ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

ADDIS ABABA INSTITUTE OF TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING

Bagasse ash as a cement replacing material

BIRUK HAILU

ADVISOR: PROF. DR. - ING. ABEBE DINKU

A Thesis Submitted to
School of Graduate Studies in Partial Fulfillment of the
Requirements for the Degree of Master of Science in Civil Engineering
(Construction Technology and Management)

December 2011

ACKNOWLEDGEMENTS

First of all, I praise the Lord God Almighty for providing me with power and grace to carry out this thesis work in particular and the postgraduate studies in general.

I would like to convey my honest gratitude to my advisor Prof. Dr.-Ing. Abebe Dinku for his useful suggestions, kind support, guidance, precious discussion, constant encouragement and valuable comments at the various stages throughout the research work.

My acknowledgment is also extended to Dr. Esayas G/Youhannes, for his valuable comments, kind support, constant encouragement, precious time and cooperation throughout the study.

I take this opportunity to express my gratitude to the Ministry of Education for sponsoring this post graduate study. In addition I am extremely thankful to Wonji/Shoa sugar factory for providing me the research material bagasse ash and for their support.

Special thanks are due to my mother W/ro Yeshi Molla, all my families and friends for their endless patience, encouragement, continuous support and help during my postgraduate study.

Biruk Hailu
Addis Ababa, December 2011

ABSTRACT

Sugarcane bagasse ash is a byproduct of the sugar factories found after burning sugarcane bagasse which itself is found after the extraction of all economical sugar from sugarcane. The disposal of this material is already causing environmental problems around the sugar factories. Due to the boost of the construction activity in the country, a huge shortage is created in most of the construction materials especially cement, resulting in steady increase of price. This research was therefore, conducted to examine the potential of bagasse ash as a cement replacing material.

Initially, bagasse ash samples were collected from Wonji sugar factory and its chemical properties were investigated. The bagasse ash were then ground until the particles passing the 63 µm reaches about 85%, which is similar to that of ordinary Portland cement. Ordinary Portland cement and Portland pozzolana cement were replaced by ground bagasse ash. Normal consistency and setting time of the pastes containing ordinary Portland cement and bagasse ash from 5% to 30% replacement were investigated. The compressive strength of mortars containing ordinary Portland cement and Portland pozzolana cement with bagasse ash from 5% to 30% replacements were also investigated. Four different concrete mixes with the bagasse ash replacing 0%, 5%, 15% and 25% of the ordinary Portland cement were prepared for 35MPa concrete with water to cement ratio of 0.55 and 350kg/m^{3}cement content. The properties of these mixes have then been assessed both at the fresh and hardened state.

The results of the mortar work have shown that, up to 10% replacement of the ordinary Portland cement by bagasse ash achieved a higher compressive strength at all test ages i.e. 3, 7 and 28 days, whereas the 15% replacement of the cement by bagasse ash in the concrete have shown a slightly lower compressive strength at 56 days. The water penetration depth was found to increase as the bagasse ash content increases and all the blended concretes showed a higher maximum penetration depth than the control concrete. It can therefore be concluded that 10% replacement of cement by bagasse ash results in a similar concrete properties and higher replacement could also be used with a slight reduction in the performance of the concrete.

TABLE OF CONTENTS

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

CHAPTER SIX

CHAPTER SEVEN

APPENDIX A

APPENDIX B

APPENDIX C

APPENDIX D

APPENDIX E

APPENDIX F

APPENDIX G

APPENDIX H

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	American Society for Testing Materials
AASHTO	American Association of State Highway and Transportation Officials
Al_2O_3	Alumina
BA	Bagasse Ash
$CaCO_3$	Calcium Carbonate
C_3S	Tricalcium Silicate
C_2S	Dicalcium Silicate
C_3A	Tricalcium Aluminate
C_4AF	Tetra Calcium Alumino Ferite
CO_2	Carbon dioxide
CaO	Calcium Oxide
$Ca(OH)_2$	Calcium Hydroxide
C–S–H	Calcium Silicate Hydrate
CSH_2	Calcium Sulfate dehydrate
cm^2	Centimeter square
ES	Ethiopian Standard
Fig.	Figure
Fe_20_3	Ferrite
Gm	Gram
Kg	kilo gram
kJ	kilo Joule
kN	kilo Newton
kg/m^3	kilo gram per meter cube
Km	Kilometer
L.O.I	Loss On Ignition
M	Meter
m^3	meter cube
Mm	Millimeter
mm^2	millimeter square
MPa	Mega Pascal
MgO	Magnesium Oxide
OPC	Ordinary Portland Cement
OD	Oven Dry
PPC	Portland Pozzolana Cement
SiO_2	Silicon dioxide
SO_3	Sulpher Trioxide

SSD	Saturated Surface Dry
W/C	Water to Cement ratio
W/B	Water to Binder ratio
%	Percent
^{o}C	Degree Centigrade
μm	Micrometer

CHAPTER ONE

INTRODUCTION

1.1 General

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 cementitious and chemical admixtures, where as 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 [7]. 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.

Cement which is one of the components of concrete plays a great role, but is the most expensive and environmentally unfriendly material. Therefore requirements for economical and more environmental-friendly cementing materials have extended interest in other cementing materials that can be used as partial replacement of the normal Portland cement. Ground granulated blast furnace slag, fly ash, silica fume, etc have been used successfully for this purpose.

Recently 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, has been tested in some parts of the world for its pozzolanic property and has been found to improve some of the properties of the paste, mortar and concrete like compressive strength and water tightness in certain replacement percentages and fineness [2]. However, nothing has been done to check the feasibility of the bagasse ash produced in Ethiopia for this purpose.

The pozzolanic property of sugarcane bagasse ash came from the silicate content of the ash. This silicate under goes a pozzolanic reaction with the hydration products of the cement and results a reduction of the free lime in the concrete [3]. 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 sugarcane is grown.

Therefore, this study attempts to make use of the bagasse ash produced in Ethiopia as a pozzolanic material to replace cement. An experimental investigation was carried out to examine the impact of adding bagasse ash to the mechanical and physical properties of pastes, mortars and concretes such as consistency, setting time, workability, compressive and flexural strength and durability.

1.2 Justification for the thesis

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 [1]. This shows that the cement industry contributes to today's worldwide concern, which is global warming. This endangers the sustainability of the cement industry and that of concrete.

In addition to its negative environmental impact cement is also one of the most expensive materials when compared to the other constituents of concrete. The raw materials for the cement production like lime are also being exploited in large amount which may result in running out of them, as it is predicted to happen in some places of the world [1].

The generation of energy by using bagasse as fuel also creates a great deal of waste material known as sugarcane bagasse ash 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 [2].

Thus this thesis deals with checking the feasibility of the agricultural byproduct bagasse ash which is produced as a waste in Ethiopian sugar factories for using it as cement replacement material.

1.3 Objectives of the research

1.3.1 General objectives

The general objectives of this research work is to assess the availability of sugarcane bagasse ash in Ethiopia and to study the feasibility of using this material found from sugar factories as a cement replacement material.

1.3.2 Specific objectives

The specific objectives of this research work can be stated briefly as follows:

A. Checking the availability of bagasse ash in the country.

B. Checking the chemical composition of the bagasse ash.
C. Evaluating the performance of paste, mortar and concrete made of bagasse ash as a replacement material by conducting some laboratory tests on the fresh and hardened state and determining the quantity of bagasse ash that can be used successfully.
D. Investigating the economical and environmental issues of using bagasse ash for cement replacement.

Finally after making such assessment on the performance of the sugarcane bagasse ash some conclusions and recommendations will be forwarded on the performance and various aspects of the material as cement replacement.

1.4 Research methodology

The following methodology has been employed to achieve the objectives of the research:

1. Literature survey, which includes concrete, cement replacement materials, bagasse ash as cement replacing material, the potential of Ethiopia for bagasse ash and some performance tests on the fresh and hardened concrete. The review includes text books, periodicals and academic journals, seminars, and research papers.

2. Sample preparation at different percentages of bagasse ash replacing cement.

3. Performing different tests on pastes, mortars and concretes at both fresh and hardened state, including determination of fineness for bagasse ash and cement and their blends, normal consistency and setting time, and compressive strength at 3, 7 and 28 days for the mortar and at 7, 28, and 56 days for the concrete including flexural tests at 7 and 28 days and water penetration test at 56 days on the hardened concrete.

4. Analysis of the test results in which the results were presented in graphical form and interpretation and discussion were made on the research findings.

5. And finally formulation of conclusion and recommendations based on the results obtained.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The cement and concrete technology has shown various advancements during the past years. One of the best advancements is the use by-product materials as a cement replacement to alleviate environmental and economical impact of cement production. These cement replacing materials were reported to improve different properties of the mortar and the concrete [2, 12, 13, 27].

Bagasse ash is one of these by-product 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.

This chapter is, therefore, dedicated in discussing about cement, different performance criteria of concrete, pozzolans and bagasse ash.

2.2 Cement

Cement is a fine grey powder which when reacted with water hardens to form a rigid chemical mineral structure which holds the aggregates together acting as glue and gives concrete its strengths. The credit for its discovery is given to the Romans, who mixed lime ($CaCO_3$) with volcanic ash, producing a cement mortar which was used during construction of such impressive structures as the Colosseum [19].

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 [14]. 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.

2.2.1 Types of cement

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.

2.2.1.1 Portland cement

Portland cement is one of the most widely used cement and is the most important hydraulic cement. It can also be used for mortar & plaster production. It 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, we get concrete.

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 [8]. 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_20_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 [7]

Chemical Name	Chemical formula	Shorthand Notation	Weight percentage
Tricalcium silicate	$3CaO.SiO_2$	C_3S	55
Dicalcium silicate	$2CaO.SiO_2$	C_2S	18
Tricalcium aluminate	$3CaO.Al_2O_3$	C_3A	10
Tetracalcium aluminoferrite	$4CaO.Al_2O_3.FeO_3$	C_4AF	8
Calcium sulfate dehydrate (gypsum)	$CaSO_4.2H_2O$	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 a low heat of hydration is required, like in mass concrete.
- Finally ASTM type V is Sulphate -resisting Portland cement which is used when high sulphate resistance is desired.

2.2.1.2 Portland Pozzolana cement

Portland pozzolana cement (PPC) is manufactured by the intergrinding of OPC clinker with 15 to 35 % of pozzolanic materials [8]. Pozzolanic materials are siliceous or aluminous materials which by themselves posses little or no cementitious 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 cementitious property.

The reaction of the pozzolanic materials with calcium hydroxide results in many advantages of PPC over OPC. If these pozzolanic materials were not reacted with the calcium hydroxide, free calcium hydroxide would have been present in the concrete resulting in higher permeability of the concrete and susceptibility to other attacks. The pozzolanic reaction reduces the porosity of the concrete by producing cementitious compound. It also reduces the heat of hydration since its reaction is slower than that of OPC, which implies that it has slower rate of strength than OPC, making it suitable for 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.

2.2.2 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 [9]. Gypsum is added to lower the rate of hydration of C_3A. The hydration of C_3S and C_2S are shown in Eq.2.1 and Eq.2.2 [9]:

$$\mathbf{C_3S + 4.3H \longrightarrow C_{1.7}SH_3 + 1.3CH} \quad \text{[Eq.2.1]}$$

$$\mathbf{C_2S + 3.3H \longrightarrow C_{1.7}SH_3 + 0.3CH} \quad \text{[Eq.2.2]}$$

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.

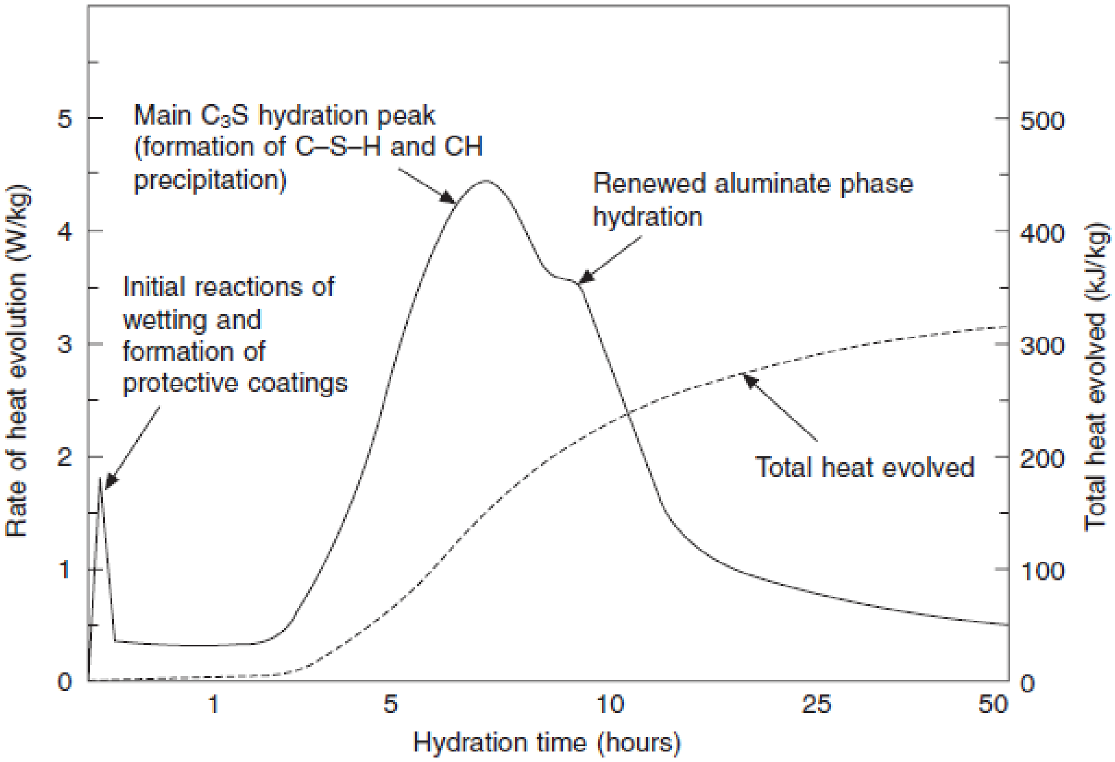

Fig. 2.1 Heat of hydration of a cement paste [9]

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 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, dissolve rapidly. The purpose of adding calcium sulfate is in order to retard the hydration of C_3A, which 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 $C_3A > C_3S > C_4AF > C_2S$ [7]. 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.

2.2.3 Physical properties of cement

Specifications for cement place limits on its physical. 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.

2.2.3.1 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 [7]. 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 [17], where as the ASTM C 150 standard recommends a minimum of 2800 cm^2/g.

2.2.3.2 Consistency of cement paste

Many of the properties of concrete are affected by its water content. The physical requirements of cement paste like setting and soundness depends on the water content of the neat cement paste. Therefore it is necessary to define and study the water content at which to do these tests. This is defined in terms of the normal consistency of the paste which is measured according to 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% [17]. The test is very sensitive to the conditions under which it is being carried out, particularly the temperature and the way the cement is compacted into the mold. The test does not correlate to the quality of the cement; it only measures the plasticity of cement paste.

2.2.3.3 Setting time

Setting is a process in which cementitious mixtures of plastic consistency is converted into a set material which has lost its deformability and crumbles under the effect of sufficiently great external force [19]. 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 [17].

2.2.4 Cement production in Ethiopia

In Ethiopia, the first cement factory was established by Italians in 1936 during the five year fascist occupation of the Country. This was the Dire dawa cement factory. 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 [24].

Table 2.2 Cement production in Ethiopia in 2009 [24]

Plant name	**Max Capacity**	**2009 Capacity**		
		PPC	**OPC**	**Total**
Mugher Cement	900,000	775,000	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	150,000
CGOCC Cement	150,000	100,000		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. Table 2.3 below shows the consumption estimates and the growth rate of cement in Ethiopia:

Table 2.3 Cement consumption in Ethiopia (million tons) [24]

Year (G.C)	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Consumption estimate(million tons)	0.67	0.77	0.75	0.74	0.82	0.82	0.97	1.04	1.17	1.81	2.00	2.50	3.2
Growth rate (%)	…	14.9	-2.6	-1.3	10.8	0.0	18.3	7.2	12.5	54.7	10.5	25.0	27.0

Due to this low supply and rising demand in the country, cement price has been increasing for quite some time. For this research Messebo OPC was purchased for Birr 480 per 100kg. 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. While the Ex-factory selling price for PPC has risen from near Birr 80 in early 2006 to Birr 155 in early 2009, the retail price at selected points in Addis Ababa has risen from around Birr 225 in late 2008 to Birr 325-350 as of May 20, 2009 [24]. 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.

2.3 Concrete

Concrete is the most commonly used modern construction materials. It forms the basis of the modern construction system. Many of our activities directly or indirectly are affected by concrete structures; the buildings we live and work in, the roads we drive on, the dams from which we get water and energy, etc can be an example. The ability of concrete to be cast into any desired shapes and configurations is the reason for its versatility.

The word concrete comes from a Latin word concretus which means to grow together [7], 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.

Concrete is mainly composed of cement, aggregate and water. Cementitious materials, pozzolanic materials, filler materials, chemical admixtures, and some other additives may also be the constituents of concrete depending on the need and their availability. All the constituents have their own purpose in the concrete. Cement with water acts as a binding medium in which the aggregates 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.

2.3.1 Strength of concrete

Strength of concrete is commonly considered its most valuable property, although in many practical cases other characteristics, such as durability and permeability, may in fact be more important. Nevertheless, strength usually gives an overall picture of the quality of concrete because it is directly related to the structure of the hardened cement paste [10].

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. The compaction of the fresh concrete reduces the amount of entrapped air and therefore increases the strength of the concrete. It is found that for each 1 % of air entrapped there will be a 5 to 6 % loss on strength [17]. Curing temperature affects the hydration of cement and hence the duration of strength gains. Cubes kept at about 10^oC will have their 7 day strength reduced by 30% and their 28 day strength by 15% [17]. Different pozzolanic materials have different effect on strength. But most of them including bagasse ash have been found to improve the strength of concrete especially at latter days due to the secondary reaction.

2.3.2 Workability of concrete

Workability is the measure of how easy or difficult it is to place, consolidate and finish concrete. It contains in it different aspects like consistency, flowability, mobility, compactability, finishability, and harshness [7]. It can also be defined in terms of the amount of mechanical work, or energy required to produce 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 a more workable mix, whereas flat, elongated and rough aggregate particles will result in reduction of workability. The increase in the ambient temperature will reduce the workability of the concrete, due to increase of evaporation and rate of hydration caused by the higher temperature.

The cement content and cement replacing materials also affect the workability. Higher cement content reduces workability. The effect of cement replacing materials depends on their nature. Finer materials result in reduction of workability while spherical materials increase it.

2.3.3 Permeability of concrete

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 (or w/cm) 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.

Tests to measure permeability usually fall into three categories [7]. Two of them involve the movement of water through concrete, while the third one involves the movement of electric charge. Here the gas and water permeability are discussed.

2.3.3.1 Gas permeability

The coefficient of permeability of gases is affected by viscosity and compressibility of the gas. For the case of laminar flow (flow of fluids in parallel layers with no disruption between the layers), the coefficient of permeability is given by equation 2.3 [20]:

$$K_g = \eta \cdot \frac{Ql}{tA} \cdot \frac{2p}{(p_1 - p_2)(p_1 + p_2)} \quad \text{…………………...……… [Eq.2.3]}$$

Where K_g = *coefficient of permeability* (m^2)

η = *viscosity of the gas* (Ns/m^2)

Q = *volume of gas flowing* (m^3)

l = *thickness of penetrated section* (m)

A = *penetrated area* (m^2)

p = *pressure at which volume Q is measured* (N/mm^2)

p_1 = *pressure at entry of gas* (N/m^2)

p_2 = *pressure at exit of gas* (N/m^2)

t = *time* (s)

Due to the wide range of pore diameters, the condition of laminar flow may not necessarily prevail for the transport of gases through the paste of concrete. For this reason the coefficient of gas permeability has also been defined as shown in equation 2.4. In this case, K_g is no longer a material characteristic but depends on the transport medium.

$$\overline{K}_g = \frac{Q}{t} \cdot \frac{l}{A} \cdot \frac{p}{p_1 - p_2} \qquad \text{[Eq.2.4]}$$

Where, $\overline{K}_g$ = coefficient of permeability (m^2/s).

2.3.3.2 Water permeability

Among the fluids penetrating concrete water is the most important one. This property of concrete is not a simple function of its porosity, but depends also on the size, distribution, shape and continuity of the pores. According to Neville, although the cement gel has a porosity of 28 percent, its permeability is only about 7×10^{-16} m/s. The reason as explained in Neville is due to the extremely fine texture of hardened cement paste: the pores and the solid particles are very small and numerous, whereas, in rocks, the pores, though fewer in number, are much larger and lead to a higher permeability. Due to this fact the water permeability of granite is about the same as that of mature cement paste with a water/cement ratio of 0.7, i.e. not of high quality [10].

The progress of hydration affects the permeability of concrete. In a fresh paste the size, shape and concentration of the unhydrated cement particles controls the permeability. As hydration proceeds the permeability decreases rapidly because the gross volume of gel is approximately

2.1 times the volume of unhydrated cement, so that the gel gradually fills some of the original water-filled space [10].

The water/cement ratio of the concrete greatly affects the permeability of concrete. The reduction in the coefficient of permeability is faster the lower the water/cement ratio of the paste. For cement pastes hydrated to the same degree, the permeability is lower the higher the cement content of the paste. Moreover, increasing the wet curing duration of concrete with a very high water/cement ratio from 1 day to 7 days reduces its water permeability by a factor of 5 [10].

In addition to these the permeability of concrete is affected by the properties of the cement used. Coarser cements tend to produce a higher permeability than finer cements. The compound composition of the cement affects the permeability of concrete because it affects the hydration of the cement paste.

Two types of water permeability methods are used to measure the penetration of water into concrete. These are the steady state water permeability and the non-steady state water permeability. In the case of steady state, water is allowed to move across the specimen until steady state flow is attained. The penetrated water is recorded when the flow of water becomes steady. The Darcy’s law is used to find the coefficient of permeability. Whereas, in the case of non-steady state, the depth of water penetration is measured without the water flow necessarily reaching a constant value. A succession of water is applied across the specimen as follows [(ISO/DIS/7031), 20]:

- 0.3MPa (3Bar) for the first 24 hours,
- 0.5MPa (5Bar) for the next 24 hours, and
- 0.7MPa (7Bar) for the last 24 hour.

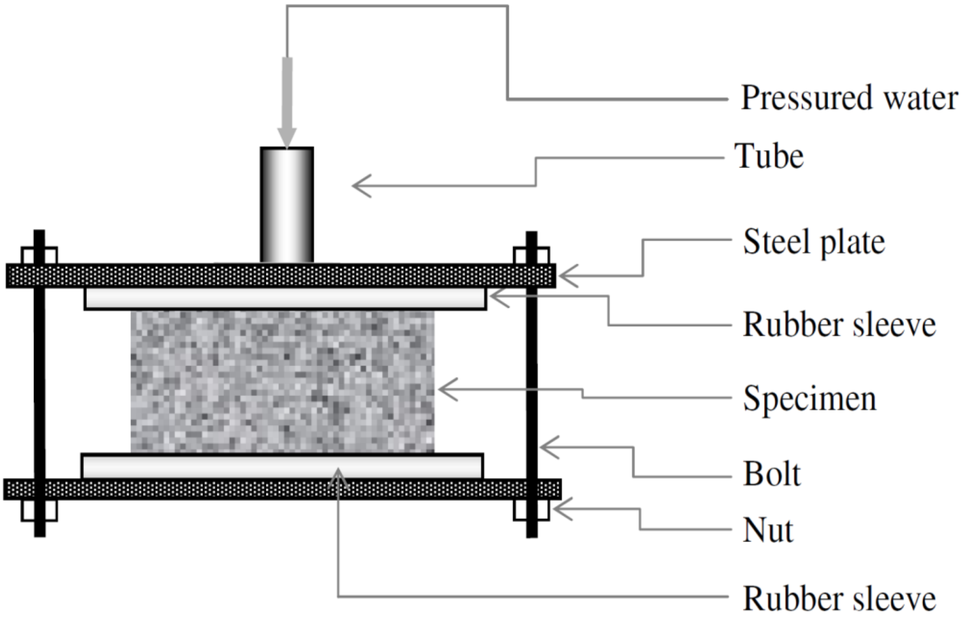

Fig. 2.2 Setup for water penetration test [20].

At the end of the 72 hours period, the specimens will be removed from the rig and split at the center as shown in Figure 2.3. Just after splitting, the maximum and average depths of penetration are visually observed and measured at a desired spacing [21, 20].

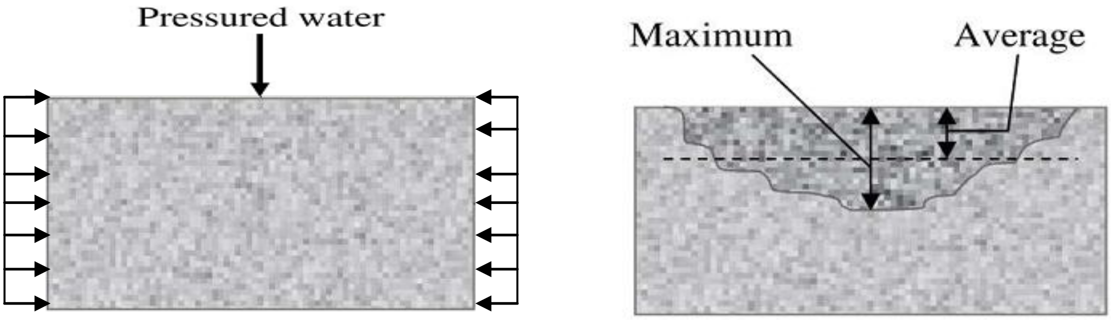

Fig 2.3 Splitting and measurement of penetration depth

2.4 Pozzolans

The modern concrete technology uses different types of admixtures in order to enhance the properties of the fresh and hardened concrete. Mineral admixtures are one of these admixtures used in concrete for a variety of purposes. They may be found naturally or artificially.

These admixtures can be divided into three main categories, which are pozzolanic, cementitious and non-reactive materials. The first two categories are added at the mixer as supplementary cementing materials. These admixtures interact chemically with the hydrating Portland cement and form a modified paste microstructure. The non-reactive admixtures are on the other hand finely divided materials such as lime-stone, silica flour, hydrated lime, etc, which may sometimes react weakly with the cement. They are blended with Portland cement to form masonry cements which have improved workability. In this research we are concerned with pozzolanic admixtures, which are described below.

2.4.1 Pozzolanic materials

Pozzolanic materials are siliceous or siliceous and aluminous materials which alone possess little or no cementitious value but will, in finely divided form and in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties [6]. Their recognition dates back long ago to the ancient Greeks and Romans. The Greeks used volcanic ash and the Romans adopted and extended the Greeks technology using ash from varieties of sources from around their empire.

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.

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 pozzolans is as shown in Table 2.4.

Table 2.4 ASTM C 618 chemical requirement for Pozzolan [28]

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

2.4.2 Pozzolanic reaction

The hydration of tri-calcium silicate and di-calcium silicate with water gives calcium silicate hydrate and calcium hydroxide. The first compound have very low solubility in water while the later one is very much soluble in water and has no cementitious value and is found as a free lime in the concrete, resulting in porosity of the concrete, which in turn results in durability problems. The siliceous and aluminous compounds found in the pozzolan in a finely divided form react with the calcium hydroxide to form highly stable cementitious substances of complex composition involving water, calcium and silica. Finely divided pozzolans and amorphous silicates result a better pozzolanic reaction. The principal reaction taking place is as shown in Eq. 2.5 [7]:

$$\text{Pozzolan} + \text{Calcium Hydroxide} + \text{water} \longrightarrow \text{Calcium Silicate Hydrate (gel)}$$

$$S + CH + H \longrightarrow C\text{-}S\text{-}H \qquad \text{[Eq. 2.5]}$$

This reaction is called pozzolanic reaction. It results in the consumption of the calcium hydroxide produced by the hydration of the cement and as a result lowers its amount in the concrete. The C-S-H formed in this reaction is not very different from that formed in the regular reaction, except the slightly lower ratio of C/S, which is the case for most of the pozzolans. The normal C/S ratio is believed to be around 2 [10].

The pozzolanic reaction in Eq. 2.5 and its kinetics are more similar to the slow rate of hydration of C_2S [7]. Thus the addition of pozzolans has similar effect with increasing the amount of C_2S. This results in the reduction of the rate of strength development and the heat of hydration, which makes it advantageous in mass concrete structures.

The progress of hydration of cement can be measured by measuring the amount of Calcium hydroxide in the paste. In a similar manner the extent of pozzolanic reaction can be followed by monitoring the decrease in calcium hydroxide over time. Figure 2.4 shows the relative amount of calcium hydroxide as the hydration time proceeds for different pozzolanic materials.

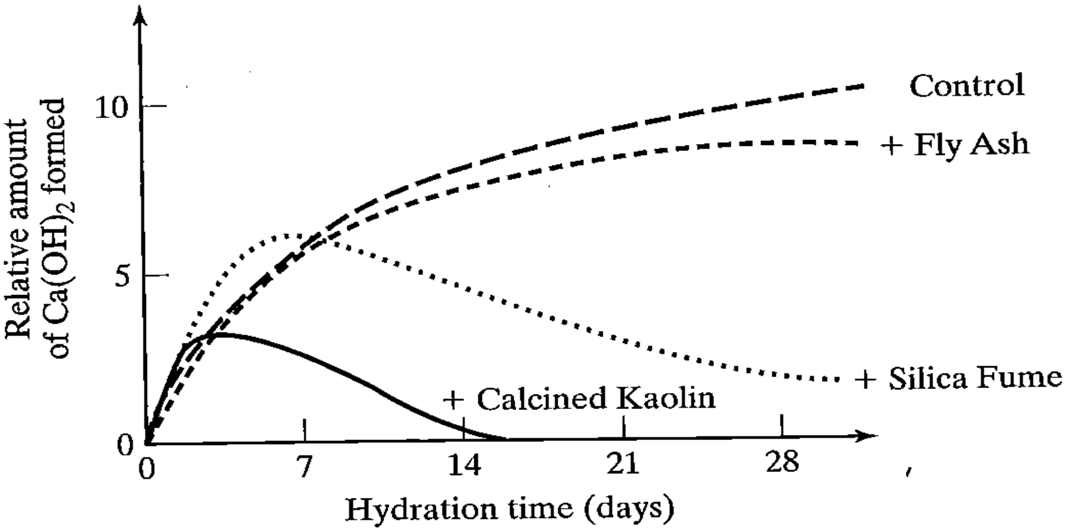

Fig. 2.4 Comparison of the rate of reaction for various pozzolanic admixtures [7]

To get the full benefit of pozzolanic materials prolonged moist curing of the concrete is required because of their slow reaction. Without this type of curing the pozzolans simply act as non-cementitious fillers.

2.5 Bagasse ash

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 sited as an example. Sugarcane bagasse ash has also been found to have such pozzolanic property.

Bagasse is a cellulose fiber remaining after the extraction of the sugar-bearing juice from sugarcane. Bagasse ash 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 [4]. The bagasse ash is about 8-10% of the bagasse and contains unburned matter, silica and alumina [2].

Bagasse ash has been a problem to the environment due to its disposal. The most significant pollutant emitted from the boilers being a particulate matter, caused by the turbulent movement of combustion gases with respect to the burning bagasse and resulting ash. Sometimes some auxiliary fuels typically fuel or natural gas may be used during startup of the boiler or when the moisture content of the bagasse is too high to support combustion, in such cases the emissions of SO_2 and NO_X will increase.

2.5.1 Pozzolanic property of bagasse ash

As described in previous sections pozzolans are siliceous or siliceous and aluminous materials which alone possess little or no cementitious value but which will, in finely divided form in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties [6].

Bagasse ash 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 [3]. This additional CSH improves the mechanical strength of the cement mortar and concrete.

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 [2]. The higher temperatures will give higher amount of silica content, but the resulting silica is in crystalline form which is not in active state.

2.5.2. Bagasse ash as cement replacing material

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

Concrete being one of the most widely used materials worldwide next to water, is not free from some negative environmental impacts. Its popularity carries with it a great cost in terms of environmental aspects. Environmental problems associated with concrete can have varied origins [11]:

1. Worldwide, over ten billion tons of concrete are being produced each year. Such volumes require vast amounts of natural resources for aggregate and cement production. In addition to this it is estimated that one ton of Portland cement production releases about one ton of

CO_2. Each of the constituents of concrete release a certain amount of CO_2 as shown in the Figure 2.5.

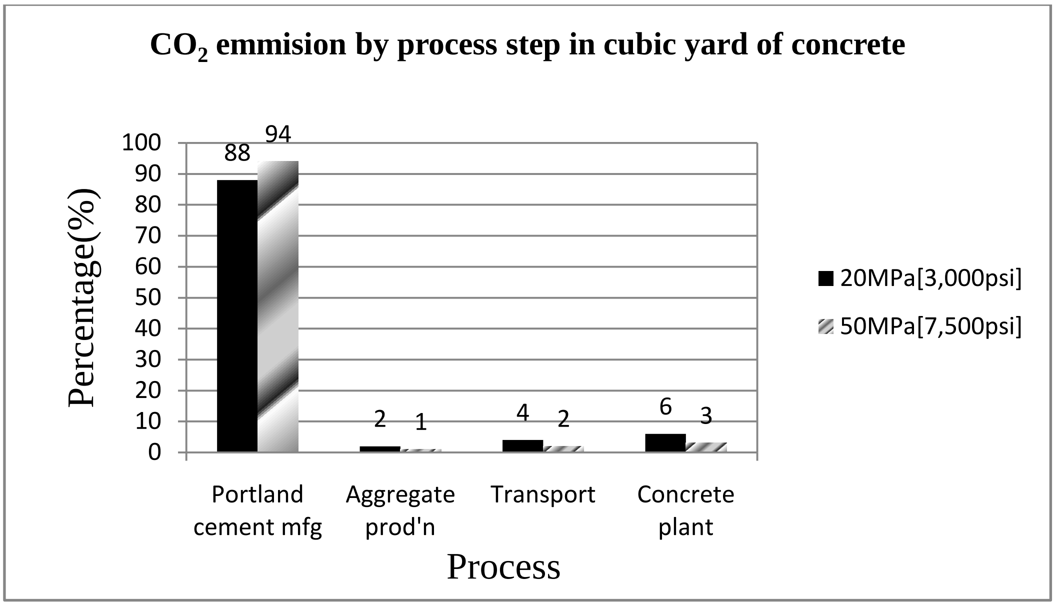

Fig.2.5 Carbon dioxide emissions by process step in a cubic yard of concrete for mixtures with the lowest (20 MPa [3,000 psi] ready mixed concrete) and highest (50 MPa [7,500 psi] precast concrete) levels of embodied energy [12]

2. The production of Portland cement is also energy intensive.

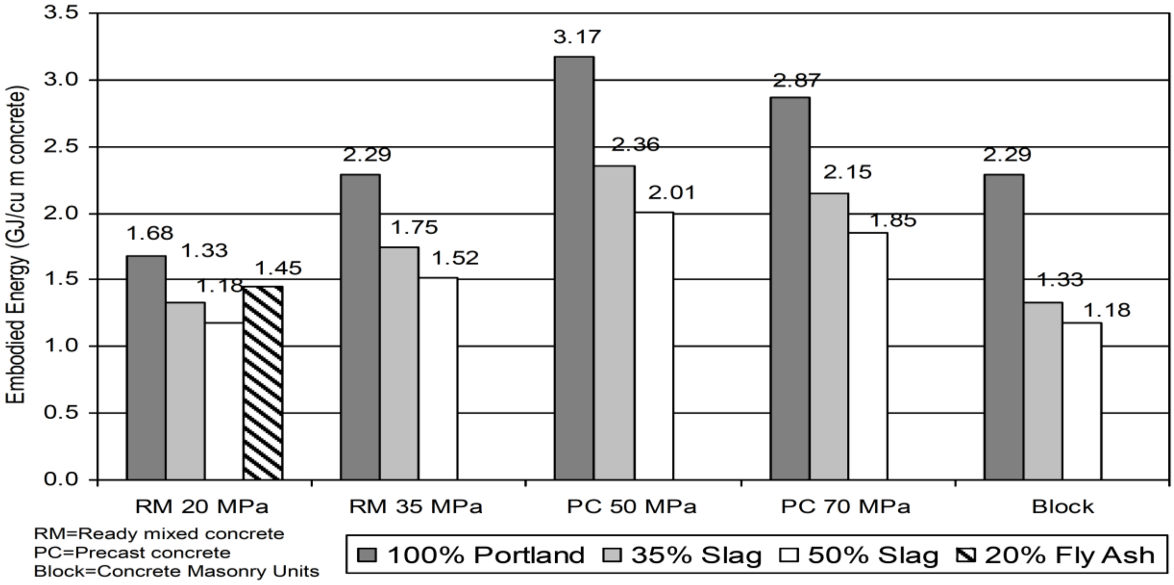

Fig.2.6 Embodied energy required to produce one cubic yard of concrete in various mixtures [12]

3. The demolition and disposal of concrete structures, pavements, etc., constitutes another environmental burden. Construction debris contributes a large fraction of solid waste disposal problem.

4. Finally, the water requirements are enormous and particularly burdensome in those regions of the earth that are not blessed with an abundance of fresh water. The concrete industry uses over 1 trillion gallons of water each year worldwide, and this does not even include wash water and curing water.

These points show that concrete industry has become the victim of its own success. However most of the environmental problems associated with concrete come from the cement in it. This means that the final product i.e. concrete is environmental friendly material by itself [1, 11]. This guides us to play on the concrete constituents which cause the problem. One of the constituent which causes the largest environmental impact is Portland cement. Therefore if we are able to minimize the amount of Portland cement in the concrete we will be able to minimize the environmental impact of the concrete industry as a whole.

Many ways were suggested to increase the compliance of the industry to the demand of sustainable development. Increased use of supplementary cementitious materials, increased reliance on recycled materials, improved sustainability and mechanical property and reuse of wash water are some of the methods.

The reduction of Portland cement in concrete can be achieved by replacing it with different supplementary cementitious materials 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.

Sugarcane bagasse ash 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 [13]. Even though little, the conducted researches confirm the suitability of this material for concrete production by replacing cement in some percentage.

When bagasse ash is used as cement replacing material, it results in some improvement on the properties of concrete. At 90 days, mortar containing ground bagasse ash at 40% replacement showed compressive strength higher than the control mortar, whereas, those that are not ground i.e. the mortar with original ash showed a lower compressive strength than the control mortar [13]. This shows that fineness of bagasse ash is important factor affecting the compressive strength of mortar. Mortar containing finer ash has a higher compressive strength than ash with a higher particle size ash. This same research concludes that mortar containing the original ash had a higher water requirement than mortar containing ground ash, which is due to the large particle size and high porosity of the original ash.

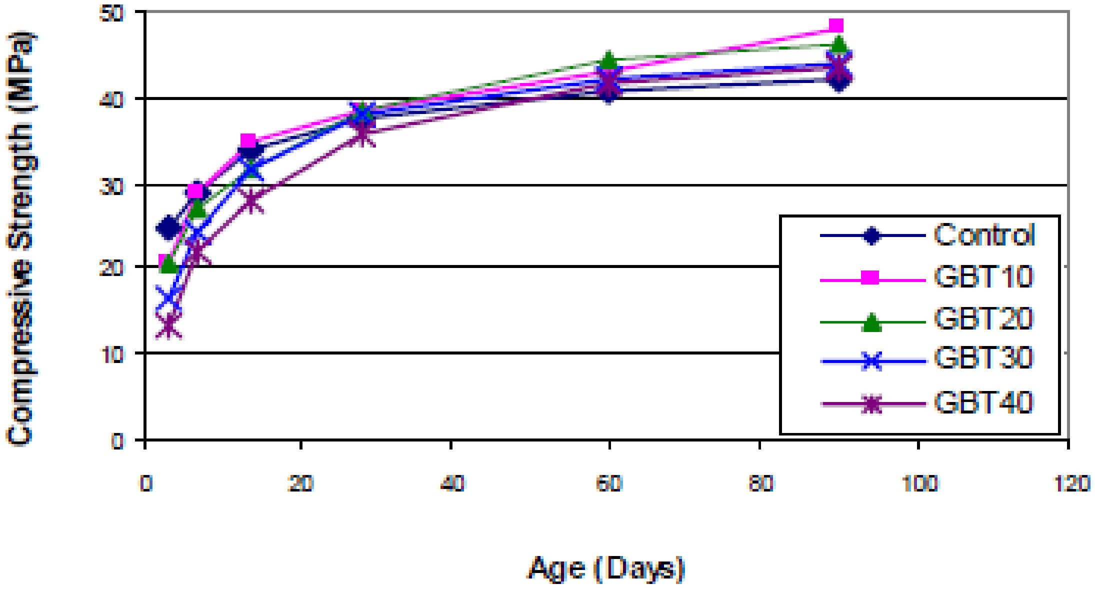

Fig. 2.7 Compressive strength of mortar for different percentage of bagasse ash (by mass replacement) [13]

Another research [2] conducted indicated that addition of sugarcane bagasse ash retarded the setting time of the mortar. But this retardation, according to the research, was negligible and was within limits specified in ASTM C 150-03 [2]. The suggested reasons were the adsorption of water at the surface of the ash, the development of film of silica gel around the cement grains, and a mutual coagulation of components with the paste. The strength activity index of the blended mortars was higher than the minimum 75% which is required by ASTM C 618-03.

This same research [2] finds that the filler effect was predominant only up to 15% ash substitution. At the 91 days the 10% and 15% replacement showed a compressive strength of 104% and 102% respectively, while at 20% and 25% replacement 92% and 84% of the control mortar.

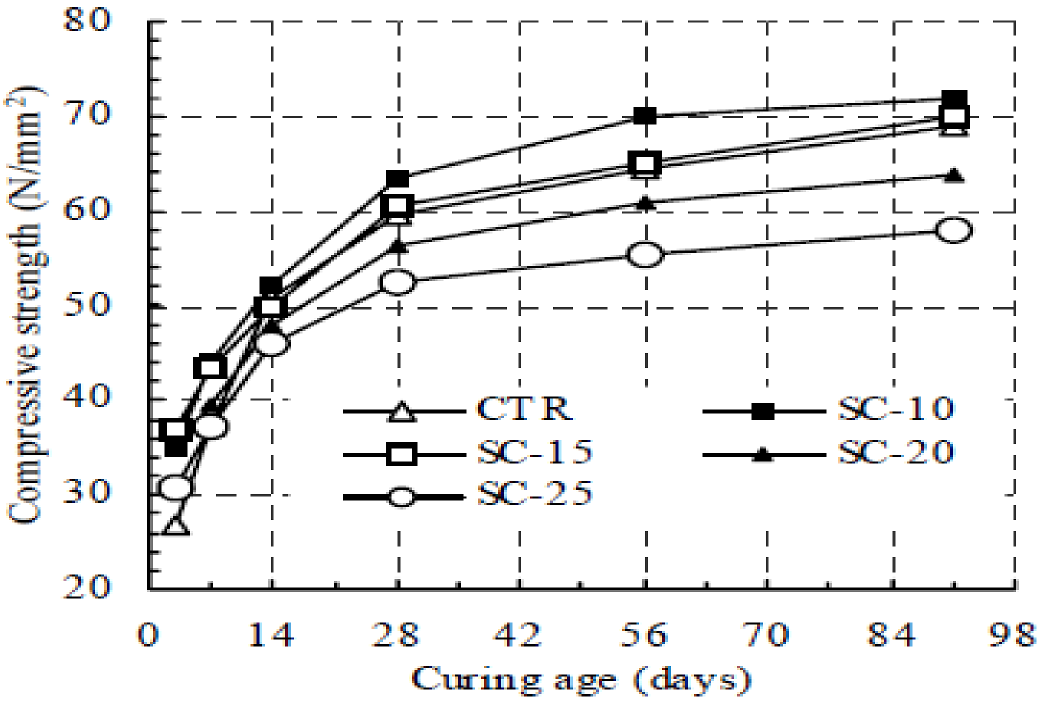

Fig. 2.8 Compressive strength of blended mortar in comparison with the control mortar (by mass replacement) [2]

From the above research outputs we can see that sugarcane bagasse ash 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 mortar or the concrete.

2.5.3 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 [15], 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 [15].

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 [15].

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 [15]. In detail, Finchaa found in the western part of the country planned to increases its production to 270,000 tons; Wonji and Shoa found 100 km east of Addis Ababa plans to increase their production to 350,000 tons; Methara Sugar Factory found 250 kms east of Addis Ababa, is also expected to increase its annual production to 190,000 tons according to the sugar development Study paper. 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.

As can be seen from the above discussion the sugar production in the country is being boosted at a high rate, even planning to hold 2.5 percent of the world sugar market in the coming five years according to the strategic plan. Boosting sugar production will also result in high amount of bagasse and bagasse ash. Table 2.5 below summarizes the expected future sugar production of the country and the respective bagasse ash potential.

Table 2.5 Estimated bagasse ash potential of Ethiopia

Factory	Expected future Production of sugar(tons/year)	Estimated Bagasse (tons/year)	Estimated Bagasse Ash (tons/year)
Wonji/ Shoa	350,000	1,050,000	84000
Metahara	190,000	570,000	45600
Finchaa	270,000	810,000	64800
Tendaho	600,000	1,800,000	144000
New 8	2,500,000	7,500,000	600000
Total	**3,910,000**	**11,730,000**	**938,400**

The above estimation is based on the targeted annual future sugar production in the country. Sugarcane consists of about 30% bagasse whereas sugar recovered is about 10% of the sugarcane, the bagasse leaves about 8-10% (8% taken for the calculation) bagasse ash as waste [2, 3, 26, and 27]. As can be seen from Table 2.5 about 0.94 million tons of bagasse ash is going to be generated annually when the five-year strategic plan comes into reality. Currently with sugar production of about 300,000 tons annually, the bagasse ash potential is about 72,000 tons annually.

CHAPTER THREE

MATERIALS USED FOR THE RESEARCH

3.1 Introduction

In this chapter, the materials used for the research are described with respect to their source and relevant physical and chemical properties. All the laboratory investigations on the aggregates, fineness of cement and bagasse ash, pastes, mortars and concretes are carried out in Addis Ababa University, Civil Engineering Department, material laboratory; whereas the chemical properties of the bagasse ash are conducted in Geological survey center of Ethiopia.

3.2 Bagasse ash

The bagasse ash used for this research was taken from Wonji Sugar factory which is located in Oromiya Regional State - North Eastern Ethiopia. The bagasse ash in this factory is collected at each 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 bagasse ash, 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^oC [2]. But it was suggested that at a temperature around 650^oC the crystallization of minerals occurs [2]. This reduces the pozzolanic activity of the bagasse ash.

For this research, fresh bagasse ash taken from the furnace was used. It was cooled in air by applying a small quantity of water, packed in sacks and transported to Addis Ababa.

Fig. 3.1 Bagasse ash after grinding

The ash is then taken to the Geological Survey center of Ethiopia for the complete silicate analysis and other related tests the result of which are given below in Table 3.3. The grinding of the ash was done in Addis Ababa University Geology laboratory using a small mill having a capacity of carrying about 100gm of bagasse ash at a time. By so doing the bagasse ash fineness was reduced to fineness similar to that of Portland cement. The grain size distribution is as shown is the Table 3.1 below:

Table 3.1 Grain size distribution for bagasse ash and OPC cement

Sieve size	Percentage passing (Bagasse ash)	Percentage passing (Cement)
150µm	100	100
125µm	98.98	100
75µm	89.8	93
63µm	84.7	81
32µm	37.76	32

The graph for the particle size distribution of the Bagasse ash and cement is as shown in Figure 3.2 below:

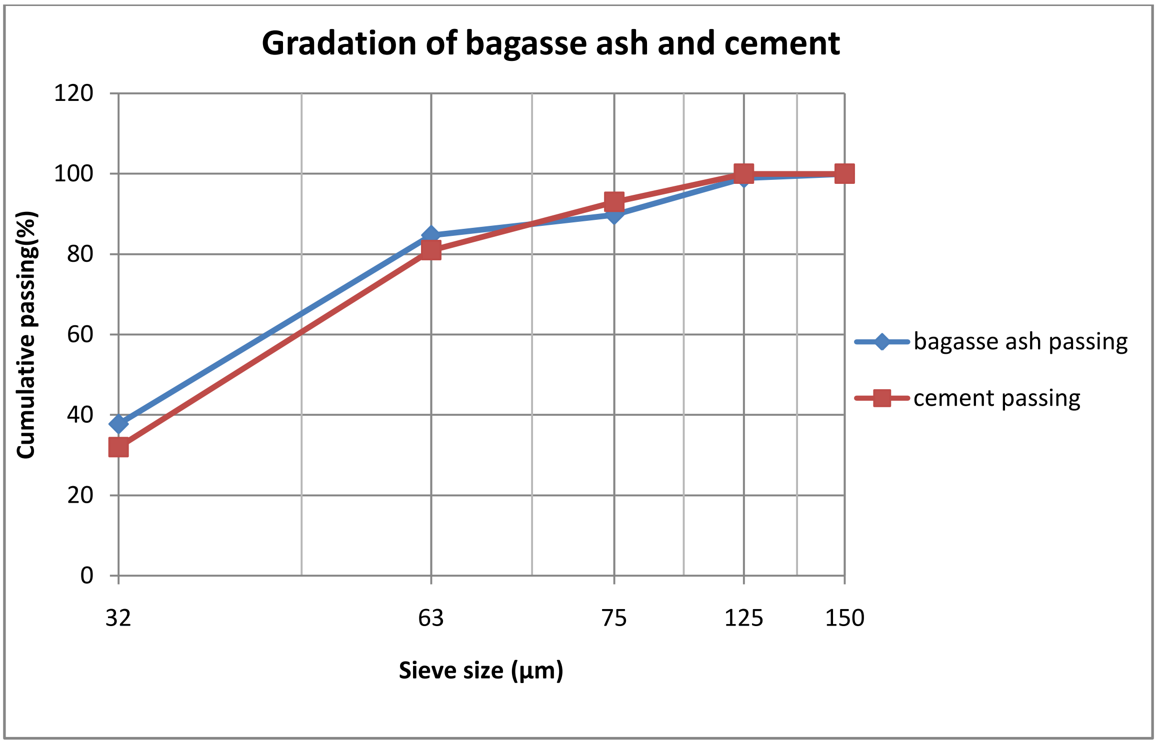

Fig. 3.2 Gradation of bagasse ash and cement

Table 3.2 Physical properties of cement and bagasse ash

Material	Density in g/cm^3	Blain air in cm^2/gm	Average size (μm)
OPC	3.15	2910	43.4
BA	2.16	4716	40.1

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.

3.3 Cement

Messebo cements are available at markets. The cements of this factory were purchased from the shops available in Addis Ababa.

This cement complies with the requirements of Ethiopian Standards, ES C.D5 201 and ES C.D5 202 [16]. The chemical and physical property of the cement is as shown in Table 3.3 [16]. In addition to Messebo OPC, Messebo PPC cement is sued for the mortar work.

Table 3.3 Chemical composition of cement and bagasse ash

Chemical Composition (%)	Messebo OPC Cement[16]	Bagasse Ash [Appendix H]
SiO_2	20.50	65.58
Al_2O_3	4.75	5.87
Fe_2O_3	3.70	4.32
CaO	63.94	1.78
MgO	1.31	1.23
Na_2O	-	1.02
K_2O	-	6.41
MnO	-	0.05
TiO_2	-	0.25
P_2O_5	-	1.35
H_2O	-	0.20
SO_3	2.41	0.18
LOI	-	10.48
Cl	-	< 0.1
$SiO_2+ Al_2O_3+ Fe_2O_3$	-	75.77

3.4 Aggregates

The relevant tests were made to identify the properties of the aggregates which are used for this research. After that, corrective measures were taken in advance before proceeding to the mix proportioning, like blending the aggregates in order to meet the grading requirement, washing the aggregates in order to meet the standard for the silt content. In general, aggregates should be hard and strong, free of undesirable impurities, and chemically stable. Soft, porous rock can limit strength and wear resistance; it may also break down during mixing and adversely affect workability by increasing the amount of fines. Aggregates should also be free from impurities: silt, clay, dirt or organic matter.

3.4.1 Properties of fine aggregate

The fine aggregate used in the concrete productions is natural sand. In order to investigate its properties for the required application different tests were carried out which include: sieve analysis and fineness modules, specific gravity and absorption capacity, moisture content, silt content and unit weight.

3.4.1.1 Silt content

The material in fine aggregates which is finer than 75μm is generally regarded as silt. This silt in the sand for the concrete has a severe effect on the quality of the concrete. It mainly affects the workability of the concrete, and also results in the reduction of strength.

From the silt content test performed on the sand, it was found that the original silt content was 13%. The Ethiopian standard restricts the silt content to a maximum of 6%. If it exceeds this maximum value the standard recommends washing or rejecting the sand. Therefore the sand was washed and its final silt content becomes 5.26%.

3.4.1.2 Sieve Analysis and fineness modules

This is a procedure for the determination of the particle size distribution of the aggregate. It is also used to determine the fineness modulus, an index to the fineness, coarseness and uniformity of aggregates. These properties of the aggregate greatly affect the property of the concrete.

The original sand sample was too coarse to meet the grading requirement and therefore it was blended with finer sand in a proportion of 70%: 30%. The grading requirement for fine aggregate according to ES C.D3.201 [17] and the grain size distribution of the fine aggregate (both the original and blended) is as shown in Table 3.4 and Figure 3.3.

Table 3.4 Sieve analysis results and standard for fine aggregate

Sieve size	Percentage passing (ES C.D3.201)	Percentage passing (Original sand)	Percentage passing (Blended sand)
9.50mm	100	100	100
4.75mm	95-100	99.9	100
2.36mm	80-100	85.1	88.7
1.18mm	50-85	53.8	64.8
600μm	25-60	22.6	41.2
300μm	10-30	5.2	19.6
150μm	2-10	0.4	2.1

The graph for the sieve analysis of the sand and the standard (ES C.D3.201) is as follows;

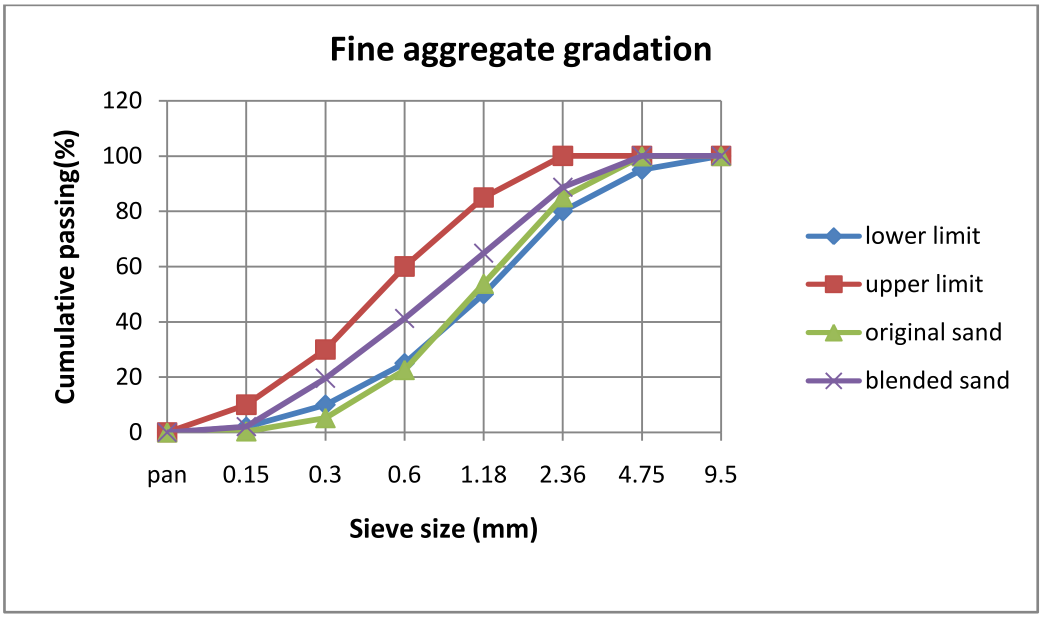

Fig. 3.3 Graph for gradation of fine aggregate

$$\text{Fineness Modules} = \frac{\sum \text{cumulative coarser (\%)}}{100} = \frac{283.6}{100} = 2.84$$

3.4.1.3 Specific gravity and absorption capacity

Specific gravity is an expression of the density of an aggregate. It is the ratio between the weight of the substance and that of the same volume of water. Aggregates contain pores in their structure, therefore the specific gravity depends on whether the pores are included in the measurement or not. Apparent specific gravity of an aggregate refers to the solid materials excluding the pores and bulk specific gravity refers to total volume i.e. including pores of the aggregate.

The following results are found for the fine aggregate:

Bulk specific gravity = 2.31
Bulk specific gravity (SSD basis) = 2.41
Apparent specific gravity = 2.58
Absorption capacity = 4.49%

3.4.1.4 Moisture content

The water to cement ratio of a concrete affects the strength and the workability of the concrete. The increase of the water to cement ratio results in a decrease of the strength of the concrete and an increase of workability. The aggregates in concrete are assumed to be inert materials. But most of the aggregates don't meet this assumption by either absorbing water (dry aggregates) or by releasing it (wet aggregates) to the mix. As a result of this property of aggregates the design water to cement ratio of the mix changes. Therefore it is important to determine both the absorption capacity and the moisture content of the aggregate.

The moisture content of fine aggregates was determined by oven drying a sample of fine aggregate (500gm) in an oven at a temperature of 110 ^{0}c for 24 hrs and dividing the weight difference by the oven dry weight. The moisture content found was 3.41 %.

3.4.1.5 Unit weight

Unit weight can be defined as the weight of a given volume of graded aggregate. It is thus a density measurement and is also known as bulk density. But this alternative term is similar to bulk specific gravity, which is quite a different quantity, and perhaps is not a good choice.

The unit weight effectively measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate particles and the voids between them. The unit weight is simply measured by filling a container of known volume and weighing it. Clearly, however, the degree of compaction will change the amount of void space, and hence the value of the unit weight. Since the weight of the aggregate is dependent on the moisture content of the aggregate, constant moisture content is required. Oven dried aggregate sample is used in this test [17]. The unit weight of the fine aggregate sample used was found to be 1.47 g/cm^{3}. The above test results are summarized in Table 3.5 below:

Table 3.5 Summary of test results for fine aggregate

No	Test Description		Test Result
1	Silt Content		5.26%
2	Moisture Content		3.41%
3	Unit wt.		1.47g/cm^{3}
4	Absorption Cap.		4.49%
5	Specific gravity	Bulk	2.31
		Bulk(SSD)	2.41
		Apparent	2.58
6	Fineness Modulus		2.84

3.4.2 Properties of the coarse aggregate

The coarse aggregates used for this research were crushed rock. Because the aggregates have been stored in the laboratory for a while, visual examination reveals that there is a dust film on their surface and therefore, the aggregates were washed thoroughly and dried in open air outside the laboratory. A maximum aggregate size of 19 mm was used in all the concrete work. After washing and drying, the coarse aggregates were sieved and stored. This has minimized segregation and thus variation in gradation from mix to mix.

In a similar manner like the fine aggregate, laboratory tests were carried out to identify the physical properties of the coarse aggregate and the results are shown in Table 3.6 below. Table 3.7 shows the sieve analysis test results.

Table 3.6 Summary of test results for coarse aggregate

No.	Test description		Test result
1	Maximum size		19mm
2	Moisture content		1.78%
3	Unit wt.		1.54g/cm^3
4	Absorption capacity		2.06%
5	Specific gravity	Bulk	2.63
		Bulk(SSD)	2.69
		Apparent	2.78

Table 3.7 Sieve analysis for coarse aggregate

Sieve size (mm)	Percent passing (ES C. D3. 201)	Percent passing (aggregate used)
37.5	100	100
19	95-100	98.84
12.5	-	46.44
9.5	25-55	25.6
4.75mm	0-10	0.16

The graph for the sieve analysis of the coarse aggregate and the standard (ES C.D3.201) is as shown in Figure 3.4;

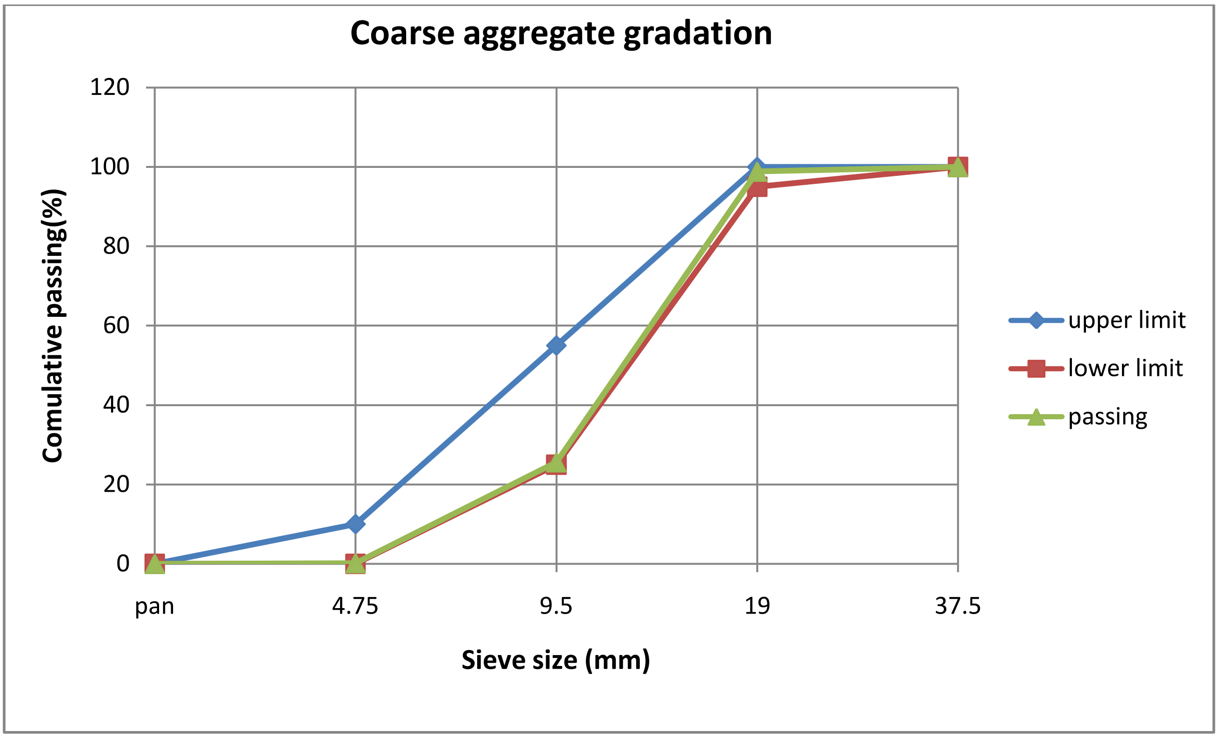

Fig. 3.4 Graph for gradation of coarse aggregate

3.5 Water

In this research, tap water supplied by Addis Ababa Water and Sewerage Authority found in the laboratory was used in all mixes.

CHAPTER FOUR

EXPERIMENTAL PROGRAM

4.1 Introduction

The main objective of the test program was to study the suitability of bagasse ash as a cement replacing material. These include studying properties of paste, mortar and concrete works by replacing part of the cement with bagasse ash in different percentages.

Three major tests were conducted in order to achieve these objectives. The first experiment was done on blended powders and pastes in which part of the cement was replaced by bagasse ash in order to determine the fineness of the blended powder, the water requirement or normal consistency and setting time of the blended paste. The second and third experiments were made on mortar and concrete in which part of the cement was replaced by bagasse ash. These tests were used to investigate the pozzolanic property of bagasse ash, its effect on the performance of the mortar and concrete such as workability, strength and permeability.

4.2 Experiment I

This experiment consists of determining the fineness of blended powders and the normal consistency and setting time of the blended pastes.

4.2.1 Fineness test

The fineness of the bagasse ash, the cement and the blended powders at different percentage were determined by the blain air permeability method. The different mixes are as shown in Table 4.1. The blain air method of determining the specific surface area is based on the relationship between the surface area of the particles in a porous bed and the rate of fluid flow through the bed. The replacements were from 5% to 30% with 5% increment.

Table 4.1 Proportion of blending of bagasse ash and cement

S. No	Code	Proportion by volume	
		Cement (%)	Bagasse* (%)
1	BAP 0	100	0
2	BAP 5	95	5
3	BAP 10	90	10
4	BAP 15	85	15
5	BAP 20	80	20
6	BAP 25	75	25
7	BAP 30	70	30

Where:

- BAP 0 indicate control Messebo OPC with 0% replacement
- BAP 5-blended powder with 95% OPC and 5% BA by volume
- BAP 10-blended powder with 90% OPC and 10% BA by volume
- BAP 15-blended powder with 85% OPC and 15% BA by volume
- BAP 20-blended powder with 80% OPC and 20% BA by volume
- BAP 25-blended powder with 75% OPC and 25% BA by volume
- BAP 30-blended powder with 70% OPC and 30% BA by volume

N.B- In all the blended mixes in this research by weight measurements were taken. However, the ratio of replacement is not 1:1 rather 1:0.69, i.e. 1kg of cement is replaced by 0.69kg of bagasse since the replacement is by volume to account for the lower density of bagasse ash (2.16g/cm^3) and to keep the paste volume constant.

4.2.2 Normal consistency test

ASTM C 595 recommends the normal consistency test of blended cements to be measured by the ASTM C 187 method, which is the method for that of hydraulic cement. Therefore, the normal consistency was measured by a vicat apparatus. This measure the resistance of the paste to the penetration of a plunger or needle of 300gm released at the surface of the paste. The procedure used for this test is as described in ASTM C 187.

Different pastes both control i.e. without bagasse ash and blended were prepared by replacing part of the Portland cement with bagasse ash. The water content was varied for each of the pastes produced until a normal consistent paste is obtained.

4.2.3 Setting time test

ASTM C 595 recommends the use of ASTM C 191 method of measuring setting time, which is used for that of hydraulic cements. The initial setting time of the paste was determined by the duration of 25mm 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.

4.3 Experiment II

This experimental program consists of preparing different mortar mixes with different percentage of bagasse ash replacing the cement. Two types of cements were used for this experiment; ordinary Portland cement and Portland pozzolana cement. In addition to cement, sand and water, $Ca(OH)_2$ powder was also used to test the activation of the bagasse ash.

4.3.1 Mix proportion of OPC-BA blended mortars

Mix proportions used in the preparation of OPC-BA mortar specimens were as shown in the Table 4.2 below. For each substitution ratio, 3 sets (3 x 3 = 9) of mortar specimens were prepared for destructive test (compressive strength) conducted at the age of 3, 7 and 28 days.

Table 4.2 OPC-BA blended mortar

Mix code	Cement type	Cement (gm)	Bagasse ash(gm)	W/B	Water (gm)	Sand (gm)
BAM 0	OPC	1000	0	0.450	450	1500
BAM 5	OPC	950	34.5	0.457	450	1500
BAM 10	OPC	900	68.5	0.465	450	1500
BAM 15	OPC	850	103.0	0.472	450	1500
BAM 20	OPC	800	137.0	0.480	450	1500
BAM 25	OPC	750	171.5	0.488	450	1500
BAM 30	OPC	700	206.0	0.497	450	1500

Where:

- BAM 0 is OPC-BA control mortar mix with 100% OPC
- BAM 5 is OPC-BA mortar mix with 95% OPC and 5% BA by volume
- BAM 10 is OPC-BA mortar mix with 90% OPC and 10% BA by volume
- BAM 15 is OPC-BA mortar mix with 85% OPC and 15% BA by volume
- BAM 20 is OPC-BA mortar mix with 80% OPC and 20% BA by volume
- BAM 25 is OPC-BA mortar mix with 75% OPC and 25% BA by volume
- BAM 30 is OPC-BA mortar mix with 70% OPC and 30% BA by volume

4.3.2 Mix proportion of PPC-BA blended mortars

Mix proportions used in the preparation of PPC-BA mortar specimens were as shown in the Table 4.3 below. For each substitution ratio, 3 sets (3 x 3 = 9) of mortar specimens were prepared for destructive test (compressive strength) conducted at the age of 3, 7 and 28 days.

Table 4.3 PPC-BA blended mortar

Mix code	Cement type	Cement (gm)	Bagasse ash(gm)	W/B	Water (gm)	Sand (gm)
BAMP 0	PPC	1000	0	0.450	450	1500
BAMP 5	PPC	950	39.0	0.455	450	1500
BAMP 10	PPC	900	78.5	0.460	450	1500
BAMP 15	PPC	850	118.0	0.465	450	1500
BAMP 20	PPC	800	157.0	0.470	450	1500
BAMP 25	PPC	750	196.5	0.475	450	1500
BAMP 30	PPC	700	236.0	0.481	450	1500

Where:

- BAMP 0 is PPC-BA control mortar with 100% PPC
- BAMP 5 is PPC-BA mortar mix with 95% PPC and 5% BA by volume
- BAMP 10 is PPC-BA mortar mix with 90% PPC and 10% BA by volume
- BAMP 15 is PPC-BA mortar mix with 85% PPC and 15% BA by volume
- BAMP 20 is PPC-BA mortar mix with 80% PPC and 20% BA by volume
- BAMP 25 is PPC-BA mortar mix with 75% PPC and 25% BA by volume
- BAMP 30 is PPC-BA mortar mix with 70% PPC and 30% BA by volume

4.3.3 Mix proportion of OPC-BA-$Ca(OH)_2$ blended mortars

In order to investigate whether bagasse ash can be activated by the addition of $Ca(OH)_2$ or not, the bagasse ash blended mortar were prepared by mixing OPC, bagasse ash and $Ca(OH)_2$. The specimens prepared were; a control mortar cube with no cement replacement, a mortar with 15% cement replacement by bagasse ash, a mortar with 15% replacement of the cement by bagasse ash and 3% and 6% replacement of the replacing bagasse ash by $Ca(OH)_2$ for 7 and 28 days test.

Table 4.4 OPC-BA-$Ca(OH)_2$ blended mortar

Mix code	Cement type	Cement (gm)	Bagasse ash(gm)	$Ca(OH)_2$ (gm)	W/B	Water (gm)	Sand (gm)
BAMA 0	OPC	700	0	0	0.450	315	1050
BAMA 15	OPC	595	72	0	0.472	315	1050
BAMA 15-3	OPC	595	69.8	2.2	0.474	315	1050
BAMA 15-6	OPC	595	67.7	4.3	0.475	315	1050

Where:

- BAMA 0 is control mortar mix with 100% OPC
- BAMA 15 is OPC-BA mortar mix with 85% OPC and 15% BA by volume
- BAMA 15-3 is OPC-BA mortar mix with 3% of the BA replaced by $Ca(OH)_2$.
- BAMA 15-6 is OPC-BA mortar mix with 6% of the BA replaced by $Ca(OH)_2$.

4.3.4 Preparation of mortar specimen and mixing procedure

Cement, bagasse ash and sand were weighted and dry mixed for about one minute. After the addition of water all of the materials were mixed for another two minutes. Immediately after wet mixing the flow table test was conducted [17]. The test specimens were then casted in a steel mold with 50mm x 50mm x 50mm cube in two layers and each layer were compacted. The specimens were then demolded in the next day i.e. after 24 hours and were placed in a curing pond prepared for the cubes until the test day.

4.4 Experiment III

This experimental program consists of preparing different concrete mixes with different percentage of bagasse ash in order to study the performance of the concrete such as its workability, compressive and flexural strength and durability aspects by using water permeability test.

4.4.1 Mix design and trial mix preparation

Mix design is the process of determining the required and specified characteristics of a concrete mixture. The required or specified concrete characteristics can be fresh concrete properties, mechanical properties of the hardened concrete such as strength and durability requirements and the inclusion or exclusion of specific ingredients [18]. Mix proportioning on the other hand is the process of determining the quantities of concrete ingredients using local materials to achieve the specified characteristics of the concrete. According to Steven H. [18], a properly proportioned concrete mix should posses the following qualities:

- Acceptable workability of the freshly mixed concrete
- Durability, strength, and uniform appearance of the hardened concrete
- Economy

Therefore the key for producing a strong, durable and economical concrete rests on the careful proportioning and mixing of the ingredients.

DOE method of mix design was used in designing the mixes. The trial mix was prepared for characteristics strength of 35MPa with water to cement ratio of 0.54 and a cement content of 350kg/m^3. The trial mix resulted in a slump of 24mm and a seven day compressive strength of 25.10MPa. The slump of the concrete was below the targeted slump which is 30-60mm. The seven day compressive strength was used to extrapolate the 28 days compressive strength. Sidney Mindess et al suggested that the ratio of the 28 days strength to the 7 days strength lies between 1.3 and 1.7 but is usually less than 1.5 and it depends on the cement type and curing temperature [7]. Taking 1.5 as the extrapolation factor, the 28 days compressive strength will be around 37.65MPa which is slightly higher than the targeted value.

For the purpose of preparing a final mix the water to cement ratio of the mix was increased to 0.55 from 0.54 by keeping the cement content constant i.e. water increased from 189kg/m^3 to 192.5kg/m^3, in order to adjust the slump. Sidney Mindess et al suggested that an increase or decrease of the water content by 6kg/m^3 will increase or decrease the slump by approximately 25mm.

The final mix proportions for 1m^3 of the different control and OPC-BA concretes are as shown in Table 4.5.

Table 4.5 Mix proportion for the concrete work

Mix code	Cement type	Cement quantity (kg/m^3)	Bagasse ash (kg/m^3)	W/B	Water (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	FA (%)	CA (%)
BA 0	Messebo OPC	350	0	0.55	192.5	650	1205	35	65
BA 5	Messebo OPC	332.5	12	0.56	192.5	650	1205	35	65
BA 15	Messebo OPC	297.5	36	0.58	192.5	650	1205	35	65
BA 25	Messebo OPC	262.5	60	0.60	192.5	650	1205	35	65

Where:

- BA 0 is a concrete mix with 0% Bagasse ash
- BA 5 is a concrete mix with 95% OPC and 5% BA by volume
- BA 15 is a concrete mix with 85% OPC and 15% BA by volume
- BA 25 is a concrete mix with 75% OPC and 25% BA by volume

4.4.2 Preparation of concrete specimens and mixing procedure

Weight measurement was used for the preparation of the constituent. After determining the relative amount of materials to be used for the specimens, the aggregates, the cements and bagasse ash were mixed dry for one minute. After the addition of water, all the materials were mixed for another two minutes. Immediately after mixing the concrete, the workability is measured by using a slump cone. The specimens were then placed 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 vibrated 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. After 24 hours the specimens were demolded from the mold and were cured in a curing pond for 14 days and left the remaining days at room temperature of the laboratory.

CHAPTER FIVE

TEST RESULTS AND DISCUSSION

5.1 Introduction

In this section discussion and analysis of laboratory test results of bagasse ash for its suitability as cement replacing material are presented and analyzed. The different properties of the bagasse ash investigated are:

- the fineness in terms of specific surface area for different replacement of cement with bagasse ash,
- the consistency and setting time of the blended pastes at different replacement contents,
- strength of mortars containing bagasse ash which replaced ordinary Portland cement and Portland pozzolana cement,
- the workability, strength (both compressive and flexural) and permeability of concrete containing bagasse ash at different replacements

5.2 Test results and discussions on Experiment I

In this part the test results on the different properties of bagasse ash and the blended pastes are discussed and analyzed.

5.2.1 Physical and Chemical properties of Bagasse Ash

As shown in Table 3.2, BA has low density (2.16g/cm^3) and higher surface area (Blaine surface area, 4716cm^2/g) as compared to OPC. Particle size analysis of ash samples indicated that average size of the ash particles was 40.1µm and 90% of the particles were of size less than 76.1µm, where as cement have an average fineness of 43.4 µm which is greater than the ash and 90% of the particles were less than 72 µm which is less than the ash. This shows that the bagasse ash is coarser than the cement for higher sieve sizes and the opposite for lower sieve sizes. This is also shown in the grain size distribution of the bagasse and the cement in Figure 3.2. This figure shows that the bagasse is finer than the cement for sieve size less than 69.4 µm (where the two graphs meet) and the cement is finer for sieve sizes greater than this size, showing that the bagasse contains some particle coarser than cement but on average it is finer than cement.

As presented in the material properties section the fineness of bagasse ash by blain air permeability method was found to be 4716 cm^2/g, which is greater than cement which was measured to have a surface area of 2910 cm^2/g. The fineness by the blain air permeability method for the different blended powders was also measured and is presented in Table 5.1 below:

Table 5.1 Fineness of bagasse ash and blended powders

S. No	Code	Blain air (cm^2/g)
1	BAP 0	2910
2	BAP 5	2929
3	BAP 10	2948
4	BAP 15	3085
5	BAP 20	3214
6	BAP 25	3359
7	BAP 30	3497
8	Bagasse ash	4716

From the results it can be seen that the blain air of the bagasse ash is higher than that of cement, and all the blended powders show a higher fineness than cement which is due to the lower density of the bagasse ash. Ajay Goyal et al [2] has reported that large surface area favors the pozzolanic reactivity of amorphous silica and other minerals.

The combined chemical composition; $SiO_2 + Al_2O_3 + Fe_2O_3 = 75.77 > 70\%$ 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. The loss on ignition (LOI) value for the bagasse ash was found to be 10.48% which was slightly higher than that specified by the same standard (10%). Moreover the bagasse ash was found to have high alkali content like K_2O (6.41%) implying high potential for alkali-silica reaction when used in concrete with silica reach aggregates.

5.2.2 Consistency of blended pastes

Normal consistency of pastes containing bagasse ashes are shown in Table 5.2. The control paste or the paste without bagasse ash had normal consistency of 32.5%. All of the pastes containing bagasse ash showed normal consistency equal and higher than the control paste. Up to 10% replacement the normal consistency was constant, at 15% replacement the normal consistency had shown a slight increment to 33%, and it increases continuously to 34.8% at 30% replacement.

Table 5.2 Normal consistency of blended pastes containing bagasse ash

S. No	Code	Consistency (%) (ASTM C 187)
1	BAP 0	32.5
2	BAP 5	32.5
3	BAP 10	32.5
4	BAP 15	33.0
5	BAP 20	33.5
6	BAP 25	34.0
7	BAP 30	34.8

This finding on the consistency of the blended pastes conformed to previous researches [2, 13]. The increment on water requirement is probably due to the higher fineness of bagasse ash (4716 cm^2/g) and its porosity as compared to cement.

The usual range of water to cement ratio for normal consistency is between 26% and 33% [17]. The pastes with replacement up to 15% showed a consistency with in this range, however, after 15% replacement the results showed slightly higher values.

5.2.3 Setting time of blended pastes

The Ethiopian standard limits the initial setting time of cement not to be less than 45 minutes and the final setting time not to exceed 10hrs. The results for the setting time in Table 5.3 indicated that addition of bagasse ash retarded the setting; however this retardation was within limits as specified by the Ethiopian standard. As the bagasse ash content increases the setting time has also showed a trend of increment, even though there are some exceptions.

Other researchers had also conformed to the increase in setting time of OPC-BA blended pastes. According to Ajay Goyal the probable reason for the increase in setting time could be the adsorption of water on the bagasse ash surface [2]. The higher the proportion of the bagasse ash, the higher was the adsorption of water increasing the normal consistency which in turn retarded the setting time. Ajay Goyal also suggested that the reduction in the amount of calcium hydroxide and also the development of films of silica gel around cement grains may have caused the retardation of setting time.

Table 5.3 Setting time of pastes containing bagasse ash

S. No	Code	Initial setting time (minutes)	Final setting time (minutes)
1	BAP 0	176	280
2	BAP 5	195	316
3	BAP 10	203	324
4	BAP 15	200	327
5	BAP 20	205	325
6	BAP 25	216	327
7	BAP 30	232	333

5.3 Test results and discussion on Experiment II

In this part different test results on the blended mortars are presented and analyzed. These includes workability of the OPC-BA blended mortar which is assessed by the flow table values, the compressive strength of the OPC-BA blended mortars and PPC-BA blended mortars and finally the compressive strength of OPC-BA-$Ca(OH)_2$ blended mortars.

5.3.1 Workability of mortar

The workability of the mortar is analyzed by the flow table test just before casting the mortar in to the mold. Table 5.4 below gives these workability values for the control and blended mortars.

Table 5.4 Flow table values of OPC-BA blended mortar

S. No	Mix Code	Flow (mm)
1	BAM 0	147
2	BAM 5	146
3	BAM 10	146
4	BAM 15	143
5	BAM 20	144
6	BAM 25	143
7	BAM 30	142

As can be seen from Table 5.4 the flow value shows a slight reduction as the bagasse ash content increases. This can be attributed to the higher specific surface area of BA that required more water to wet the surface as compared to the OPC in the control specimen.

5.3.2 Compressive strength of OPC-BA and PPC-BA mortars

The compressive strength of mortar for both Messebo OPC and Messebo PPC were tested and analyzed. The detailed results of the laboratory tests are given in the appendix. The average results for both OPC-BA and PPC-BA mortars are as shown in Table 5.5 and Table 5.6 respectively:

Table 5.5 Compressive strength of OPC-BA mortar

S. No	Mix Code	Average compressive strength					
		3 days		7 days		28 days	
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)
1	BAM 0	54.6	21.85	89.6	35.85	134.6	53.86
2	BAM 5	57.6	23.05	93.4	37.36	140.1	56.01
3	BAM 10	55.9	22.35	90.6	36.24	138.5	55.42
4	BAM 15	47.5	18.98	82.7	33.09	134.1	53.64
5	BAM 20	45.0	18.00	77.5	31.01	126.7	50.68
6	BAM 25	43.8	17.53	71.6	28.64	114.8	45.95
7	BAM 30	42.7	17.09	68.9	27.57	109.3	43.74

Table 5.6 Compressive strength of PPC-BA mortar

S. No	Mix Code	Average compressive strength					
		3 days		7 days		28 days	
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)
1	BAMP 0	31.8	12.74	57.3	22.90	109.3	43.71
2	BAMP 5	30.3	12.11	53.5	21.39	94.1	37.62
3	BAMP 10	28.8	11.53	51.6	20.66	93.3	37.33
4	BAMP 15	27.5	11.01	50.0	19.99	91.0	36.41
5	BAMP 20	26.3	10.54	43.7	17.50	88.2	35.27
6	BAMP 25	23.1	9.25	40.5	16.21	79.8	31.91
7	BAMP 30	22.4	8.96	37.5	14.98	69.8	27.93

There are different test methods which are used to study the secondary or pozzolanic hydration of blended pastes. X-ray Diffraction (XRD) Analysis, Thermal Analysis or Thermogravimetric analysis (TGA) and Scanning Electron Microscopy (SEM) are some of the analysis methods used to check the secondary reaction depending on different principles. Since none of these methods are available in the laboratory, other indirect tests are conducted as an indication for the existence of pozzolanic reaction in the bagasse ash blended pastes.

As shown in the tables above mortar specimens were prepared for both OPC and PPC blended with BA. This is done in order to investigate how the bagasse ash acts in the two cement types.

As shown in Table 5.5, the bagasse ash at 5% and 10 % replacement with OPC have shown a higher compressive strength value than the control throughout the tests period i.e. 3, 7 and 28 days. However, Table 5.6 shows that the mortar work with PPC didn’t show any improvement on the compressive strength at any replacement percentage. Rather the compressive strength of the mortar with bagasse ash and PPC had shown a reduction, which is also shown in Figure 5.2. A similar trend was found by undergraduate research on self-compacting concrete by using bagasse ash supervised by Dr. Esayas in Addis Ababa University [32].

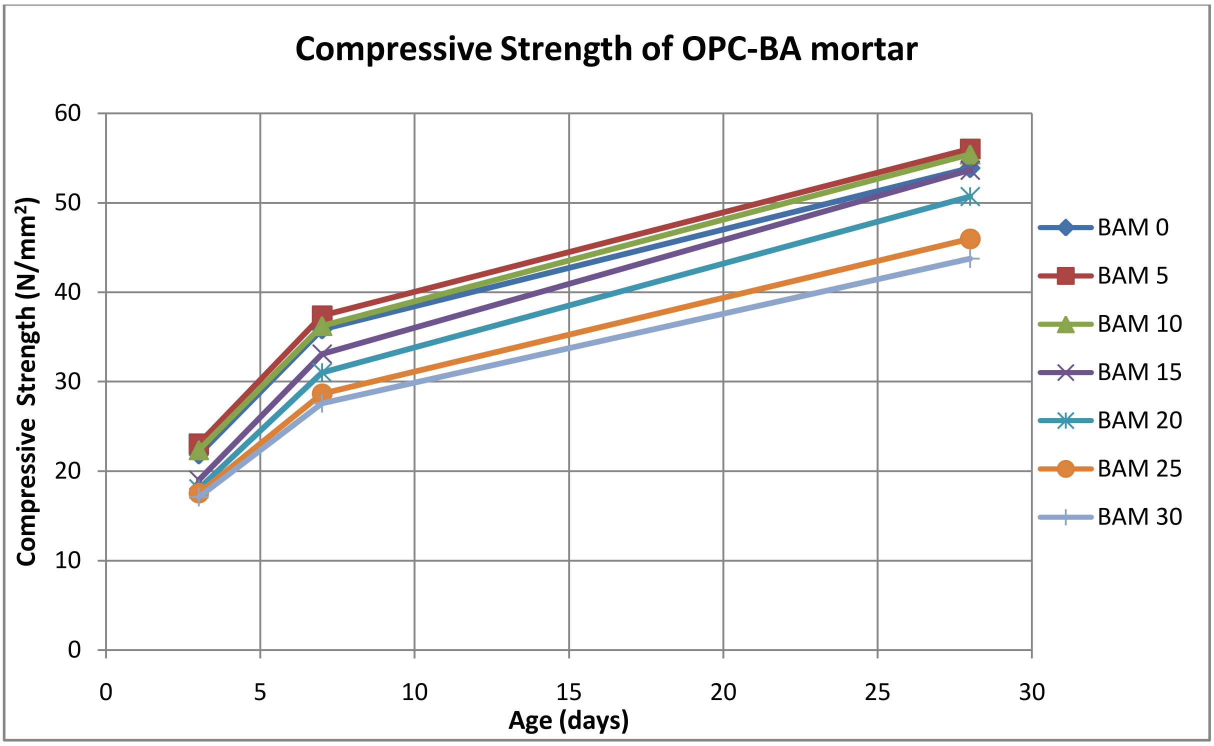

Fig.5.1 Compressive strength of OPC-BA mortar

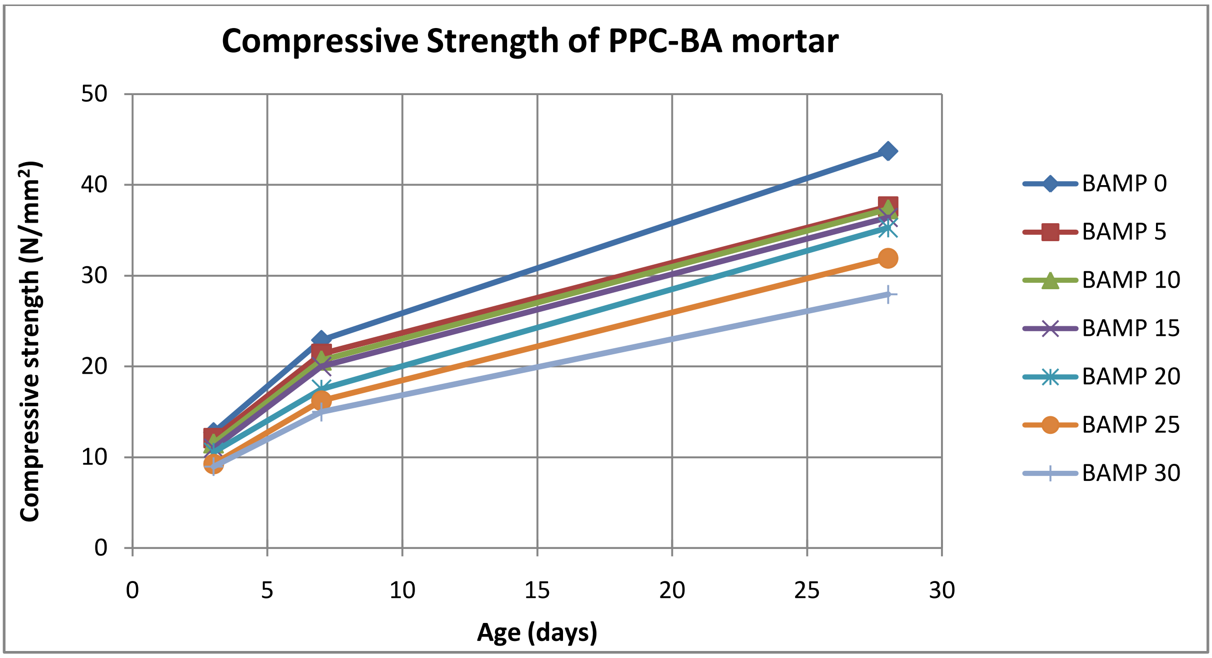

Fig. 5.2 Compressive strength of PPC-BA mortar

From Figures 5.1 and 5.2 and Tables 5.5 and 5.6 it is clear that the bagasse ash acts in different ways with OPC and PPC. It is known that PPC contains a higher amount of silica, i.e. it under goes a secondary chemical reaction by itself. The addition of bagasse ash (reach in silica) in this cement will not result in compressive strength improvement because there will be a high amount of unhydrated silica due to the competition for the $Ca(OH)_2$ released from the hydration of the cement particles. As a result of this, the compressive strength of the PPC-BA mortars has shown decrement.

OPC on the other hand contains a smaller amount of silica by itself. The addition of bagasse ash in this cement had resulted in a higher compressive strength for 5% and 10% replacement. This is probably due to the pozzolanic reaction between the bagasse ash and the $Ca(OH)_2$ from the cement hydration. Different researches also proved the existence of pozzolanic reaction using different advanced methods as stated before. According to Ajay Goyal et al., the intensity of $Ca(OH)_2$ in the 91days cured sample significantly reduced with corresponding increase in the intensity of C-S-H. This partly proved the existence of pozzolanic reaction in the blended paste.

As a measure of pozzolanic activity, strength activity index (AI) was calculated at 3, 7, and 28 days, as per ASTM C 618 definition. As shown in Table 5.7, Strength activity index for all OPC-BA blended mortars at 3, 7 and 28 days were higher than the minimum requirement of 75% specified in ASTM C 618.

Table 5.7 Strength activity index of OPC-BA mortar

Mix code	Age of specimen		
	3 days	7 days	28 days
BAM 0	100	100	100
BAM 5	105.5	104.2	104
BAM 10	102.3	101.1	102.9
BAM 15	86.9	92.3	99.6
BAM 20	82.4	86.5	94.1
BAM 25	80.2	79.9	85.3
BAM 30	78.2	76.9	81.2

Increasing the percentage replacement of cement by bagasse ash caused a decrease in the compressive strength, which conformed to another research [32]. For example, BAM 5, BAM 10, BAM 15, BAM 20, BAM 25 and BAM 30 mortars which contained bagasse ash at 5, 10, 15, 20, 25 and 30% had an activity index of 104, 102.9, 99.6, 94.1, 85.3 and 81.2% at 28 days, respectively. This is due to the high replacement of cement by bagasse ash, thus reducing cement content of the mixture which in turn causes a reduction in the hydration reaction.

The strength activity index had also shown a general pattern of increasing for most of the specimen with age. For example, BAM 15 had a strength activity index of 86.9, 92.3 and 99.6% at 3, 7 and 28 days respectively. The increase with age of the strength activity index can also partly show the pozzolanic nature of the bagasse ash i.e. since pozzolanic reactions are slower and dependant on the hydration of the cement. Other researches [13] also conformed to the increment of strength activity index as the age of the specimen increases. If the blended mortars in this research were tested at latter days (like 90 days) their strength activity index may show further improvement over the early day’s strength activity index.

The PPC-BA blended mortar on the other hand showed a different strength activity index pattern. This is shown below:

Table 5.8 Strength activity index of PPC-BA mortar

Mix code	Age of specimen		
	3 days	7 days	28 days
BAM 0	100	100	100
BAM 5	95.1	93.4	86.1
BAM 10	90.5	90.2	85.4
BAM 15	86.4	87.3	83.3
BAM 20	82.7	76.4	80.7
BAM 25	72.6	70.8	73.0
BAM 30	70.3	65.4	63.9

Increasing the replacement of bagasse ash resulted in a reduction of the strength activity index of the PPC-BA mortar as in the case of OPC-BA mortar, which conformed to another research [32]. However most of the PPC-BA blended mortar showed a decrease in strength activity index as the age of the specimen increased which is different from that of OPC-BA blended mortar. Moreover none of the PPC-BA mortars have shown improvement over the control mortar which is not the case for OPC-BA mortar.

5.3.3 Activation of OPC-BA mortar with $Ca(OH)_2$

The compressive strength of the activated bagasse ash are tested and analyzed. The detailed results of the laboratory tests are given in the appendix. The average results are as shown in Table 5.9.

Table 5.9 Compressive strength of activated OPC-BA mortar

S. No	Mix code	Average compressive strength			
		7 days		28 days	
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)
1	BAMA 0	85.7	34.30	131.4	52.57
2	BAMA 15	75.9	30.35	129.0	51.62
3	BAMA 15-3	77.5	30.99	129.4	51.78
4	BAMA 15-6	77.5	31.02	129.5	51.80

Figure 5.3 below shows the compressive strength results of all mortars at 7 and 28 days. At both i.e. 7 and 28 days, all the mortars containing bagasse ash had a lower strength than that of the control mortar. However, the mortars containing 3% and 6% $Ca(OH)_2$ have shown a slight strength improvement over the mortar containing 15% bagasse ash with no $Ca(OH)_2$. This strength difference between the OPC-BA mortar and OPC-BA-$Ca(OH)_2$ mortar was more visible at the early day of the mortar. The probable reason for this may be that the OPC-BA mortar without $Ca(OH)_2$ is much slower than all the other mortars because it have to wait the hydration reaction of the cement in order to have its pozzolanic reaction, where as the OPC-BA-$Ca(OH)_2$ mortar at 3% and 6% $Ca(OH)_2$ is more faster than the OPC-BA mortar because it contains some free $Ca(OH)_2$ which are available to react with the silica present in the bagasse ash. But at latter days both the OPC-BA mortar and OPC-BA-$Ca(OH)_2$ mortar had a more closer compressive strength value, which shows that as the hydration of OPC proceeds the bagasse ash in OPC-BA mortar have found free $Ca(OH)_2$ which is similar to the one present in OPC-BA-$Ca(OH)_2$ mortar.

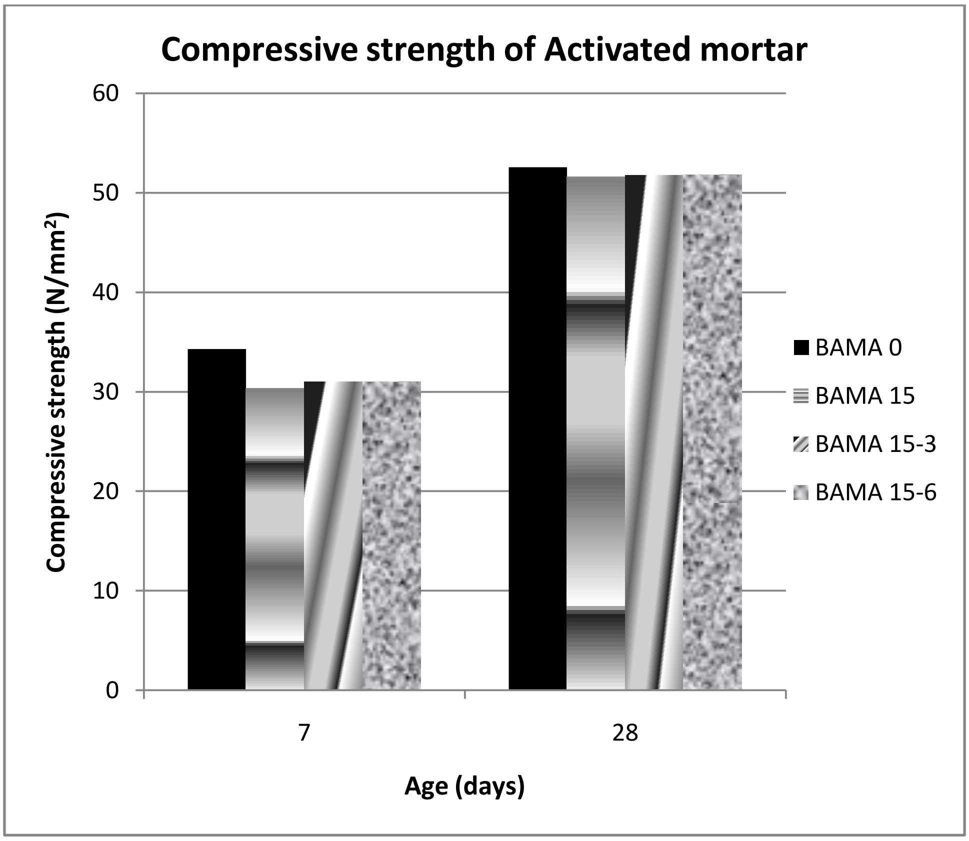

Fig. 5.3 Compressive strength of activated OPC-BA mortar

On the other hand the 6% replacement of bagasse ash with $Ca(OH)_2$ had resulted in a higher compressive strength than the 3% replacement. But this improvement over the 3%

replacement was very small and also the difference gets smaller as the age increases. This is shown in Table 5.10 below.

Table 5.10 Strength activity index for activated mortar

Mix code	Strength activity index	
	7 days	28 days
BAMA 0	100	100
BAMA 15	88.5	98.2
BAMA 15-3	90.35	98.50
BAMA 15-6	90.44	98.53

As can be calculated from Table 5.9, the OPC-BA-$Ca(OH)_2$ mortar at 3% replacement had shown a strength of 102.1% and 100.3% of that of BAMA 15 mortar at 7 and 28 days respectively. On the other hand, the mortar with 6% replacement of the bagasse ash with $Ca(OH)_2$ had shown a strength of 102.2% and 100.3% of that of the OPC-BA mortar at 7 and 28days respectively. This shows that, at the early ages there is about 2% increment of compressive strength by using $Ca(OH)_2$ as an activator. Though the increment is very small to be regarded as improvement, the overall behavior of the OPC-BA-$Ca(OH)_2$ mortars partly indicated the presence of pozzolanic reaction between the bagasse ash and the cement.

5.4 Test results and discussion on Experiment III

The different test results on both the fresh and hardened concrete are presented and analyzed in this part of the thesis.

5.4.1 Fresh concrete properties

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.

The trial mix for the control concrete gave a slump of 24mm, which is less than the targeted slump i.e. 30-60mm. In order to make the slump in the targeted range, the free water to cement ratio of the mix had been changed from 0.54 to 0.55. This adjustment had resulted in a slump of 35mm which is in the required range. Table 5.11 below gives the slump for all OPC-BA concrete mixes:

Table 5.11 Slump test results

S. No	Mix Code	Replaced OPC (%)	W/B	Observed Slump (mm)
1	BA 0	0	0.55	35
2	BA 5	5	0.56	35
3	BA 15	15	0.58	33
4	BA 25	25	0.60	32

As can be seen from Table 5.11 the slumps of the concrete containing bagasse ash have shown a slight reduction as the bagasse ash content increases. Table 5.2 (normal consistency table), shows that the normal consistency of the blended pastes increased with increase of the bagasse ash, this can also be an indication that in order to get a certain slump, OPC-BA blended concretes needs a higher water content than a concrete with no bagasse ash. The probable reason for this may be the higher specific surface area of the bagasse ash 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 bagasse ash content increases.

Fig. 5.4 Slump test of concrete

5.4.2 Hardened concrete properties

This part discusses the different properties of the hardened concrete which greatly affect the performance of concrete. In this research unit weight, compressive strength, flexural strength and water permeability of the concretes are tested and presented in the sections below.

5.4.2.1 Results and discussions on unit weight

The weights and the dimension of the concrete cubes for this research are measured just before testing them for the compressive strength. These tests were conducted at 7, 28 and 56 days. The results for the weight and dimension are given in the appendix. In this section the unit weights of the concrete are calculated by using the 28 days weight and dimension and the results are as shown in Table 5.12.

Table 5.12 Unit weights of control and blended concretes

S. No	Mix code	Replaced OPC (%)	Unit wt. (kg/m^3)	Reduction (%)
1	BA 0	0	2359	0.00
2	BA 5	5	2343	0.68
3	BA 15	15	2331	1.19
4	BA 25	25	2320	1.65

From the results, it was found out that a slight reduction of unit weight up to 1.65 % was observed when 25% of the cement was replaced by bagasse ash in sample BA 25. Whereas 0.68% and 1.19 % reductions were observed for 5 and 15 % bagasse ash replacement in sample BA 5 and BA 15 respectively.

The low density of the bagasse ash, 2.16g/cm^3, as compared to 3.15g/cm^3 for that of OPC resulted in a reduction of unit weights of the blended concretes. Figure 5.5 below also shows the reduction in unit weight as bagasse ash content increases.

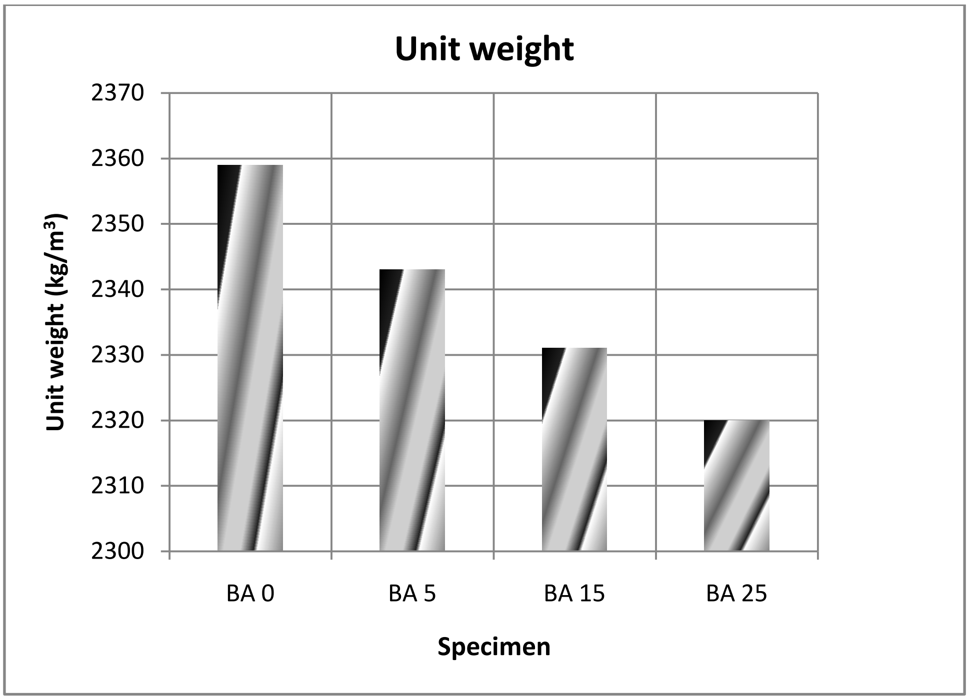

Fig.5.5 Graphical comparison of unit weight values

Even though it is small, the concretes with the bagasse ash have shown a reduction in unit weight. A low density concrete is beneficial in many ways over a high density concrete. Using a lighter concrete, reduces the size of structural members and also reduces the pressure on formworks.

5.4.2.2 Results and discussions on compressive and flexural 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. Figure 5.6 below shows a compressive strength test under progress.

Fig.5.6 Compressive strength of concrete being tested

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. Table 5.13 shows this compressive strength values:

Table 5.13 Average compressive strength values of concrete

S. No	Mix code	Average compressive strength					
		7 days		28 days		56 days	
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)
1	BA 0	551.9	24.53	960.1	42.67	1034.5	45.98
2	BA 5	580.0	25.78	1008.0	44.80	1101.9	48.97
3	BA 15	484.0	21.51	927.5	41.22	1006.6	44.74
4	BA 25	433.8	19.28	839.0	37.29	922.7	41.01

As can be seen from Table 5.13, the compressive strength of the concrete with 5% bagasse ash has shown improvement over the control concrete by about 5% at 28 days. On the other hand BA 15 and BA 25 i.e. concretes with 15% and 25% bagasse ash, had shown a strength reduction by about 3.4% and 12.6% at 28 days. This shows that the compressive strength of the OPC-BA blended concrete decreases with increase in the bagasse ash content. The probable reason for this is due to the high replacement of cement by bagasse ash, thus reducing cement content of the mixture which in turn causes a reduction in the hydration reaction. In addition to this the high content of bagasse ash resulted in a higher water requirement, making the water unavailable for the hydration of the cement. Figure 5.7 below shows the trend in compressive strength of the concrete.

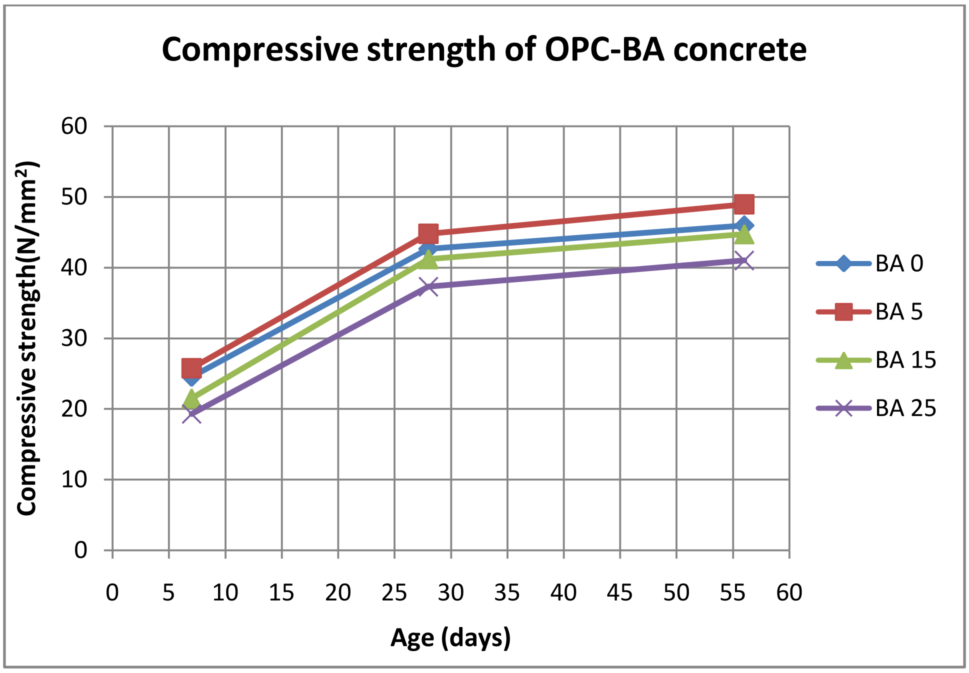

Fig. 5.7 Compressive strength of OPC-BA concrete

As in the case of the mortar mix, the strength of the OPC-BA concretes had also shown increase in activity index for most of the mixes as the age of the specimen increased. For example the concrete BA 15 i.e. the concrete with 15% bagasse ash, had a strength activity index of 87.7% at 7 days which increase to 96.6% at 28 days and 97.3% at 56 days. This is one evidence which shows that there may be a pozzolanic reaction between the bagasse ash and the cement i.e. if the bagasse had been only a filler such strength activity improvement over time would not be noticed. Table 5.14 below shows the strength activity index for all the concretes.

Table 5.14 Strength activity index of OPC-BA concrete

Mix code	Age of specimen		
	7 days	28 days	56 days
BA 0	100.0	100.0	100.0
BA 5	105.1	105.0	106.5
BA 15	87.7	96.6	97.3
BA 25	78.6	87.4	89.2

Flexural strength of concrete is one way of estimating the tensile strength of concrete. During this test the specimen is subjected to a bending moment. For a bending force applied downward on a member supported simply at its two ends, fibers above the neutral axis are generally subjected to compressive stresses and those below the neutral axis to tensile stresses.

Fig. 5.8 Specimen to be tested for flexure

The flexural strength tests were conducted at seven and twenty eight days. These results are summarized in Table 5.15**.** The calculation of the flexural stress is as follows:

$C = D/2$ cm……………………………………………………………… [Eq. 5.1]
$M = PL/3$ N.m…………………………………………………………… [Eq. 5.2]
$I = bd^3/12\ m^4$…………………………………………………………… [Eq. 5.3]
$\sigma = Mc/I$ MPa………………………………………………………… [Eq. 5.4]

Where: P = Failure Load σ = Bending strength
M = Maximum Moment L = span of specimen
I = Moment of Inertia D = depth of specimen
C = Centroidal depth W = width of specimen

Table 5.15 Average flexural strength value of the concretes

S. No	Mix code	Average flexural strength			
		7 days		28 days	
		Load (kN)	Strength (N/mm^2)	Load (kN)	Strength (N/mm^2)
1	BA 0	5.8	4.35	6.2	4.68
2	BA 5	5.8	4.33	6.2	4.68
3	BA 15	5.1	3.83	5.6	4.23
4	BA 25	4.7	3.50	5.5	4.10

The flexural strength had shown a reduction pattern as the bagasse ash content of the concrete increases. BA 5 i.e. the concrete with 5% bagasse ash, has a slightly lower flexural strength at the seven day which become equal to the control at the 28-day.

5.4.2.3 Results and discussions on water permeability of OPC-BA concrete

The non-steady state water permeability test was selected for this research. It was conducted on normal concrete cubes having a dimension of 150mm x 150mm x 150mm. The surfaces of the cubes were polished to remove any unwanted particles on the surfaces. The cubes where then placed in the permeability apparatus and the bolts were tightened to prevent any leakage of water. The specimens ready for test are as shown in Figure 5.9 below.

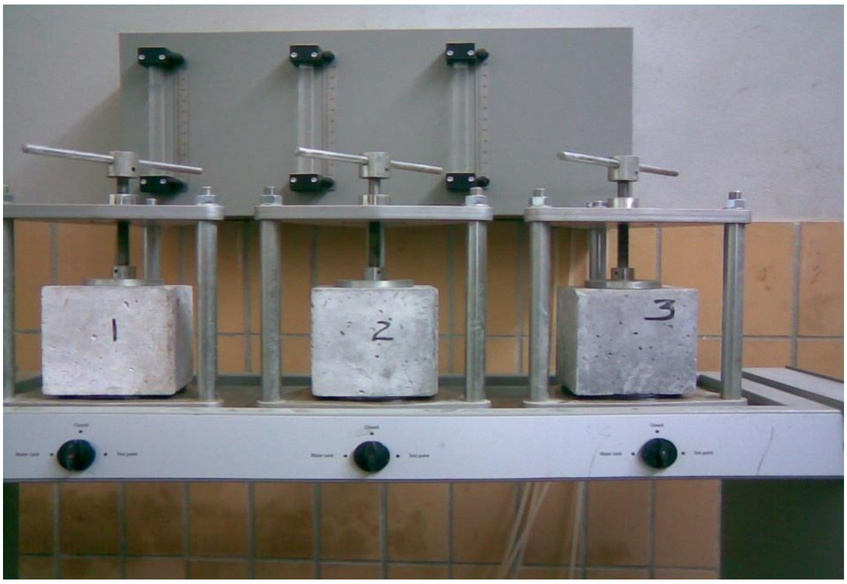

Fig. 5.9 Specimens ready for water permeability test

The pressure of the water is then adjusted to 3 bar (0.3 MPa) for the first 24 hours, 5 bar (0.5MPa) for the next 24 hours and finally 7 bar (0.7 MPa) for the last 24 hours i.e. total of 72 hours. At the end of the 72 hours period, all the valves supplying water and compressed air to the specimens were closed and the cubes were removed from the permeability rig and split. Upon visual examination, the portion of the specimen into which water has penetrated appears darker than the rest, and immediately after splitting, this zone was marked and measurements were taken.

Figure 5.10, below shows a typical water penetrated sample just after splitting. To determine the average depth of penetration with more accuracy, measurements were taken at 10mm intervals. Table 5.15 lists the average and maximum depth of penetrations obtained for different samples (detailed results are given in the appendix).

Fig. 5.10 Typical concrete sample just after splitting at the end of the water penetration test

Table 5.16 Results of the water penetration depth

S. No	**Mix code**	**Penetration depth (mm)**	
		Average	**Maximum**
1	BA 0	22.67	27.42
2	BA 5	20.68	27.62
3	BA 15	23.48	29.24
4	BA 25	24.79	34.37

As given in Table 5.15 above, the results of the water penetration test, i.e. the average and maximum depths of water penetration show some variation over the different types of concrete specimens with different percentage of bagasse ash. The average depth of water penetration varied from 20.68 to 24.79 for BA 5 and BA 25 respectively. The corresponding variation for the maximum depth of penetration was from 27.42 to 34.37 for BA 0 and BA 25 respectively. It can be said that the degree of variation from the most impermeable concrete to the most permeable concrete was about 25% depending on the maximum depth. The concrete with 5% bagasse ash (BA 5) have shown some improvement on the average depth of penetration over the control concrete, i.e. 20.68mm for BA 5 and 22.67mm for BA 0, whereas the maximum depth of penetration increased slightly to 27.62 from 27.42 for that of BA C. This shows that the concrete with 5% bagasse ash have some weak points which make its maximum water penetration depth higher. Therefore the concretes with bagasse ash are more permeable than the control concrete. However, permeability is not a big concern for most parts of Ethiopia and such a slight increment in permeability will not be a problem to use bagasse ash. Figure 5.11 below shows the penetration depth as a function of concrete types.

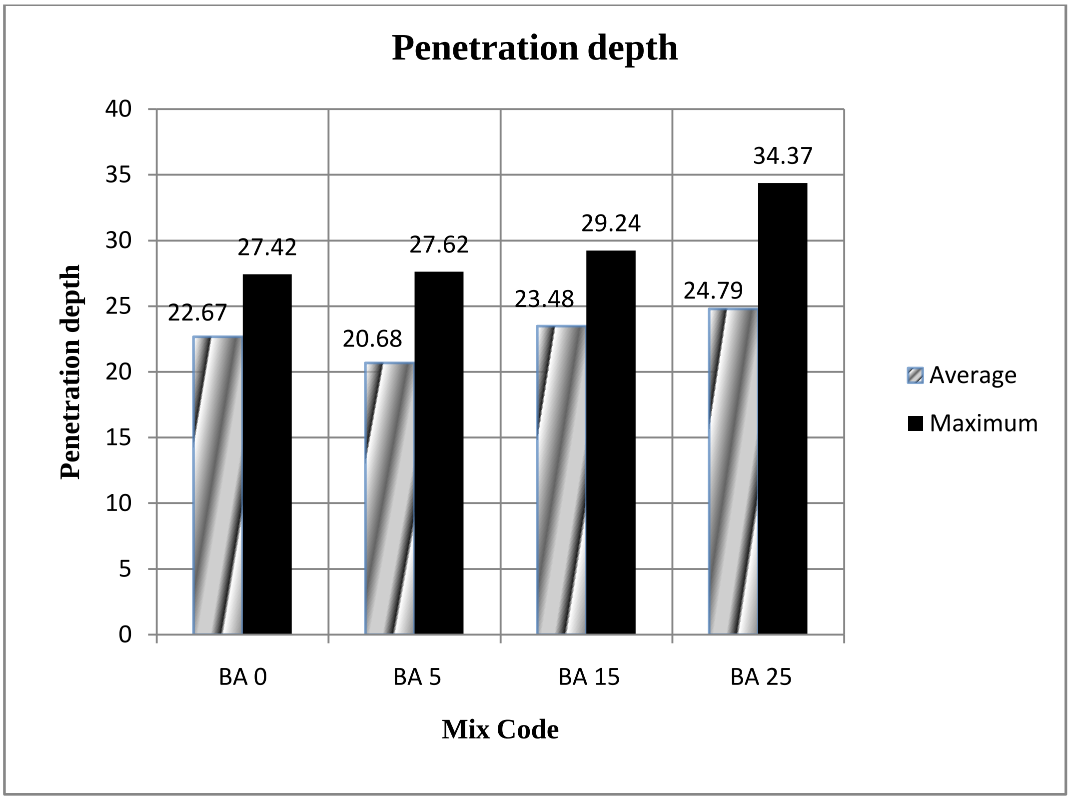

Fig. **5.11** Graph showing penetration depth

According to Neville, it is possible to use the depth of penetration of water as a qualitative assessment of concrete: a depth less than 50mm classifies the concrete as impermeable; and depth less than 30mm, as impermeable under aggressive conditions. In this regard it can be noted that all the concretes in this research are impermeable concretes, whereas all the concretes, with the exception of BA 25, are impermeable under aggressive conditions.

CHAPTER SIX

ENVIRONMENTAL AND ECONOMICAL ANALYSIS

6.1 Introduction

Our today's world is greatly concerned with sustainability of human activities. Sustainability is mainly concerned about the world we will be leaving behind for future generations. Social, environmental, and economical issues of our activities are its focus points.

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

Bagasse ash was found to have a great potential to be used as a cement replacing material in some parts of the world. The use of this material as a cement replacement reduces the cost of cement, the CO_2 emission, and also energy.

6.2 Environmental advantages

As presented in the literature review part (Sec. 2.3.2), the cement industry releases about one ton of CO_2 for each ton of Portland cement production. In addition to this concrete consumes vast amount of natural resources for aggregate and cement production. Replacing the portion of Portland cement with bagasse ash can substantially reduce the environmental impact of concrete. The most significant environmental factors are virgin material use and emissions.

6.2.1 Virgin material saving

Using bagasse ash, which is a recycled material, will save a great deal of virgin materials. This is because when inventorying the materials that are used to manufacture concrete, only the virgin materials are included in the comparative calculations not recovered materials (i.e. bagasse ash), because recovered materials already exist and would be disposed if not productively utilized. Table 6.1 shows the comparative calculation of virgin materials.

Different assumptions were made in order to get the virgin material saving. These are as follows:

- the mass of raw materials to manufacture Portland cement is assumed to be 1.6 times as much as the mass of finished Portland cement [12],
- 5% wastage was assumed for the bagasse ash production, even though only transportation and grinding is involved,
- bagasse ash is not included as a virgin material, because it is a recycled material.

Table 6.1 Raw material input for one cubic meter of concrete

Mix Code	**BA 0**	**BA 5**	**BA 15**	**BA 25**
OPC (kg/m^3)	560	532	476	420
BA (kg/m^3)	0	12.6	37.8	63
Water (kg/m^3)	192.5	192.5	192.5	192.5
Coarse agg. (kg/m^3)	1205	1205	1205	1205
Fine agg. (kg/m^3)	650	650	650	650
Total (kg/m^3)	2607.5	2592.1	2561.3	2530.5
Virgin mat. (kg/m^3)	2607.5	2579.5	2523.5	2467.5
Saving (%)	0	1.07	3.22	5.37

As can be seen from Table 6.1, using bagasse ash as a cement replacement has resulted in saving of virgin materials. For example, the 15% replacement saved about 3.22% of virgin materials when compared to the control concrete, which is about 84kg/m^3. If the strategic plan of the country comes into reality, there will be about 2.08 million tons of virgin material saving annually with bagasse ash production of about 0.94 million tons (Sec. 2.5.3).

6.2.2 CO_2 emission

Different gasses are emitted in the manufacturing process of Portland cement. Of all the gases CO_2 is the most important when we are talking about environmental issues and also the greatest in amount. The saving in CO_2 emission was estimated in Table 6.2. Different assumptions were taken in order to estimate the saving.

The assumptions are as follows:

- negligible amount of CO_2 is emitted in the manufacture of bagasse ash since the process only requires grinding,
- one ton of Portland cement production release one ton of CO_2 [1],

- CO_2 emission during manufacturing of Portland cement is assumed to be 91% of the total process in concrete production (from literature review sec. 2.3.2, by interpolation).

Table 6.2 CO_2 emission for one cubic meter of concrete

Mix Code	BA 0	BA 5	BA 15	BA 25
CO_2 (kg/m^3)	384.6	367.1	332.1	297.1
Saving (%)	0	4.55	13.65	22.75

As can be seen from the simple calculations performed, using bagasse ash saves a great deal of CO_2 emission to the environment. For example using 15% bagasse ash saves about 52.5 kg/m^3 of CO_2 when compared to the control concrete.

With 0.94 million tons of bagasse ash production, considering about 5% wastage and 1:0.69 weight replacements i.e. 1 kg of cement is replaced by 0.69 kg of bagasse ash in order to account for the high volume of bagasse ash, results in reduction of about 1.3 million tons of CO_2 to the atmosphere annually.

6.3 Economical advantages

The detail cost break down and economical analysis of the cost advantages of using bagasse ash was not analyzed because of the variability and unavailability of the necessary data required. However, the economic advantages of using bagasse ash as a cement replacing material can be made qualitatively.

The production of cement is energy intensive and depends on the availability of raw materials near to the cement manufacturing area. The process is mainly classified into three, the raw material preparation process, the clinker burning process and the finish grinding process. Off all this processes, clinker burning is the most energy intensive process, accounting for about more than 90% of the fuel consumed and about 30% of the electric power consumption and the rest about 40% of the electric power is consumed by the finish grinding process and about 30% by the raw material preparation [29].

Fuel costs are a large part of the manufacturing cost of the cement industry, making cement plants to have aggressive energy consumption. Moreover, the clinker burning process as shown above take more than 90% of the fuel consumption, implying that it is the most expensive part of the cement production.

From this research work it was found that about 10% replacement of cement by bagasse ash results in a comparable concrete characteristics in strength, durability and workability. The production cost of bagasse ash is much lower than that of Portland cement. This is because the production of bagasse ash requires only transportation and grinding. This implies that, using bagasse ash to the minimum totally reduces the cost of clinker production (the most expensive one) by 10% (if 10% replacement is chosen), not mentioning the raw material preparations and other costs associated with cement production.

Therefore from the above stated evidences an economical advantage can be exploited by using bagasse ash as a cement replacing material in countries like Ethiopia with a plan to boost sugar production.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

The Conclusions and Recommendations that could be drawn from the results of this research and experiments are summarized as follows:

7.1 Conclusions

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

1. The chemical composition test reveals that the bagasse ash from Wonji sugar factory can be assigned as class N pozzolana, as prescribed by ASTM C 618, i.e. SiO_2+ Al_2O_3+ Fe_2O_3 is greater than 70%.

2. Higher replacements of cement by bagasse ash resulted in higher normal consistency (implying higher water demand for certain workability) and longer setting time.

3. The workability of mortar and concrete containing bagasse ash decreases slightly as the bagasse ash content increases which is due to the higher water demand of bagasse ash.

4. The investigation of this thesis has revealed that replacement of ordinary Portland cement by bagasse ash from 5% to 10% results in a better compressive strength than that of the control mortar with 100% ordinary Portland cement. And the compressive strength decreases as the bagasse ash replacement increases over 10%. Moreover, all of the OPC-BA blended mortars satisfy the ASTM C 618 minimum pozzolanic activity index requirement i.e. 75%.

5. All the PPC-BA mortars have shown a lower compressive strength than the control mortar with the 20% and 25% replacements showing a 28 days strength activity index less than the ASTM minimum requirement of 75%.

6. The difference in the trend of strength development of OPC-BA (increasing with age for most of the mixes and having improvement up to 10% replacement) and PPC-BA (decreasing with age for most of the mixes and having a lower compressive strength than the control for all blended mixes) mortars partly show the presence of pozzolanic reaction.

7. The results of the concrete work revealed that, the unit weight of the concretes containing bagasse ash have shown a slight reduction. It was found that a reduction of unit weight up to 1.65% was observed when 25% of the cement was replaced by bagasse ash.

8. The compressive strength results of the concrete have revealed that the concrete with 5% cement replacement by bagasse ash have shown a 5% compressive strength improvement at 28 days over the control concrete with 100% ordinary Portland cement. The 15% and 25% replacements have shown 3.4% and 12.6% reduction at 28 days of the control concrete. Therefore up to 10% we can say that there is no strength reduction, which is also shown in the mortar work.

9. The flexural strength of the concrete has decreased as the replacement percentage of the bagasse ash increased. At 28 days the control concrete and the concrete containing 5% bagasse ash have shown the same flexural strength where as the 15% and 25% replacements have shown a lower flexural strength value.

10. The research revealed that the water penetration depth increases as the bagasse ash content of the concrete increases and all the concretes with bagasse ash have a penetration depth greater than the control with the exception of the average penetration depth for the concrete with 5% bagasse ash. But all the concretes were found to be impermeable according to Neville’s classification, since they have a penetration depth less than 50mm.

11. The consistency of the ash was found to vary from mix to mix which is one of the main problems associated with by-product materials.

12. Since bagasse ash is a by-product material, its use as a cement replacing material reduces the levels of CO_2 emission by the cement industry and also saves a great deal of virgin materials. In addition its use resolves the disposal problems associated with it in the sugar industries.

13. Finally the results of this research work have revealed that cement could advantageously be replaced with bagasse ash up to 10%. This replacement results in similar 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.

7.2 Recommendations

In Ethiopia, even though the construction industry is booming these days, it is still in its infant stage and needs much more effort to be made on the different construction materials. The awareness about the different cement replacing materials and their advantages is negligible, implying more work to be done on the area.

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

1. Sugarcane bagasse ash as investigated in this research work can be used as a cement replacing material with economical, technical and environmental benefits. Therefore concerned bodies like sugar industries, cement industries and government entities should be made aware about this potential cement replacing material and promote its standardized production and usage.

2. The sugar and cement factories in collaboration with higher education organizations in the country should work together and establish a research team to further study the use of bagasse ash as a cement replacing material.

3. This research studied some of the basic physical and chemical properties of Wonji sugar factory bagasse ash as a cement replacing material. However, further studies are required on the following items:

    - Studies should be made using controlled burning of the bagasse at different temperature and holding time.
    - The effects of different fineness of the bagasse ash should be studied as well.
    - The bagasse ash from different sources like, Metahara, Finchaa and the coming new sugar factories should be studied.
    - 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).

REFERENCES

[1] Naik T.R. and Moriconi G., Environmental-friendly durable concrete made with recycled materials for sustainable concrete construction, University of Wisconsin-Milwaukee, 2006.

[2] 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.

[3] Noor Ul Amin, Chemical activation of bagasse ash in cementitious system and its impact on strength development, J.chem.soc.pak, No 4, Abdul Wali Khan University, Pakistan, 2010.

[4] Patcharin Worathanakul, Wisaroot Payubnop, and Akhapon Muangpet, Characterization for Post-treatment Effect of Bagasse Ash for Silica Extraction, World Academy of Science, Engineering and Technology, 2009.

[5] Ghazali M. J., Azhari C. H., Abdullah S. & Omar M. Z., Proceeding of world congress on engineering, London, Characterization of Natural Fibers (Sugarcane Bagasse) in Cement Composites, 2008.

[6] Moises Frıas, Villar-Cocina E. and Valencia-Morales E., Characterization of sugarcane straw waste as pozzolanic material for construction: calcining temperature and kinetic parameters, Eduardo Torroja Institute (CSIC), 2007.

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

[8] Shetty M.S., Concrete Technology Theory and Practice, Chand S. and Company LTD, College of Military Engineering (CME), Pune Ministry of Defense, 2005, pp.2-5, 35-36.

[9] John Newman and Ban Seng Choo, Advanced Concrete Technology Constituent Materials, Butterworth-Heinemann Elsevier Ltd, 2003, pp.1/15-1/19.

[10] Neville, A. M., Properties of Concrete, Longman Scientific & Technical, 3rd edition, 1994.

[11] Meyer C., concrete as a Green Building Material, Columbia University, New York, NY, USA, 10027. http://www.civil.columbia.edu/meyer/publications/publications/87%20Concrete%20as%20a%20Green%20Building%20Material.pdf

[12] Jan R. Prusinski, Medgar L. Marceau and Martha G. Vangeem, Life cycle inventory of slag cement, http://www.slagcement.org/Sustainability/pdf/Life%20Cycle%20Inventory%20of%20Slag%20Cement%20Concrete.pdf

[13] Nuntachai Chusilp, Napongsatorn Likhitsripaiboon and Chai Jaturapitakkul, Development of bagasse ash as a pozzolanic material in concrete, As. J. Energy Env., 10(03), 149-159, 2009.

[14] International Finance Corporation environment and social development department, world Bank Group, A Guide to Biodiversity for the Private Sector, http://www.ifc.org/biodiversityguide

[15] Ethiopia plans to take 2.5pc of the world sugar market,30 December 2010,19:54, http://www.ethiopiafirst.info/news/index.php?option=com_content&view=article&id=412:ethiopia-plans-to-take-25pc-of-the-world-sugar-market&catid=1:latest-news&Itemid=1

[16] Nigus G/Egziabher, comparison of concrete properties produced using Mugher, Messebo and Diredawa cements, M.Sc thesis, Addis Ababa university school of graduate studies, November 2005.

[17] Abebe Dinku, Construction Materials Laboratory Manual, Addis Ababa University Printing Press, June 2002.

[18] Steven Kosmatka H., Beatrix Kerkhoff, and William Panarese C., Design and Control of Concrete Mixtures, 14th edition, 2003, pp.149-160.

[19] Peter Hewlett, Lea's Chemistry of Cement and Concrete, Elsevier Science & Technology Books, January 2004, pp.1-5.

[20] Birhanu Bogale, Comparison of concrete durability as produced by various cements manufactured in Ethiopia, Addis Ababa University department of civil engineering, school of graduate studies, February 2007.

[21] Desta S. K., Some Laboratory Tests on the Durability of Concrete, Prosjektrapport, NTNU Trondheim, Norway, March 2000.

[22] Desta S. K., "*Utilization of Ethiopian Natural Pozzolans*", Dr. Ing. Thesis, Norwegian University of Science and Technology, Trondheim, Norway, March 2003.

[23] Joseph F. Lamond and James H. Pielert, Significance of tests and properties of concrete and concrete making materials, ASTM International, April 2006.

[24] Access Capital Research, invest in Ethiopia, sector updater, cement, May 27, 2009.

[25] Ethio Resource Group for Heinrich Boll Foundation and Forum for Environment, Diversity and security for the Ethiopian Power System, A preliminary assessment of risks and opportunities for the power sector, August 2009.

[26] Rangnekar D.V., integration of sugarcane and milk production in western India. http://www.fao.org/docrep/003/s8850e/S8850E17.htm

[27] Marcos oliveira de paula, Sugarcane bagasse ash as partial Portland cement replacement material, University Federal of Viçosa, march 20, 2009.

[28] ASTM, concrete and mineral aggregates (including manual of concrete testing), part 10, Easton, Md., USA, 1972

[29] The Energy Conservation Center (ECC), Output of a Seminar on Energy Conservation in Cement Industry, United Nations Industrial Development Organization, 1994.

[30] 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.

[31] Abebe Dinku, The need for standardization of aggregates for concrete production in Ethiopian construction industry, Addis Ababa University department of civil engineering, may 2005.

[32] Belen G., Bethlehem W., Elshaday W., Helina B., Development of an economical self compacting concrete in Ethiopia, Final year research paper, Addis Ababa University department of civil engineering, June 2011.

APPENDIX A

COMPRESSIVE STRENGTH OF OPC-BA MORTARS

A-1 Three Days Compressive strength of OPC-BA mortars

No	Age (days)	Dimension (mm)			Weight (gm)	Failure load (kN)	Compressive strength(MPa)
		L	W	H			
BAM 0							
1	3	50.34	50.87	50.11	268	54.8	21.93
2		50.12	49.75	50.44	271	54.4	21.78
3		50.18	50.00	50.33	268	54.6	21.84
Average					**269**	**54.6**	**21.85**
BAM 5							
1	3	50.23	50.28	50.22	269	56.3	22.51
2		51.01	50.55	50.47	267	58.3	23.34
3		50.11	50.23	50.19	268	58.2	23.30
Average					**268**	**57.6**	**23.05**
BAM 10							
1	3	50.10	50.21	51.05	268	53.6	21.45
2		50.32	50.12	50.16	272	55.5	22.21
3		50.32	50.37	50.42	267	58.5	23.39
Average					**269**	**55.9**	**22.35**
BAM 15							
1	3	50.21	50.42	49.87	267	48.1	19.25
2		50.11	50.21	50.04	263	47.9	19.16
3		50.12	50.71	50.11	268	46.3	18.53
Average					**266**	**47.4**	**18.98**
BAM 20							
1	3	50.11	50.21	50.26	261	46.9	18.76
2		50.13	50.21	50.54	268	43.3	17.31
3		50.39	50.32	50.04	260	44.8	17.94
Average					**263**	**45.0**	**18.00**
BAM 25							
1	3	50.12	50.42	50.54	257	43.3	17.31
2		50.01	50.16	49.56	260	45.4	18.15
3		50.66	50.01	50.57	260	42.8	17.13
Average					**259**	**43.8**	**17.53**
BAM 30							
1	3	50.22	50.65	50.06	257	40.8	16.32
2		50.08	50.04	50.12	255	43.4	17.35
3		50.12	50.45	50.31	256	44.0	17.61
Average					**256**	**42.7**	**17.09**

A-2 Seven Days Compressive strength of OPC-BA mortars

No	Age (days)	Dimension (mm)			Weight (gm)	Failure Load(kN)	Compressive strength (MPa)
		L	W	H			
BAM 0							
1	7	50.46	50.40	50.43	275	92.2	36.90
2		50.08	50.03	50.41	277	86.8	34.71
3		50.04	50.05	50.13	276	89.8	35.94
Average					**276**	**89.6**	**35.85**
BAM 5							
1	7	50.31	50.23	50.01	272	95.0	38.01
2		49.95	50.15	50.74	270	90.6	36.23
3		50.18	50.22	50.91	271	94.6	37.84
Average					**271**	**93.4**	**37.36**
BAM 10							
1	7	50.20	50.10	51.03	268	91.3	36.51
2		50.30	50.18	50.17	271	89.4	35.78
3		50.09	50.06	50.43	271	91.1	36.43
Average					**270**	**90.6**	**36.24**
BAM 15							
1	7	50.20	50.03	50.13	272	83.8	33.53
2		50.19	50.18	50.46	273	81.1	32.45
3		50.19	50.11	50.19	274	83.2	33.29
Average					**273**	**82.7**	**33.09**
BAM 20							
1	7	50.18	50.23	50.46	268	80.0	32.01
2		50.18	50.04	50.34	272	76.4	30.56
3		50.32	50.29	50.49	273	76.1	30.46
Average					**271**	**77.5**	**31.01**
BAM 25							
1	7	50.32	50.51	50.17	268	70.8	28.31
2		49.95	49.87	50.25	269	71.4	28.56
3		50.45	50.33	50.45	267	72.6	29.05
Average					**268**	**71.6**	**28.64**
BAM 30							
1	7	50.21	50.45	50.22	268	68.1	27.25
2		50.47	50.09	50.17	266	65.0	26.01
3		50.41	50.15	50.14	264	73.6	29.45
Average					**266**	**68.9**	**27.57**

A-3 Twenty eight Days Compressive strength of OPC-BA mortars

No	**Age (days)**	**Dimension (mm)**			**Weight (gm)**	**Failure Load(kN)**	**Compressive strength(MPa)**
		L	**W**	**H**			
BAM 0							
1	28	50.19	50.12	50.00	271	137.0	54.82
2		50.39	50.38	50.04	275	134.2	53.68
3		50.01	50.12	50.23	276	132.7	53.09
Average					**274**	**134.6**	**53.86**
BAM 5							
1	28	49.52	50.15	49.84	271	141.5	56.62
2		49.80	50.03	49.17	268	142.2	56.86
3		50.12	50.23	50.11	268	136.4	54.56
Average					**269**	**140.1**	**56.01**
BAM 10							
1	28	49.84	50.11	51.13	267	141.7	56.70
2		50.31	50.02	50.17	272	139.1	55.66
3		50.24	50.01	50.13	271	134.8	53.91
Average					**270**	**138.5**	**55.42**
BAM 15							
1	28	49.71	50.58	50.01	266	134.8	53.94
2		50.10	50.17	50.33	271	132.1	52.83
3		50.11	50.12	50.42	267	135.4	54.15
Average					**268**	**134.1**	**53.64**
BAM 20							
1	28	49.96	50.24	50.55	270	128.3	51.32
2		50.42	50.04	50.05	264	126.8	50.72
3		50.33	50.14	50.53	264	125.0	50.00
Average					**266**	**126.7**	**50.68**
BAM 25							
1	28	50.30	50.25	50.29	262	114.4	45.76
2		50.01	49.97	50.22	264	116.5	46.61
3		50.11	49.56	50.04	266	113.6	45.47
Average					**264**	**114.8**	**45.95**
BAM 30							
1	28	50.22	50.55	50.42	266	112.2	44.89
2		50.01	50.07	50.05	265	107.2	42.87
3		49.74	50.02	50.14	261	108.6	43.46
Average					**264**	**109.3**	**43.74**

APPENDIX B

COMPRESSIVE STRENGTH OF PPC-BA MORTARS

B-1 Three Days Compressive strength of PPC-BA mortars

No	Age (days)	Dimension (mm)			Weight (gm)	Failure Load(kN)	Compressive strength (MPa)
		L	W	H			
BAMP 0							
1	3	50.19	50.12	50.00	269	33.9	13.58
2		50.39	50.38	50.04	272	29.6	11.83
3		50.01	50.12	50.23	272	32.0	12.81
Average					**271**	**31.8**	**12.74**
BAMP 5							
1	3	49.52	50.15	49.84	267	32.5	13.01
2		49.80	50.03	49.17	271	29.4	11.78
3		50.12	50.23	50.11	272	28.8	11.54
Average					**270**	**30.3**	**12.11**
BAMP 10							
1	3	49.84	50.11	51.13	275	27.4	10.98
2		50.31	50.02	50.17	270	27.6	11.03
3		50.24	50.01	50.13	268	31.4	12.58
Average					**271**	**28.8**	**11.53**
BAMP 15							
1	3	49.71	50.58	50.01	265	27.1	10.86
2		50.10	50.17	50.33	271	26.3	10.53
3		50.11	50.12	50.42	271	29.1	11.64
Average					**269**	**27.5**	**11.01**
BAMP 20							
1	3	49.96	50.24	50.55	267	22.9	9.16
2		50.42	50.04	50.05	265	30.8	12.34
3		50.33	50.14	50.53	272	25.3	10.12
Average					**268**	**26.3**	**10.54**
BAMP 25							
1	3	50.30	50.25	50.29	265	25.6	10.24
2		50.01	49.97	50.22	264	21.8	8.73
3		50.11	49.56	50.04	266	21.9	8.78
Average					**265**	**23.1**	**9.25**
BAMP 30							
1	3	50.22	50.55	50.42	262	23.2	9.28
2		50.01	50.07	50.05	265	21.3	8.51
3		49.74	50.02	50.14	265	22.7	9.09
Average					**264**	**22.4**	**8.86**

B-2 Seven Days Compressive strength of PPC-BA mortars

No	Age (days)	Dimension (mm)			Weight (gm)	Failure Load(kN)	Compressive strength (MPa)
		L	W	H			
BAMP 0							
1	7	50.47	50.78	51.27	280	53.3	21.31
2		50.48	50.51	50.38	276	59.1	23.63
3		50.22	50.13	50.12	278	59.4	23.76
Average					**278**	**57.3**	**22.90**
BAMP 5							
1	7	50.37	50.30	50.08	274	51.3	20.53
2		50.48	50.43	50.63	271	54.5	21.80
3		50.21	50.23	50.12	277	54.6	21.84
Average					**274**	**53.5**	**21.39**
BAMP 10							
1	7	50.32	50.12	51.11	274	51.6	20.63
2		50.34	50.13	50.14	270	52.6	21.05
3		50.14	50.42	50.21	275	50.7	20.30
Average					**273**	**51.6**	**20.66**
BAMP 15							
1	7	50.24	50.23	50.17	271	50.5	20.19
2		50.70	50.49	50.61	271	48.1	19.25
3		50.12	50.22	50.32	274	51.3	20.53
Average					**272**	**50.0**	**19.99**
BAMP 20							
1	7	50.31	50.14	50.19	270	44.6	17.83
2		50.17	49.96	50.12	271	42.6	17.03
3		50.12	50.21	50.31	269	44.1	17.64
Average					**270**	**43.8**	**17.5**
BAMP 25							
1	7	50.46	50.41	50.12	268	40.8	16.32
2		50.51	50.30	50.82	264	38.6	15.45
3		50.17	49.78	50.41	269	42.1	16.86
Average					**267**	**40.5**	**16.21**
BAMP 30							
1	7	50.23	50.15	50.11	267	36.3	14.51
2		50.11	50.17	50.41	266	38.4	15.36
3		50.02	50.03	50.15	268	37.7	15.07
Average					**267**	**37.5**	**14.98**

B-3 Twenty eight Days Compressive strength of PPC-BA mortars

No	Age (days)	Dimension (mm)			Weight (gm)	Failure Load (kN)	Compressive strength (MPa)
		L	W	H			
BAMP 0							
1	28	50.21	50.18	50.25	271	107.6	43.03
2		50.14	50.11	50.26	274	109.9	43.96
3		50.21	50.47	50.25	271	110.3	44.14
Average					**272**	**109.3**	**43.71**
BAMP 5							
1	28	50.31	50.41	50.01	267	94.5	37.81
2		50.42	50.33	50.01	264	90.1	36.03
3		50.12	50.13	50.41	264	97.5	39.02
Average					**265**	**94.1**	**37.62**
BAMP 10							
1	28	50.41	50.65	51.14	263	93.8	37.51
2		50.21	50.13	50.12	267	92.1	36.83
3		50.58	50.14	50.12	265	94.1	37.65
Average					**265**	**93.3**	**37.33**
BAMP 15							
1	28	50.15	50.12	50.03	264	93.2	37.29
2		50.00	50.01	50.21	264	89.1	35.63
3		50.38	50.12	50.01	267	90.8	36.31
Average					**265**	**91.0**	**36.41**
BAMP 20							
1	28	50.21	50.44	50.11	265	86.4	34.57
2		50.21	50.12	49.65	261	89.8	35.94
3		50.15	50.19	50.30	263	88.2	35.30
Average					**263**	**88.1**	**35.27**
BAMP 25							
1	28	50.14	50.12	50.38	263	78.4	31.35
2		50.11	50.10	50.20	259	80.3	32.11
3		50.74	50.21	50.12	261	80.7	32.27
Average					**261**	**79.8**	**31.91**
BAMP 30							
1	28	50.62	50.41	50.21	257	67.5	27.01
2		50.32	50.41	50.12	261	68.8	27.53
3		50.21	50.13	50.32	262	73.1	29.25
Average					**260**	**69.8**	**27.93**

APPENDIX C

COMPRESSIVE STRENGTH OF OPC-BA-Ca(OH)$_2$ MORTARS

C-1 Seven Days Compressive strength of OPC-BA-Ca(OH)$_2$ mortars

No	Age (days)	Dimension (mm)			Weight (gm)	Failure Load(kN)	Compressive strength (MPa)
		L	W	H			
BAMA 0							
1	7	50.66	50.94	50.64	282	86.3	34.51
2		50.61	50.52	50.41	278	85.1	34.03
3		50.43	50.41	50.32	283	85.9	34.36
Average					**281**	**85.7**	**34.30**
BAMA 15							
1	7	50.44	50.49	50.55	271	77.6	31.05
2		50.42	50.64	50.62	276	74.9	29.97
3		50.41	50.23	50.42	275	75.1	30.03
Average					**274**	**75.9**	**30.35**
BAMA 15-3							
1	7	50.51	50.45	50.43	275	77.2	30.88
2		50.32	50.53	50.47	272	76.3	30.53
3		50.53	50.42	50.32	275	78.9	31.56
Average					**274**	**77.5**	**30.99**
BAMA 15-6							
1	7	50.52	50.44	50.67	271	75.9	30.38
2		50.44	50.54	50.35	273	78.8	31.51
3		50.54	50.58	50.47	272	77.9	31.17
Average					**272**	**77.5**	**31.02**

C-2 Twenty eight Days Compressive strength of OPC-BA-Ca(OH)$_2$ mortars

No	Age (days)	Dimension (mm)			Weight (gm)	Failure Load(kN)	Compressive strength (MPa)
		L	W	H			
BAMA 0							
1	28	50.41	50.35	50.48	273	130.3	52.11
2		50.39	50.42	50.30	277	132.3	52.94
3		50.05	50.52	50.33	278	131.6	52.65
Average					**276**	**131.4**	**52.57**
BAMA 15							
1	28	50.65	50.51	50.42	266	131.4	52.58
2		50.63	50.67	50.54	265	128.1	51.25
3		50.22	50.24	50.54	267	127.6	51.04
Average					**266**	**129.0**	**51.62**
BAMA 15-3							
1	28	50.24	50.21	51.41	267	127.3	50.94
2		50.51	50.24	50.53	271	130.8	52.32
3		50.42	50.38	50.45	269	130.1	52.07
Average					**269**	**129.4**	**51.78**
BAMA 15-6							
1	28	50.45	50.65	50.09	266	129.4	51.78
2		50.45	50.15	50.33	270	130.1	52.03
3		50.45	50.48	50.57	271	129.0	51.60
Average					**269**	**129.5**	**51.80**

APPENDIX D

COMPRESSIVE STRENGTH OF OPC-BA CONCRETES

D-1 Seven Days Compressive strength of OPC-BA concretes

No	Age (days)	Dimension (mm)			Weight (gm)	Failure Load(kN)	Compressive strength (MPa)
		L	W	H			
BA 0							
1	7	153.39	149.96	150.19	8039	576.7	25.63
2		152.01	150.21	151.32	8328	527.6	23.45
3		151.95	151.74	150.65	7999	551.5	24.51
Average					**8122**	**551.9**	**24.53**
BA 5							
1	7	150.51	150.21	151.81	8177	597.8	26.57
2		150.56	150.21	150.54	8058	615.4	27.35
3		152.14	151.95	151.51	8122	526.9	23.42
Average					**8119**	**580.0**	**25.78**
BA 15							
1	7	150.06	150.11	153.28	7843	529.4	23.53
2		151.23	152.24	150.12	8154	434.7	19.32
3		152.21	151.95	151.65	8219	487.8	21.68
Average					**8072**	**484.0**	**21.51**
BA 25							
1	7	151.31	150.21	150.00	7915	448.2	19.92
2		152.55	151.01	152.00	7967	421.6	18.74
3		151.12	150.32	150.17	7852	431.5	19.18
Average					**7911**	**433.8**	**19.28**

D-2 Twenty eight Days Compressive strength of OPC-BA concretes

No	Age (days)	Dimension (mm)			Weight (gm)	Failure Load(kN)	Compressive strength (MPa)
		L	W	H			
BA 0							
1	28	152.44	150.36	149.93	8037	985.9	43.82
2		150.15	150.01	149.51	8113	957.4	42.55
3		151.21	152.51	152.41	8180	936.9	41.64
Average					**8110**	**960.1**	**42.67**
BA 5							
1	28	151.33	150.53	150.21	8005	1029.6	45.76
2		151.54	152.02	150.12	8203	972.2	43.21
3		152.31	150.72	149.87	7972	1022.2	45.43
Average					**8060**	**1008.0**	**44.80**
BA 15							
1	28	152.58	150.01	149.53	7950	921.6	40.96
2		152.64	150.02	151.13	8067	900.7	40.03
3		150.73	150.32	151.21	8013	960.1	42.67
Average					**8010**	**927.5**	**41.22**
BA 25							
1	28	153.01	152.77	149.34	8122	821.9	36.53
2		151.23	149.91	149.82	7749	859.7	38.21
3		151.56	150.24	150.45	8057	835.4	37.13
Average					**7976**	**839.0**	**37.29**

D-3 Fifty six Days Compressive strength of OPC-BA concretes

No	Age (days)	Dimension (mm)			Weight (gm)	Failure Load(kN)	Compressive strength (MPa)
		L	W	H			
BA 0							
1	56	151.30	149.67	150.32	7965	1023.7	45.50
2		151.24	150.16	150.50	8028	1017.7	45.23
3		151.35	150.47	150.56	8076	1062.2	47.21
Average					**8023**	**1034.5**	**45.98**
BA 5							
1	56	150.15	149.43	152.70	7850	1113.9	49.51
2		152.21	150.20	151.01	8203	1080.7	48.03
3		151.03	150.35	150.75	7854	1111.0	49.38
Average					**7969**	**1101.9**	**48.97**
BA 15							
1	56	151.94	149.86	149.88	7838	959.2	42.63
2		150.73	150.65	159.54	7786	1017.2	45.21
3		151.23	150.45	148.96	7830	1043.5	46.38
Average					**7818**	**1006.6**	**44.74**
BA 25							
1	56	149.90	150.00	149.83	7787	910.1	40.45
2		150.32	150.10	149.32	7802	974.9	43.33
3		151.24	150.45	149.81	7835	883.1	39.25
Average					**7808**	**922.7**	**41.01**

APPENDIX E

FLEXURAL STRENGTH OF OPC-BA CONCRETES

E-1 Seven Days flexural strength of OPC-BA concretes

No	Age (days)	Dimensions (cm)			P (kN)	M (N.m)	I (m^4)	C (cm)	σ (MPa)
		L	B	D					
BA 0									
1	7	49.00	10.28	10.18	5.8	725.00	8.33E-06	5.00	4.35
2		50.60	10.38	10.26	6.0	750.00	8.33E-06	5.00	4.50
3		50.30	10.00	10.12	5.6	700.00	8.33E-06	5.00	4.20
Average									**4.35**
BA 5									
1	7	49.00	10.20	10.43	5.8	725.00	8.33E-06	5.00	4.35
2		50.00	10.33	10.14	5.4	675.00	8.33E-06	5.00	4.05
3		50.20	10.10	10.21	6.1	762.50	8.33E-06	5.00	4.58
Average									**4.33**
BA 15									
1	7	50.00	10.39	10.10	5.2	650.00	8.33E-06	5.00	3.90
2		50.60	10.12	10.21	4.7	587.50	8.33E-06	5.00	3.53
3		50.10	10.21	10.34	5.4	675.00	8.33E-06	5.00	4.05
Average									**3.83**
BA 25									
1	7	50.60	10.44	10.24	4.7	587.50	8.33E-06	5.00	3.53
2		50.70	10.37	10.24	4.7	587.50	8.33E-06	5.00	3.53
3		50.20	10.28	10.14	4.6	575.00	8.33E-06	5.00	3.45
Average									**3.50**

E-2 Twenty eight Days flexural strength of OPC-BA concretes

No	Age (days)	Dimensions (cm)			P (kN)	M (N.m)	I (m^4)	C (cm)	σ (MPa)
		L	B	D					
BA 0									
1	28	50.60	10.20	10.26	5.9	737.50	8.33E-06	5.00	4.43
2		50.40	10.12	10.31	6.1	762.50	8.33E-06	5.00	4.58
3		50.00	10.32	10.31	6.7	837.50	8.33E-06	5.00	5.03
Average									**4.68**
BA 5									
1	28	50.00	10.29	10.08	5.8	725.00	8.33E-06	5.00	4.35
2		50.60	10.14	10.09	6.2	775.00	8.33E-06	5.00	4.65
3		50.40	10.20	10.23	6.7	837.50	8.33E-06	5.00	5.03
Average									**4.68**
BA 15									
1	28	50.40	10.43	10.28	6.3	787.50	8.33E-06	5.00	4.73
2		50.20	10.21	10.34	4.7	587.50	8.33E-06	5.00	3.53
3		50.20	10.20	10.41	5.9	737.50	8.33E-06	5.00	4.43
Average									**4.23**
BA 25									
1	28	50.60	10.38	10.23	5.3	662.50	8.33E-06	5.00	3.98
2		50.30	10.20	10.23	5.0	625.00	8.33E-06	5.00	3.75
3		50.22	10.30	10.15	6.1	762.50	8.33E-06	5.00	4.58
Average									**4.10**

APPENDIX F

WATER PENETRATION TEST MEASUREMENTS

Mix Code		**BA 0**	**BA 5**	**BA 15**	**BA 25**
Penetration depths measured at 10mm intervals (mm)	D1	19.48	15.31	10.58	18.22
	D2	20.35	14.91	17.79	19.85
	D3	21.11	15.05	19.15	24.93
	D4	23.18	20.30	25.42	24.59
	D5	23.22	24.44	28.72	26.9
	D6	22.46	26.61	26.94	25.26
	D7	22.20	25.77	26.65	29.21
	D8	20.00	23.86	28.81	26.81
	D9	22.95	23.33	29.24	28.45
	D10	26.22	26.16	25.29	31.21
	D11	26.96	27.62	23.60	34.37
	D12	24.72	27.29	25.48	33.24
	D13	27.42	22.67	23.27	25.92
	D14	25.67	15.54	23.73	15.63
	D15	19.04	12.58	19.87	15.92
	D16	17.79	9.39	21.13	15.2
Avg (mm)		**22.67**	**20.68**	**23.48**	**24.73**
Max (mm)		**27.42**	**27.62**	**29.24**	**34.37**

APPENDIX G

SAMPLE PHOTOS TAKEN DURING THE RESEARCH

Photo 1. Bagasse ash

Photo 2. Mortar mixer

Photo 3. Setting time test under progress

Photo 4. Mortar specimens after compressive strength test

Photo 5. Blain air permeability apparatus and materials to be tested

Photo 6. Coarse aggregate under specific gravity test

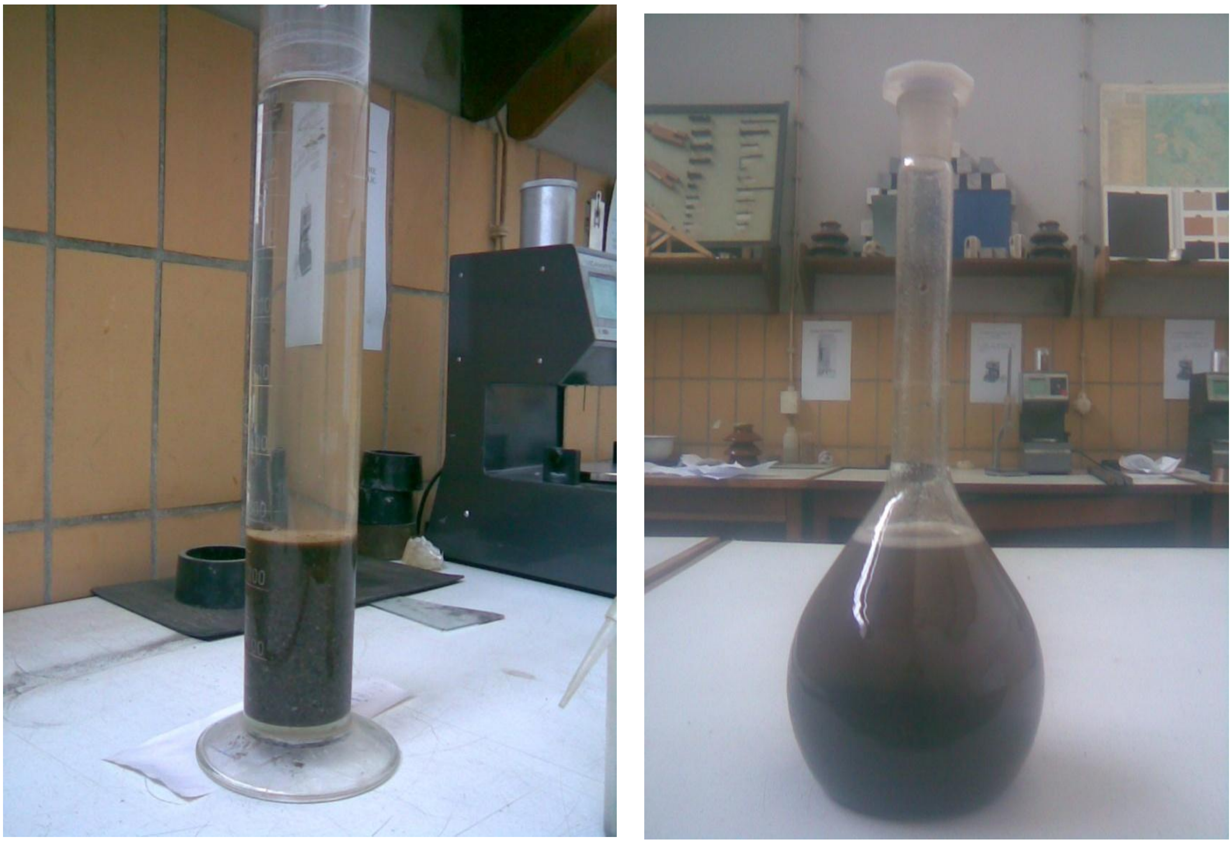

Photo 7. Fine aggregate under test

Photo 8. $Ca(OH)_2$ used for activation

Photo 9. Flow table apparatus for mortar

Photo 10. Mortar specimens after casting

Photo 11. Concrete ingredients to be mixed (left) and being mixed (right)

Photo 12. Oiled concrete molds (left), concrete spacimens being trowled (top right) and concrete specimens ready to be cured (bottom right)

Photo 13. Concrete specimens in curing pond (left) and after curing (right)

Photo 14. Concrete specimen to be tested for flexure (left) and concrete flexural specimen after failure (right)

Photo 15. Slump test

Photo 16. Concrete compressive strength test

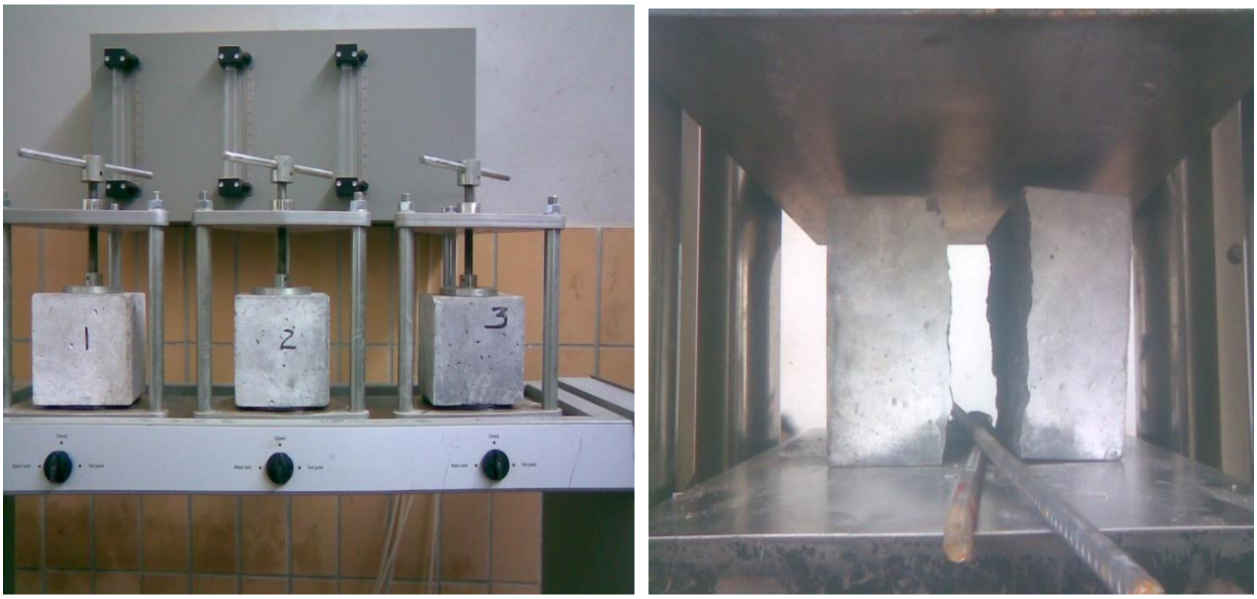

Photo 17. Specimens assembled on the permeability apparatus (left) and splitting the permeability cube (right)

Photo 18. Water penetrated concretes

APPENDIX H

CHEMICAL COMPOSITION OF BAGASSE ASH