0%,10%, 15%, 20%,25% and 30% by weight of cement in concrete. The results show that the SBA concrete had significantly higher compressive strength compared to that of the concrete without SBA. It is found that the cement could be advantageously replaced with SBA up to maximum limit of 15%. Although the optimal level of SBA content was achieved with 15% replacement. Partial replacement of cement by SBA increases workability of fresh concrete; therefore use of super plasticizer is not essential.

H.S. Otuoze et al., had investigated on "Characterization of Sugar Cane Bagasse ash and ordinary Portland Cement blends in Concrete", The SBA is obtained by burning Sugar cane Bagasse at between 600-700^{o}c, since the sum of SiO_2, Al_2O_3 and Fe_2O_3 is 74.44%, For strength test , mix ratio of 1:2:4 was used and OPC was partially replaced with 0% ,5%, 10%, 15%, 20%, 25%, 30%, 35%, 40% by weight in concrete. Compressive strength values of hardened concrete were obtained at the ages of 7,14,21,28 curing days. Based on the test conducted, it can be concluded that SBA is a good pozzolana for concrete cementation and partial blends of it with OPC could give good strength development and other engineering properties in concrete. An optimum of 10% SBA blends with OPC could be used for reinforced concrete with dense aggregate. Higher blends of 15% and up to 35% of SBA with OPC are acceptable for plane or mass concrete. From the above research outputs, we can see that SBA can be used as a cement replacing material. When used in proper replacement percentage as given by research for the locally available bagasse ash, it can improve various properties of the concrete.

2.4.3 Availability of Bagasse ash in Ethiopia

In order to assess the potential of bagasse ash production in Ethiopia, it is imperative to evaluate the sugarcane crop yield in the country. There were three state owned sugar factories functioning in the country in 2010. Their annual production capacity is about 300,000 tons, the sugarcane covering about 10,000 hectares of land. This annual production is not sufficient to satisfy the local sugar demand forcing the government to annually import 1.5 million quintals from abroad.

To avoid this shortage of sugar in the country the government plans to establish eight new sugar factories in the coming five years with a total estimated capacity of 2.250 million tons at the start of their production according to the strategic plan and covering about 225,000 hectares.

Beside this the government is undertaking expansion projects on the existing factories to increase their production capacity. At the end of this expansion projects on Fincha, Methara and Wonji and Shoa sugar factories the additional (not including the current production) total aggregate production capacity is expected to be around 365,000 tons of sugar annually. In detail, Finchaa sugar factory is found in the western part of the country planned to increases its production to 270,000 tons; Wonji and Shoa sugar factory found 100 km far from east of Addis Ababa plans to increase their production to 350,000 tons; Methara Sugar Factory found 250 km far from east of Addis Ababa, is also expected to increase its annual production to 190,000 tons according to the sugar development Study. Tendaho sugar factory which will be established with the help of the Indian government is expected to have an annual production capacity of 600,000 tons is expected to be completed at the end of 2011.

3. MATERIAL AND METHODS

3.1 Investigation of the physical properties of SBA

The investigation of physical properties of SBA was to determine density, fineness and particle size of SBA.

3.1.1 Materials

The materials used in the investigation of physical properties of SBA were:

Bagasse ash: The SBA used as partial replacement of cement in this research was taken from Wonji Sugar factory which is located in Oromiya Regional State North Eastern Ethiopia. The BA in this factory is collected at 8 hour interval from the furnace and dumped around the factory very close to the residence of the factory workers. It was not possible to measure the temperature in the furnace while taking the BA, because the measuring instrument was not long enough to go through the furnace. Even though it was not possible to measure the temperature, most furnaces have a temperature above that is required for complete combustion which is around 800^{o}c. But it was suggested that at a temperature around 650^{o}c the crystallization of minerals occur. This reduces the pozzolanic activity of the bagasse ash(Hailu et al., 2016).

Equipments: different sieve size meshes were used to compare particle size distribution of BA and OPC, balance and the Blaine air permeability were used for evaluating fineness of BA.

3.1.2 Methods

Sufficient amount of BA taken from the furnace was packed in sacks and transported to Addis Ababa Institute of Technology. Before investigation of the physical properties, the BA was dried in atmospheric temperature by which moisture contained in it was removed. The dried BA sieved with 250µm sieve, large and lumpy particles along with part of bagasse ash larger than 250µm was sieved out. The picture below shows BA before and after sieved with 250µm sieve.

Fig 3.1 Bagasse ash before (left) and after (right) sieving with 250 µm sieve

Particle size: The particle size distribution of BA sieved with 250µm and cement was done in chemical engineering unit operation laboratory. The particle size distribution is as shown is the Table 3.1 below:

Table 3.1 Particle size distribution of sieved bagasse ash with 250 µm sieve and OPC cement

Sieve size(µm)	Percentage passing BA	Percentage passing OPC
200	78.54	100
150	71.35	100
100	68.7	98.1
75	50.8	95
50	35.5	82.5
32	8.63	5
Pan	3.52	0.0

Density: the density of BA basically defines as the mass per unit volume. For this study the density of BA was tested in geological survey center of Ethiopia.

Fineness test: The fineness of cement is measured as specific surface area by observing the time taken for a fixed quantity of air to flow through a compacted cement bed of specified dimensions and porosity. Under standardized conditions the specific surface of cement is proportional to $\sqrt{T}$ where T is the time for a given quantity of air to flow through the compacted cement bed. The number and size range of individual pores in the specified bed are determined by the cement particle size distribution which also determines the time for the specified air flow (ES 1176-6:2005, 2005).

It is calculated from its specific surface as follows:

$S = (SS\sqrt{T})/\sqrt{T_S}$……………………………………………………………………Eq. 3.1

Where:

S = Specific surface of the test sample (cm^2/g)

SS = Specific surface of the standard sample used in calibration of apparatus (cm^2/g)

T = Measured time interval of manometer drop for test sample (seconds)

Ts = Measured time interval of manometer drop for standard sample used in calibration of apparatus (seconds).

In the same manner the fineness of BA was measured by brain air permeability apparatus in chemical engineering laboratory.

The apparatus used in this research is calibrated using standard sample cement which its specific surface (SS) is 2183 cm^2/g. And the corresponding measured time interval during calibration with the standard sample (T_S) is 15 seconds.

The fineness test for the BA used for this research was conducted using three samples of cement and the average time interval required to flow air through the three samples is taken as the measured time interval of manometer drop for test sample (T). The time interval from the three samples was obtained as 61, 59 and 60 Seconds. The average time interval of the three samples is therefore 60 Seconds. Then substituting in Eq. 3.1 and the specific surface of BA used were calculated as follows: -

$S = (2183\ cm^2/g * \sqrt{60}\ Sec)/\sqrt{15}\ Sec = 4371.6\ cm^2/g$

3.2 Investigation of the chemical composition of SBA

The chemical composition of BA was tested in the Geological Survey center of Ethiopia for the complete silicate analysis and other related tests. $LIBO_2$ FUSION, HF attack, gravimetric, colorimetric and AAS analytical method was used in order to assess its chemical composition. The result of chemical composition of BA is given below in Table 3.2. Compounds from Al_2O_3-MnO in table 3.2 was evaluated by $LIBO_2$ (lithium metaborate) fusion method. Si_2O was determined by HF (hydro fluoric acid) attack. P_2O, Tio_2, SO_3 and Cl were determined by colorimetric method. H_2O and LOL were determined by gravimetric method.

Table 3.2. The chemical composition of bagasse ash.

Component	Percentage (%)
SiO_2	74.94
Al_2O_3	8.30
Fe_2O_3	4.44
CaO	1.84
MgO	1.08
Na_2O	1.28
K_2O	2.76
MnO	0.20
P_2O_5	0.66
TiO_2	0.27
H_2O	1.00
LOL	2.29
SO_3	2.15
Cl^-	<0.10
SiO_2+Al_2O_3+ Fe_2O_3	87.68

3.3 The compressive strength of concrete

3.3.1 Materials

The main materials used in preparation of concrete specimen and checking compressive strength of concrete were listed below.

Cement: Dangote brand ordinary Portland cement (OPC) was used in this research to prepare the control and BA as partial replacement of cement specimens. The chemical composition of the cement is inferred relative to the standard restrained by ES 11766:2005 for OPC cements.

Table 3.3 Oxide composition of OPC cement as per ES 1176-6:2005.

Oxide	Percentage
SiO_2	18-24
Al_2O_3	2.6-8
Fe_2O_3	1.5-7
CaO	61-69
MgO	0.5-4
SO_3	0.2-4
K_2O	0.2-1

Fine aggregate: the Fine aggregate used for this research was ordinary river sand free from debris were brought from nearby having specific gravity of 2.6 and particle size below 4.75 mm were used.

Coarse aggregate: The coarse aggregate used for this research is crushed rock that was available in Addis Ababa construction area. In order to free the aggregate from undesirable dust material, it was thoroughly washed and dried in open air. A maximum size of 20 mm coarse aggregate was used.

Water: tap water accessible within the Addis Ababa Water and Sewerage Authority found in the laboratory was used for all mixing and curing of concrete.

Balance: to measure materials cement, aggregate, bagasse ash and water.

Slump cone: to measure workability of concrete or slump test.

Compressive strength testing machine: Was used to test the concrete cubes for crushing compressive strength 7, 14, 21 and 28 days respectively.

3.3.2 Methodology

Preparation of mixing and concrete specimens: Five different proportions of concrete mixes (bagasse ash ranging from 5% to 20% by weight of cement) including the control mix were prepared with a water cement W/(C+BA) ratio of 0.45 for a design cube compressive strength M25 grade. For each substitution ratio, 3 sets (4 x 3 = 12) of concrete specimens were prepared for compressive strength test conducted at the age of 7, 14, 21 and 28 days. For this experimental analysis total 60 concrete specimens were casted.

Cement, BA and aggregate were weighing using weight measurement. After determining the relative amount of materials to use for the specimens, the aggregates, cements and BA were dry mix for one minute at different percentages of BA as replacing of cement (0%, 5%, 10% and 20%) then added water. After the addition of water, all the materials were mixed for another two minutes. Immediately after mixing, workability or slump test were measured by using slump cone for each BA replacement mixing and control mix. The cast moulds are cleaned of dust particles by using mineral oil on all Sides before concrete are poured in to the moulds. The well mixed concrete was filled in to the moulds and kept on vibration table. Then the specimens were place on a firm and level surface of prepared moulds (150mm x 150mm x 150mm) by compacting in two layers using vibrating table. The specimens were vibrating for 45 seconds and 30 seconds for the two steel moulds and one steel moulds, respectively. After vibration the top surface is finished using a trowel. Then After 24 hours the specimens were demoulded from the moulds and were cured in a curing pond for 7, 14, 21 and 28 days at room temperature of the laboratory. The mix proportion of one cubic concrete (150mm x150 x 150) M25 concrete was prepared as shown in table 3.4.

Table 3.4 Mix proportion for the concrete preparation

Mix cod	Cement type	Cement quantity (gm)	Bagasse ash (gm)	W/(C+BA)	Water (gm)	FA (gm)	CA (gm)
BAC0	Dangote OPC	2362.5	0	0.45	1063.13	3542.75	4725
BAC 5	Dangote OPC	2244.38	118.13	0.45	1036.13	3542.75	4725
BAC10	Dangote OPC	2126.25	236.25	0.45	1063.13	3542.75	4725
BAC15	Dangote OPC	2009.7	354.38	0.45	1063.13	3542.75	4725
BAC20	Dangote OPC	1890	472.5	0.45	1063.13	3542.75	4725

Where:

BAC0 is a concrete mix with 100% OPC and 0% BA by mass

BAC 5 is a concrete mix with 95% OPC and 5% BA by mass

BAC 10 is a concrete mix with 90% OPC and 10% BA by mass

BAC 15 is a concrete mix with 85% OPC and 15% BA by mass

BAC 20 is concrete mix with OPC 80%OPC and 20% BA by mass

Workability of fresh concrete: The workability was measured using slump cone. The concrete slump can be classified according to the nature of concrete fall. There are 3 types of the slump test, these are:

True slump: In a true slump concrete just subsides shortly and more or less maintain the mould shape. This type of slump is most desirable.

Shear slump: If one-half of the cone slides down in an inclined plane, it is called a shear slump. Shear slump indicates lack of cohesion in the concrete mix.

Collapse slump: In this case, fresh concrete collapses completely.

The true slump is the only reliable condition to get an idea about the workability of concrete. If other types occur, the test should be repeated. The slump test for this work was true slump test.

The concrete slump test is an empirical test that measures consistency of fresh concrete. The slump test was carried out in the form of a frustum of a cone having an upper diameter of 100 mm, and a lower diameter of 200 mm and a height of 300 mm. The mould and base plate were dampened and placed on a level ground. With the mould being held firmly on to the base plate, the mould was filled up in three layers, each being compacted with 25 strokes of the steel tamping. After the top layer had been compacted, the surface of the concrete was struck off by a sawing and rolling motion of the tamping rod. The spilled concrete was then removed from the base plate and the mould was raised by a steady uplift. The difference between the height of the mould and that of the highest point of the slumped test specimen was measured using a straight. The slump test was performed for the concrete with and without SBA to check the workability of fresh concrete.

Checking compressive strength of prepared concrete: After the completion of the required curing period 7, 14, 21 and 28 days every specimen was checked for the compressive strength in the compressive strength machine as shown in figure 3.2. After the necessary investigations tested samples were placed outside of the laboratory.

Figure 3.2 Concrete compressive strength tests

3.4 Evaluating water absorption of developed concrete

3.4.1 Materials

The Cylindrical concrete developed with different mix percent of BA and control mix concrete was used for evaluating water absorption test and water also used to immersing the concrete. **Equipments:** Oven to dry the cylindrical concrete before immersed in water and balance to measure the weight of concrete before and after absorption was used.

3.4.2 Methodology

Like preparation of cubic concrete for compressive strength test similarly cylindrical concrete were used to evaluate water absorption with different BA as partial replacement of cement (0%, 5%, 10%, 15% and 20%) mixings. Specimens were prepared and tested for each mix at the age of 28 curing days. After the required curing period, the cylindrical specimens (100 mm x200mm) were oven dried at temperature of 105 ° C for 24 h and weighed. Then immersed in water for 24h and weighed again. Water absorption was calculated as follows.

Water absorption: WA% = $\frac{Ws - W_d}{W_d} x100\%$

Where Wd is the weight of the dried specimens before the absorption test and Ws is the weight of the dried specimens immersed in water for 24 h.

4. RESULTS AND DISCUSSION

In this section discussion of physical properties and chemical composition laboratory test results of BA for its suitability as cement replacing in concrete production and evaluating the developed concrete properties were presented and analyzed. The different properties of the BA and developed concrete are:

- The fineness of BA in terms of specific surface area, particle size distribution and density compared with OPC.
- The chemical properties of BA in terms of chemical compositions.
- The workability of fresh concrete, compressive strength and water absorption of hardened concrete containing BA which replaced ordinary Portland cement.

4.1 Physical and chemical properties of SBA

In this part the test results were the physical properties of BA in terms fineness, particle size distribution and density and chemical properties of bagasse ash in the form of chemical composition.

4.1.1 Physical properties of SBA

Table 4.1 Physical properties of cement and SBA

Material	Density in cm^2/g	Blain air in cm^2/gm	Average size (µm)
OPC	3.15	2910	74
BA	1.92	4371.6	43

N.B: the average size of the particle is the sieve size at which 50% of the particles passes, and is determined by linear interpolation**.**

The graph for the particle size distribution of the BA and cement is as shown in Figure 4.1 below

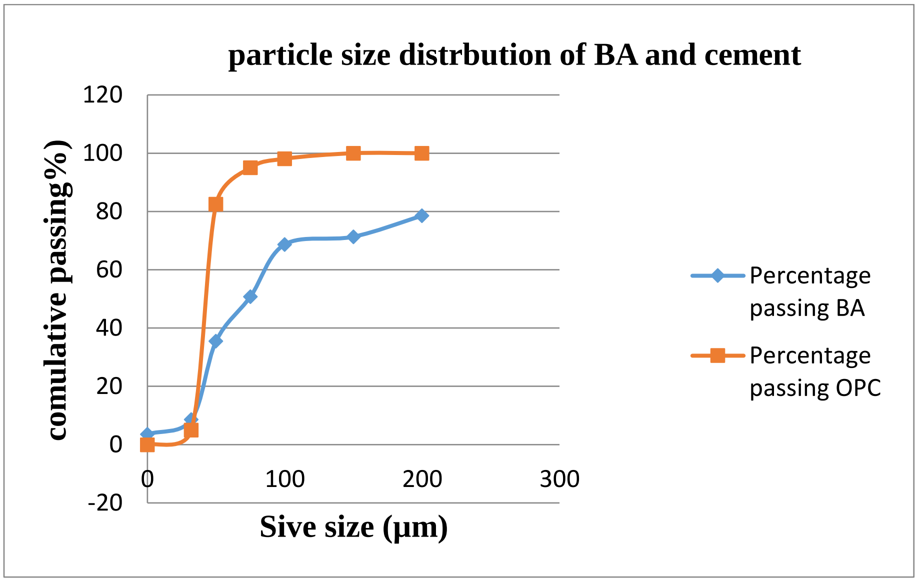


Figure 4.1 particle size distributions of bagasse ash and cement

As shown in Table 4.1 Particle size analysis of bagasse ash samples indicated that average size of the BA passed with 250µm particles was 74µm. The cement had an average size of 43µm which is greater than the ash. This is also shown in the particle size distribution of BA and cement in Figure 4.1. This figure shows that the bagasse ash is coarser than the cement for higher sieve sizes greater than 20µm (where the two graphs meet) and the cement is finer for sieve sizes greater than 20µm sieve size, this showing that the BA passed with 250µm contains some finer particle than cement but almost it is coarser than cement.

The fineness of BA by blain air permeability method was found to be 4371.6cm^2/g, which is greater than cement which was measured to have a surface area of 2910 cm^2/g. The advantage of high specific surface area of BA is to increase the rate of reaction of free lime released during the hydration of cement and forms additional calcium silicate hydrate as new hydration product which improves the mechanical properties of hardened concrete.

As shown in Table 4.1, BA has low density (1.92g/cm^3) and higher surface area (Blaine surface area, 4371.6cm^2/g) as compared to OPC. From the results it can be seen that the blain air of the bagasse ash is higher than that of cement, this show bagasse ash has a higher fineness than cement which is due to the lower density of the bagasse ash (Hailu et al 2016) has reported that large surface area favors the pozzolanic reactivity of amorphous silica and other minerals.

4.1.2 Chemical composition of SBA

The chemical composition tests were carried for the elements that characterize the nature of SBA which included; Silicon dioxide (SiO_2), Aluminum oxide (Al_2O_3), Iron oxide (Fe_2O_3), Sodium oxide (Na_2O), Potassium oxide (K_2O) Calcium oxide (CaO), Magnesium oxide (MgO), Sulfur trioxide (SO_3), Loss on ignition (LOI)(Kigozi, 2016).

Atomic absorption spectrometry (AAS): AAS is an analytical technique that measures the concentration of elements. The technique makes use of wavelength of light specifically absorbed by an element.AAS works by atoms of different elements absorb characteristic wavelength of light. The grater the number of atoms there is in the vapour, the more radiation is absorbed. The amount of light absorbed is proportional to the number of atoms.

Table 4.2: Chemical composition of cement and bagasse ash

Chemical Composition (%)	Dangote OPC cement (2005)	Bagasse ash
SiO_2	18-24	74.94
Al_2O_3	2.6-8	8.3
Fe_2O_3	1.5-7	4.44
CaO	61-69	1.84
MgO	0.5-4	1.08
Na_2O	-	1.28
K_2O	0.2-1	2.76
MnO	-	0.20
P_2O_5	-	0.66
TiO_2	-	0.27
H_2O	-	1.00
LOL	-	2.29
SO_3	0.2-4	2.15
Cl^-	-	<0.01
$SiO_2+Al_2O_3+Fe_2O_3$	30.55	87.68

Results from the analysis of the chemical composition of SCBA are shown in Table 4.2. It was observed that the biggest composition of ash is silicon dioxide. This plays the major role in binding as it forms complexes that include Tricalcium silicate and Dicalcium silicate which are the major components of cement hence making it a material with good binding properties.

The combined chemical composition of SiO_2, Al_2O_3, and Fe_2O_3 = 87.68 > 70% testified the pozzolanic nature of bagasse ash as per ASTM C- 618 specifications. According to this specification, the bagasse ash qualifies to be a Class N Pozzolan.

4.1.3 Workability of fresh concrete

In order to assess the workability of the fresh concrete the slump test was conducted. A concrete mix should be workable enough in order to be placed, compacted and finished. The ingredients in concrete should be in such a proportion as to allow a good workability of the concrete and sufficient strength to support the required load after hardening. Table 4.3 below gives these workability values for the control and blended concrete.

Table 4 .3 Slump test results

S.No	Mix code	W/(C+BA) (%)	Slump value(mm)
1	BAC0	0.45	65
2	BAC5	0.45	50
3	BAC10	0.45	45
4	BAC15	0.45	40
5	BAC20	0.45	20

As can be seen from Table 4.3 the slumps of the concrete containing BA have shown a slight reduction as the BA content increases. This can be an indication that OPC-BA blended concretes needs higher water content than a concrete with no BA. The reason for this might be the higher specific surface area of the BA and its lower density giving it a higher porosity, resulting in higher water demand. In order to get similar slump for the control and OPC-BA concrete, the water content can be increased as the BA content increases.

4.1.4 Unit weight of hardened concrete

In this research unit weight, compressive strength, and water absorption of the hardened concretes are tested and presented in the sections below.

Results on unit weight: The weights of cylindrical concrete where measured before immersed in water in water absorption test was used for evaluating the unit weight of concrete mixed with and without BA as replacement of cement after 28 days curing and dried in oven. The unit weights of the concrete are shown in Table 4.4 given below.

Table 4.4: Unit weights of concretes

Mix code	Unite wt.(gm)	Reduction (%)
BAC0	3514	0.0
BAC5	3509	0.15
BAC10	3500	0.26
BAC15	3490	0.28
BAC20	3475	0.43

From table 4.4, the result was found out that a slight reduction of unit weight up to 0.43 % was observed when 20% of the cement was replaced by bagasse ash in sample BAC20. Whereas 0.15%, 0.2 6% and 0.28 % reductions were observed for 5, 10 and 15 % bagasse ash replacement in sample BAC5, BAC10 and BAC15 respectively. The low density of the bagasse ash, 1.92g/cm^3, as compared to 3.15g/cm^3 for that of OPC resulted in a reduction of unit weights of the blended concretes.

4.2 The compressive strength of concrete

The compressive strength test of concrete is the most common test type for the hardened concrete. The reasons for these are many codes and design manuals are based on this property, many other properties of concrete depend on the compressive strength and when compared to other tests this is an easy one. The compressive strength for concrete grade M25 (1:1 ½:2) were investigated for the control mix and while cement was partially replaced by SBA.

The compressive strength of each of the concrete is determined by testing the cubes in a compression machine. For each of the mixes the average value of three samples is taken as their compressive strength. The results of average compressive strength test at different curing days (7, 14, 21 and 28) are provided in table 4.5.

Figure 4.2 Specimen before (left) and after (right) testing compressive strength

Table 4.5: Average compressive strength values of concrete

S. No	Mix code	Average compressive strength (Mpa)			
		7 day	14 day	21day	28 day
1	BAC0	28.37	32.68	33.38	36.6
2	BAC5	29.76	33.6	36.08	38.84
3	BAC10	25.24	28.37	32.54	36.12
4	BAC15	24.76	28.37	30.91	32.82
5	BAC20	23.25	27.75	29.98	32.12

From the figure 4.3 the compressive strength of the concrete cubes for all the mix ratios increases with curing days increasing. The average compressive strength value of concrete with 5% bagasse ash was showing a relatively high strength value than the control and BA of 10, 15 and 20 concrete samples for all curing days (7, 14, 21and 28). The 21and 28 day compressive strength value of concrete with 5% bagasse ash replacement was showing a strength enhancement of about 8% and 6%, respectively. The 14 days compressive strength of concrete with 10% and 15% had slows the same strength value 28.37Mpa. Similarly, compressive strength of concrete with 0% BA and 10% BA gives almost similar compressive strength values of 36.6 and 36.12 Mpa at the 28 day. From these results cement could advantageously replaced by BA up to 5% in high concrete properties to that of control concrete. Higher percentage replacement of BA can also be used with a slight reduction in the performance of the concrete.

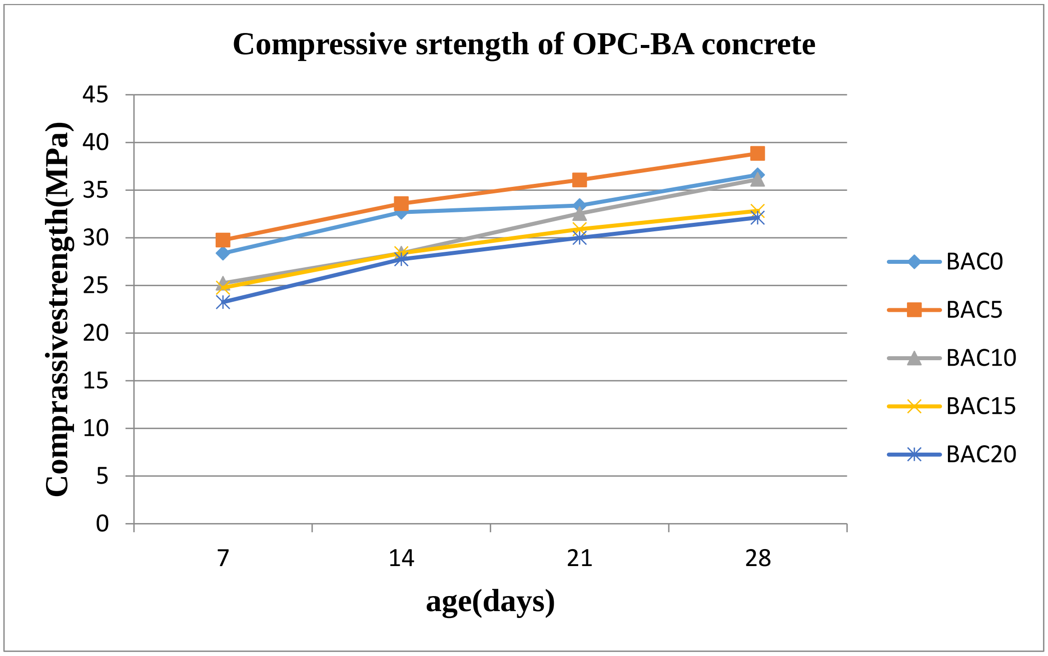


Figure 4.3 Compressive strength of OPC-BA concrete

4.3 Water absorption

The water absorption of concrete mixes containing SBA is given in Table 4.6 with the exception of the mix containing 5 % BA (BAC5), there was a slight increase in water absorption with an increasing amount of BA. Mixes BAC5 have a slightly lower water absorption observed than the control mix (BAC0). However, the mixes containing 10 % SCBA (BAC10) show a slight increase of 0.3 % on water absorption compared to the control mix (BAC0) when the cement replacement of SCBA increases to 20 %, the water absorption increases evidently. The high water absorption of the mixes containing BA was due to the porous nature and rough surface of the BA particles. The percentage water absorption is a measure of pore volume or porosity in hardened concrete, which is occupied by water in saturated conditions. Thus, 5 % cement replacement of BA may be considered as the optimum limit water absorption.

Table 4.6: the percentage water absorption of concrete

Mix code	Average weight of concrete (gm)		Water absorption (%)
	Before absorption	After absorption	
BAC0	3493.3	3641.3	4.3
BAC5	3509	3622.7	3.2
BAC10	3464.2	3624.5	4.6
BAC15	3504	3675.7	4.9
BAC20	3377.5	3547	5

The percentage of water absorption was calculated as follows from table 4.6

Water absorption: WA% = $\frac{Ws - W_d}{W_d} x100\%$

Where Wd is the weight of the dried specimens before the absorption test and Ws is the weight of the dried specimens immersed in water for 24 h.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This research carried out to investigate sugar cane bagasse ash as a partial replacement of cement in concrete production. The following conclusions were derived from the experimental results of bagasse ash properties and concrete with BA.

- Bagasse ash has low density ($1.92 g/cm^3$) and higher surface area (Blaine surface area, $4371.6 cm^2/g$) as compared to OPC which has $3.15 g/cm^2$ density.
- The analysis of the chemical composition of SCBA was shown that the maximum composition of bagasse ash is silicon dioxide (SiO_2). This plays the major role in binding as it forms complexes that include Tricalcium silicate and Dicalcium silicate which are the major components of cement hence making it a material with good binding properties.
- The combined chemical composition of BA were investigated in this study had; SiO_2, Al_2O_3 and Fe_2O_3 = 87.68 > 70% testified the pozzolanic nature of bagasse ash as per ASTM C- 618 specifications. According to this specification, the bagasse ash qualifies to be a Class N Pozzolan.
- It has been observed that the experimental result for the 5% replacement of bagasse ash concrete to OPC has increase in compressive strength of concretes with comparison 0%, 10%, 15% and 20% replacement of BA at all curing days. The 21and 28 days compressive strength value of concrete with 5% bagasse ash replacement was showing a strength enhancement of about 8% and 6% respectively. Therefore, the BA concrete performed better when compared to ordinary cement concrete up to 5% replacement of SBA. Beyond 5% replacement of bagasse ash, the compressive strength decreased.
- Water absorption of concrete with BA increases as the bagasse ash content of the concrete increases and all the concretes with bagasse ash have water absorption greater than the control with the exception of the average water absorption for the concrete with 5% bagasse ash. Therefore, concrete with 5% BA replacement of OPC may be considered as the optimum limit water absorption.
- Since Bagasse ash is a by-product material from sugar factory, its use as a partial replacement of cement reduces the levels of CO_2 emission by the cement industry and also

saves a great deal of virgin materials. In addition of its use resolves the disposal problems associated with it in the sugar industries.

- Finally, the results of this experimental work have concealed that cement could advantageously be replaced with BA up to 5%. This replacement results in high concrete properties to that of the control concrete. Higher replacement percentages can also be used with a slight reduction in the performance of the concrete.

5.2 Recommendations

From this experimental study it is indicated that using SBA as partial replacement of ordinary Portland cement to increase the compressive strength of concrete up to 5% BA. From this study the following recommendations are forwarded:

- Find out optimum amount of SBA that can be used in concrete production for partially replacement of cement without significant loss of strength.
- Studies should be made using controlled burning of the bagasse at different temperature and holding time.
- Assess the use of SBA in concrete for the various properties of concrete with variation content of SBA. Example modulus of elasticity, flexure test and drying shrinkage etc.
- It can be suggested that for sugar factory, providing a suitable furnace near the factory for burning sugar cane bagasse and their bagasse ash disposal.
- Studies should be made to check the pozzolanic reaction of the bagasse ash using more advanced methods like X-ray Diffraction (XRD) Analysis, Thermal Analysis (TGA) and Scanning Electron Microscopy (SEM).

6 .REFFERENCES

Abdulkadir, T. S., Oyejobi, D. O., & Lawal, A. A. (2014). Evaluation of sugarcane bagasse ash as a replacement.

Ajay Goyal and Anwar A.M., Hattori Kunio, Ogata Hidehiko, Properties of Sugarcane bagasse ash and its potential as cement-pozzolana binder, Ain Shams University, December 2007

Amin, N. (2015). Use of Bagasse Ash in Concrete and Its Impact on the Strength and Chloride Use of Bagasse Ash in Concrete and Its Impact on the Strength and Chloride Resistivity. (February). https://doi.org/10.1061/(ASCE)MT.1943-5533.0000227

Bahurudeen, A., & Santhanam, M. (2014). Performance Evaluation of Sugarcane Bagasse Ash-Based Cement for Durable Concrete. (July).

Commission, E. (2001). Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques in the Cement and Lime Manufacturing Industries December 2001. (December).

Denamo Addissie, Handling of Concrete making materials in the Ethiopian construction industry, Addis Ababa University department of civil engineering, school of graduate studies, October 2005

Environmental-friendly durable concrete made with recycled materials for sustainable concrete construction. (2014). (February).

Gowda, K. (2015). A study on bagasse ash replaced plain cement concrete. (July).

Hailu, B., Unsw, T., & Tekle, B. H. (2016). Bagasse ash as a cement replacing material school of graduate studies bagasse ash as a cement replacing material a thesis submitted to. (July). https://doi.org/10.13140/rg.2.1.2257.8166

Jagadesh, P., Ramachandramurthy, A., & Murugesan, R. (2018). Overview on properties of sugarcane bagasse ash (SCBA) as Pozzolan. 47(October), 1934–1945.

J.O. Agunsoye and V.S.Aigbodion, “Bagasse filled recycled polyethylene bio-composites: Morphological and mechanical properties study,” Results in Physics, vol(3),pp.187-194,2013.

Keflegen, A. (2018). Addis Ababa Institute of Technology School of Civil and Environmental Engineering Hydraulic Engineering Stream. (JUN).

Kigozi, J. (2016). Investigation of sugar cane bagasse ash as a binding material for the. (may).

M. Balakrishnan, V.S. Batra “Valorization of solid waste in sugar factories with possible applications in India: review” journal of Environmental Mangement, 92, 2886-2891, 2011.

Mulay, S., Vesmawala, G., Patil, Y., & Gholap, V. (2017). Experimental Investigation of Sugarcane Bagasse Ash Concrete Under Sodium Hydroxide Solution of Bagasse Ash. 5(1), 1–8. https://doi.org/10.11648/j.ajce.20170501.11

Naik T.R. and Moriconi G., Environmental-friendly durable concrete made with recycled materials for sustainable concrete construction, University of WisconsinMilwaukee, 2006

Osore, B. Y., & Kwena, C. (2016). University of nairobi ash (scba) on mechanical properties of concrete. (march).

Sidney Mindess, Francis Young J., David Darwin, concrete, 2nd edition, Prentice-Hall INC, 2003, pp.47, 96, 121 and 222.

Worathanakul, P., Payubnop, W., & Muangpet, A. (2018). Characterization for Post-treatment Effect of Bagasse Ash for Silica Extraction. (August 2009).

Xiaolu Guo, Huisheng Shi, Warren A. Dick “Compressive strength and mocrostructural characteristics of class C fly ash geopolymer” Cement and concrete composites, 32, 142-147, 2010

APPENDIX A

COMPRESSIVE STRENGTH OF OPC-BA CONCRETES

Seven Days Compressive strength of OPC-BA concretes

BAC0			
No	**age(days)**	**failure load (KN)**	**compressive strength (MPa)**
1		621.5	27.62
2		665.6	29.58
3	7	628.3	27.92
Average		**638.47**	**28.37**
BAC5			
1		726.6	32.43
2		627.9	27.91
3	7	650.9	28.93
Average		**668.47**	**29.76**
BAC10			
1		583.5	25.93
2		520	23.11
3	7	600	26.67
Average		**567.83**	**25.24**
BAC15			
1		544	24
2		563.4	25
3	7	568.7	25.28
average		**558.7**	**24.76**
BAC20			
1		461.3	20.5
2		548.1	24.36
3	7	542.1	24.9
average		**517.17**	**23.25**

Fortin day's compressive strength of concrete OPC-BA

	BAC0		
No	age(days)	failure load(KN)	compressive strength(Mpa)
1	14	717	31.9
2		743	33.05
3		744.6	33.09
Average		**734.87**	**32.68**
BAC5			
1	14	766.2	34.05
2		790.3	35.12
3		715.6	31.8
Average		**757.37**	**33.66**
BAC10			
1	14	649.8	28.88
2		677.3	30.1
3		588.1	26.14
Average		**638.4**	**28.37**
BAC15			
1	14	641.9	28.53
2		626.2	27.83
3		631.9	28.08
Average		**633.33**	**28.15**
BAC20			
1	14	619.3	27.53
2		615.7	27.37
3		638.2	28.36
Average		**624.4**	**27.75**

Twenty one days compressive strength of OPC-BA concrete

BAC0			
No	**age (days)**	**failure load (KN)**	**Compressive strength (MPa)**
1		753.9	33.5
2		770.4	34.24
3	21	728.9	32.4
Average		**751.07**	**33.38**
BAC5			
1		769.6	35.42
2		818	36.32
3	21	835.5	36.5
Average		**807.7**	**36.08**
BAC10			
1		713	31.69
2		737.6	32.78
3	21	746.1	33.16
average		**732.23**	**32.54**
BAC15			
1		675.9	30.04
2		741.7	32.96
3	21	669	29.73
average		**695.53**	**30.91**
BAC20			
1		702	31.2
2		659.3	29.3
3	21	662.1	29.43
average		**674.47**	**29.98**

Twenty eight days compressive strength of OPC-BA concrete

BAC0			
No	**age(days)**	**failure load (KN)**	**Compressive strength(Mpa)**
1		773.9	34.4
2		822.15	36.54
3	28	873.9	38.84
Average		**823.32**	**36.59**
BAC5			
1		897.7	39.75
2		871.4	38.73
3	28	856.1	38.05
Average		**875.07**	**38.84**
BAC10			
1		809.3	35.97
2		819.4	36.42
3	28	809.6	35.98
Average		**812.77**	**36.12**
BAC15			
1		690.2	30.2
2		800.5	35.58
3	28	736.9	32.7
Average		**742.53**	**32.83**
BAC20			
1		685.2	30.46
2		728.8	32.39
3	28	754.5	33.53
Average		**722.83**	**32.13**

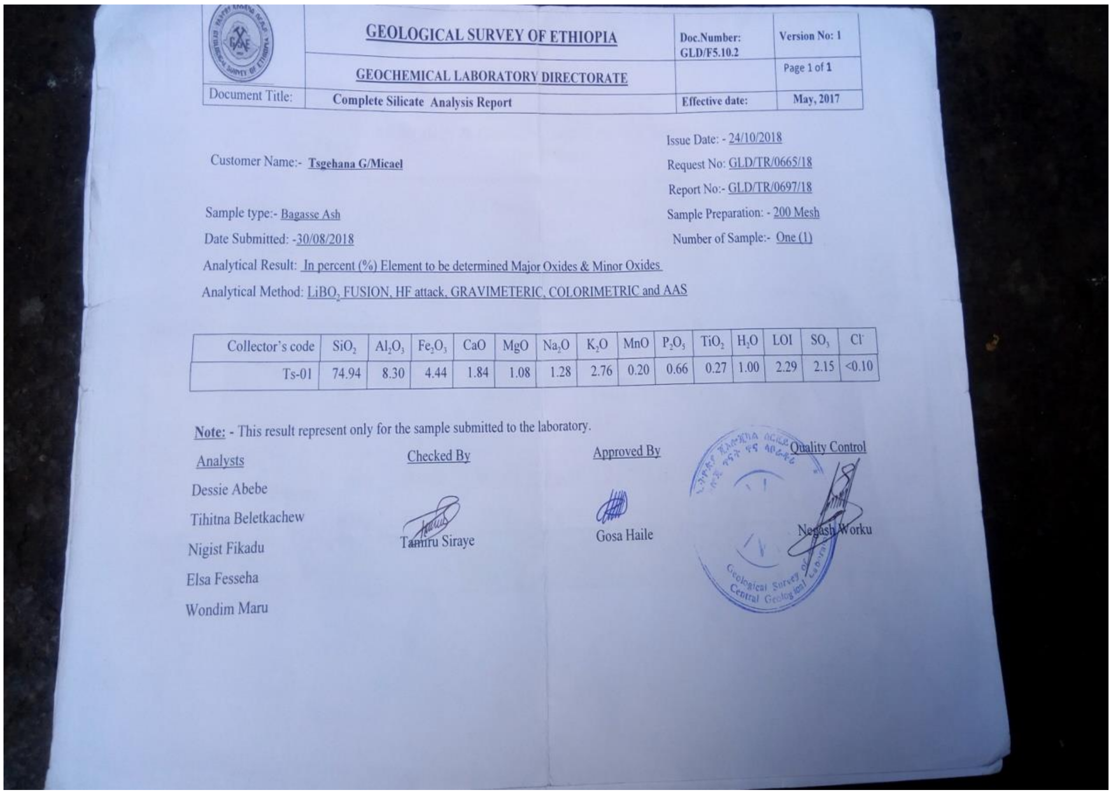
APPENDEX B

WATER ABSORBTION OF CONCRETE

BAC0		
No	weight before absorption	weight after absorption
1	3490.3	3646
2	3496.2	3637
3	3493.5	3641
Average	**3493.33**	**3641.33**
BAC5		
1	3514	3620
2	3503	3635
3	3510	3613
average	**3509**	**3622.7**
BAC10		
1	3500	3675
2	3502	3671
3	3510	3681
average	**3504**	**3675.67**
BAC15		
1	3474.9	3631
2	3452.1	3617
3	3465.5	3625.6
average	**3464.17**	**3624.53**
BAC20		
1	3378.7	3561
2	3380	3545.8
3	3373.8	3534.7
Average	**3377.5**	**3547.17**

APPENDIX C

COMPLETE SILICA ANALYSIS REPORT



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: - 24/10/2018

Customer Name:- Tsgehana G/Micael

Request No: GLD/TR/0665/18

Report No:- GLD/TR/0697/18

Sample type:- Bagasse Ash

Sample Preparation: - 200 Mesh

Date Submitted: -30/08/2018

Number of Sample:- One (1)

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

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

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	SO_3	Cl^-
Ts-01	74.94	8.30	4.44	1.84	1.08	1.28	2.76	0.20	0.66	0.27	1.00	2.29	2.15	<0.10

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

Analysts: Dessie Abebe, Tihitna Beletkachew, Nigist Fikadu, Elsa Fesseha, Wondim Maru

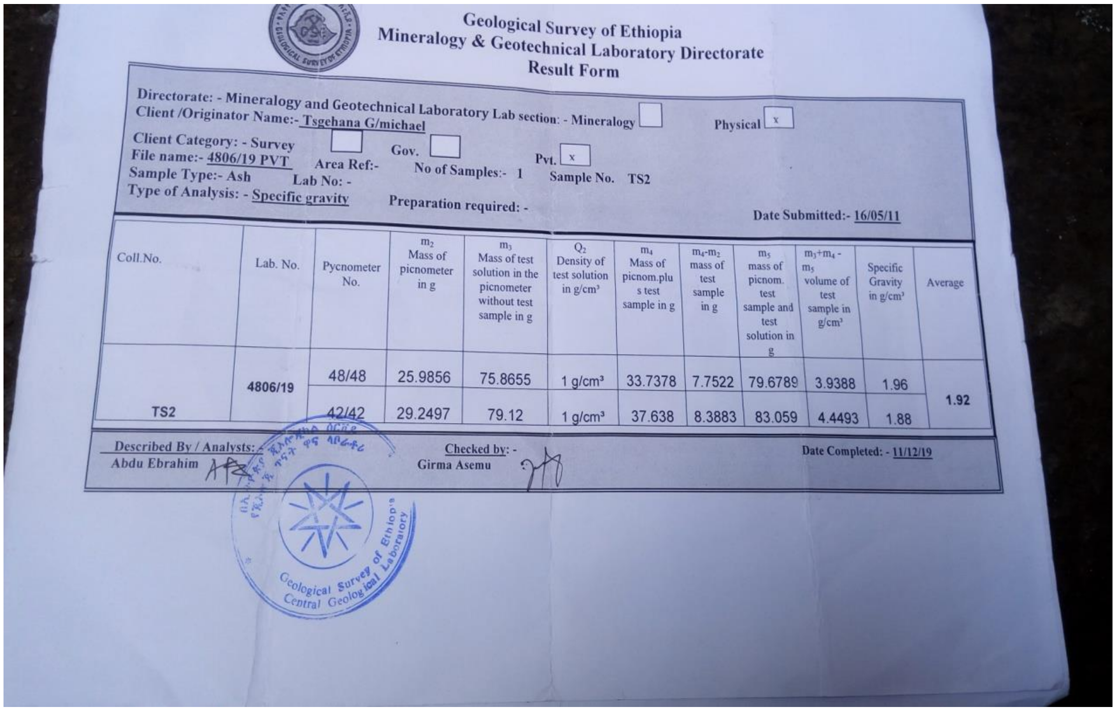
Checked By: Tamiru Siraye

Approved By: Gosa Haile

Quality Control: Negash Worku

APPENDIX D

DENSITY OF BAGASSE ASH REPORTED



Geological Survey of Ethiopia
Mineralogy & Geotechnical Laboratory Directorate
Result Form

Directorate: - Mineralogy and Geotechnical Laboratory Lab section: - Mineralogy [ ] Physical [x]
Client /Originator Name:- Tsgehana G/michael
Client Category: - Survey [ ] Gov. [ ] Pvt. [x]
File name:- 4806/19 PVT Area Ref:- No of Samples:- 1 Sample No. TS2
Sample Type:- Ash Lab No: -
Type of Analysis: - Specific gravity Preparation required: - Date Submitted:- 16/05/11

Coll.No.	Lab. No.	Pycnometer No.	m_2 Mass of picnometer in g	m_3 Mass of test solution in the picnometer without test sample in g	Q_2 Density of test solution in g/cm³	m_4 Mass of picnom.plus test sample in g	m_4-m_2 mass of test sample in g	m_5 mass of picnom. test sample and test solution in g	m_3+m_4-m_5 volume of test sample in g/cm³	Specific Gravity in g/cm³	Average
TS2	4806/19	48/48	25.9856	75.8655	1 g/cm³	33.7378	7.7522	79.6789	3.9388	1.96	1.92
		42/42	29.2497	79.12	1 g/cm³	37.638	8.3883	83.059	4.4493	1.88	

Described By / Analysts: - Abdu Ebrahim
Checked by: - Girma Asemu
Date Completed: - 11/12/19

APPENDIX E

SAMPLE PHOTOS TAKEN DURING THE RESEARCH

Photo 1 Bagasse ash before and after passed 250 µm size sieves

Photo 2 fine aggregate

Photo 3 Blain air permeability apparatu

Photo 4 Slump test

Photo 5 Concrete compressive strength test

Photo 6 concretes before and after compressive strength test

Photo 7 cylindrical concrete in oven dyer

Photo 8 concrete in water absorption test