

**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY**  
**SCHOOL OF CIVIL AND ENVIRONMENTAL**  
**ENGINEERING**



**Increasing compressive strength  
property of bagasse ash blended concrete by  
using chemical activator ( $\text{NaSO}_4$ )**

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**A Thesis in Structural Engineering**

By Lidya Fekadu

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled ‘**Increasing compressive strength property of bagasse ash blended concrete by using chemical activator (NaSO<sub>4</sub>)**’ presented by **LIDYA FEKADU**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

Dr. Esayas Gebreyohannes

\_\_\_\_\_

Advisor

Signature

\_\_\_\_\_

Date

\_\_\_\_\_

Internal Examiner

\_\_\_\_\_

Signature

\_\_\_\_\_

Date

\_\_\_\_\_

External Examiner

\_\_\_\_\_

Signature

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Date

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## **UNDERTAKING**

I certify that research work titled “Increasing compressive strength property of bagasse ash blended concrete by using chemical activator (NaSO<sub>4</sub>)” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Lidya Fekadu

Signature

## **ABSTRACT**

The use of sugar cane bagasse ash is being studied for application in the construction industry because of its technical, economic and to a large extent, environmental advantages. This study has investigated the improvement of early strength development of concrete containing bagasse ash by addition of chemical activator.

bagasse replacement is done 10%, 20% and 30% by volume of cement and casted with and without activator.

The compressive strength properties of bagasse ash blended cement paste, mortar and concrete with and without activator were studied. The results indicate that bagasse ash blended concrete gives higher strength when activated with sodium sulfate.

X- ray diffraction test also held on bagasse ash blended cement paste casted and cured for 7days and 28 days. The result verified the strength improvement is due to increasing the bagasse pozzolanic activity.

**Key word:** Chemical Activation

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## LIST OF ABBREVIATIONS

- H H<sub>2</sub>O
- S SiO<sub>2</sub>
- C CaO<sub>2</sub>
- C<sub>3</sub>S Alite 3CaO·SiO<sub>2</sub> or Ca<sub>3</sub>SiO<sub>5</sub>
- C<sub>2</sub>S Belite 2CaO·SiO<sub>2</sub> or Ca<sub>2</sub>SiO
- C<sub>3</sub>A Aluminate 3CaO·Al<sub>2</sub>O<sub>3</sub> or Ca<sub>3</sub>Al<sub>2</sub>O<sub>6</sub>
- C<sub>4</sub>AF Ferrite 4CaO·Al<sub>2</sub>O<sub>3</sub>·Fe<sub>2</sub>O<sub>3</sub> or Ca<sub>4</sub>Al<sub>2</sub>Fe<sub>2</sub>O
- C-S-H Calcium silicate hydrate/ tobermorite gel
- CH calcium hydroxide/portlandite
- AFt alumino-ferrite trisulfate hydrate/ Ettringite C<sub>3</sub>A·3CaSO<sub>4</sub>·32H<sub>2</sub>O
- AFm alumino-ferrite monosulfate hydrate/ 3C<sub>3</sub>A·CaSO<sub>4</sub>·12H<sub>2</sub>O
- XRD X-ray diffraction
- SCBA Sugar cane bagasse ash

## CHAPTER 1 INTRODUCTION

Environmental protection becomes global concern. The increase in CO<sub>2</sub> emission is getting attention. One of the main contributors for polluting environment is cement production. In average the manufacture of one ton of Portland-cement clinker releases nearly one ton CO<sub>2</sub> into the atmosphere.[1]

Also cement production uses lots of energy consumption. These issues lead to search for new construction materials that can be used with cement in concrete production. Pozzolanic materials like sugar cane bagasse ash are emerging materials used to replace the amount of cement partially. These materials are efficient to withstand high strength and durability properties. Also since the artificial pozzolan are wastes from industries, their usage brought environmental and economic advantage.

The shortcoming of of these pozzolanic materials is their lower early strength. Recently activation of pozzolanic materials to achieve high strength becomes research's concern. Various studies are being undertaken in the direction of chemical activation of pozzolana blended cement. Fly ash, slag, and natural pozzolan are being dealt in detail. But there are few papers regarding bagasse and the activation mechanism studied needs curing at elevated temperature, which is not applicable for casting on site.

Sugar cane is abundant agricultural product in Ethiopia as well as in world. Bagasse is an abundant waste produced in sugar factories after extraction of juice from Sugarcane. . In many countries including Ethiopia this type of bulky waste usually used as the boiler fuel in the sugar mills. The burning of bagasse as fuel leaves bulk quantity of ash called sugar cane bagasse ash.

The huge supply of bagasse ash needs meaningful disposal. The tables below indicate the production of sugar cane production and harvested area in 2014 and the potential of bagasse ash production in Ethiopia.

Increasing compressive strength property of bagasse ash blended concrete by using chemical activator (NaSO<sub>4</sub>)

**Table 1.1 World bagasse ash production<sup>1</sup>**

Continent	Mha/Mton	Region	Mha/Mton
Africa	1.48/95.53	Eastern	0.54/39.16
		Middle	0.24/5.26
		Northern	0.22/22.14
		Southern	0.33/23.31
		Western	0.15/5.67
America	14.18/1007.71	Northern	0.35/27.60
		Central	1.39/111.89
		Caribbean	0.64/27.43
Asia	11.03/748.41	South	11.81/840.80
		Eastern	1.79/127.31
		Southern	6.44/430.44
Europe	$73 \times 10^{-6}/5.89 \times 10^{-3}$	Southeastern	2.80/190.64
Oceania	0.43/32.59		
World	27.12/1884.25		

**Table 1.2 Bagasse ash production potential in Ethiopia<sup>2</sup>**

S.No.	Sugar factories	Tone of cane per day (TCD)	Annual crushing capacity (Ton)	Bagasse (Ton)	Bagasse ash (Ton)
1	Wonji Shoa	12,500	3,000,000	870,000	108,750
2	Metchara	5,000	1,200,000	348,000	43,500
3	Fincha	12,000	2,880,000	835,200	104,400
4	Tendahu	26,000	6,240,000	1,809,600	226,200
5	Beles I	12,000	2,880,000	835,200	104,400
6	Beles II	12,000	2,880,000	835,200	104,400
7	Beles III	12,000	2,880,000	835,200	104,400
8	Kuraz I	12,000	2,880,000	835,200	104,400
9	Kuraz II	12,000	2,880,000	835,200	104,400
10	Kuraz III	12,000	2,880,000	835,200	104,400
11	Kuraz IV	24,000	5,760,000	1,670,400	208,800
12	Kuraz V	24,000	5,760,000	1,670,400	208,800
13	Kesem	11,000	2,640,000	765,600	95,700
14	Arjo dedesa	8,000	1,920,000	556,800	69,600
15	Wolkayte	24,000	5,760,000	1,670,400	208,800
		<b>218,500</b>	<b>52,440,000</b>	<b>15,207,600</b>	<b>1,900,950</b>

<sup>1</sup> The table is taken from a book 'Waste and Supplementary Cementitious Materials in Concrete' page 562. The abbreviations Mton and Mha are million tons, and million hectare respectively.

<sup>2</sup> The table taken from a research paper 'Bagasse Ash as a Partial Substitute of Cement on Concrete Rigid Pavement' page 15

BA may be classified as a probable pozzolanic material, with the main factors affecting reactivity being the crystallinity of the silica present in the ash and the presence of impurities such as carbon and unburned material.

When pozzolanic materials are added to cement, the silica (SiO<sub>2</sub>) present in these materials reacts with free calcium hydroxide released during the hydration of cement and forms additional calcium silicate hydrate (C-S-H) as new hydration products which improve the mechanical properties of concrete.

The optimum percent replacement of bagasse ash by volume of cement is found to be 10%. [2][3] Beyond that setting and hardening are extended, and early compressive strength and often also ultimate strength are significantly reduced. This limits the applicability of the material.

During the past two decades, alkali-activated cements and concretes have attracted strong interests all over the world due to their advantages of low energy cost, high strength and good durability compared to Portland cements. [4] Chemical activation technique is being applicable in fly ash, slag, and natural pozzolan and found to be effective.

This paper discusses about chemical activation of bagasse ash blended cement and its effect in the compressive strength property of hardened concrete. This chapter gives an overview of how the research is done and justifies the relevance of the research. Chapter 2 discusses what literatures are stated about the concept of activation of pozzolanic materials, Chapter 3 discusses materials used and their chemical and physical properties, Chapter 4 discusses the experimental program, Chapter 5 discusses the result obtained and analysis of the result, and the final chapter summarizes the study by giving some conclusions and recommendations.

## **1.1 Statement of the problem**

Construction industry in Ethiopia is growing faster. As concrete is the back bone of the construction industry, and cement is one of major constituent in concrete, the demand of cement is increasing day by day and large cement production industries being rise to satisfy the demand. Portland cement, the principal hydraulic binder used in modern concrete is not only energy-intensive (4 GJ/tonne of cement) but also responsible for large emissions

of CO<sub>2</sub>. The world's yearly cement output of 1.5 billion tonnes of mostly Portland cement, accounts for nearly 7 percent of the global CO<sub>2</sub> emissions. [1]

On the other hand wastes from industries are another concern of environmental pollution. Partial or full replacement of cement with those industrial wastes has a twofold advantage.

## **1.2 Scientific relevance**

A number of researches conducted on sugarcane bagasse ash on its strength, durability, shrinkage, chemical attack and other properties of bagasse ash blended concrete. And it is found to be good pozzolanic material. But it has its own shortcomings on its low workability, higher setting time, and slower early strength gain. This research addresses the last issue i.e. to find out the right chemical activator to improve and study early strength gain of bagasse ash blended concrete.

## **1.3 Research Objectives**

### **1.3.1 General objectives**

The general objectives of this research work are to study the relationship between cement hydration and pozzolanic reaction of sugarcane bagasse ash and how it influences the compressive property of blended concrete.

### **1.3.2 Specific objectives**

- Find out the proper activator of bagasse ash blended concrete
- Investigate compressive strength development of bagasse ash blended concrete.
- Analyze and compare compressive test results with and without chemical activator.

## **1.4 Research methodology**

The following methodology has been followed to achieve the objectives of the research stated above:

#### **1.4.1 Literature survey**

Multiple of written documents, books, journals, conference and research papers are reviewed to understand the process of hydration, to observe its impact on pozzolanic reaction of bagasse ash, to discover the right chemical activator and the activation mechanism.

#### **1.4.2 Sample preparation**

Bagasse ash, cement, coarse and fine aggregate and sodium sulfate as an activator are prepared to cast cement paste, mortar and concrete specimens.

#### **1.4.3 Performing compressive strength tests on pastes, mortars and concretes**

Compressive strength test is performed at 3, 7 and 28 days to understand the activator involvement on pozzolanic reaction and cement hydration process.

#### **1.4.4 Performing X – ray diffraction tests on pastes**

Xrd test is performed on pastes with and without activator cured for 7 and 28 days.

#### **1.4.5 Analysis of test results**

Compressive and Xrd test results are analyzed to arrive at a conclusion.

## **CHAPTER 2 LITERATURE REVIEW**

Cement is building material widely used in the world for all kinds of construction. Even though it has various advantages, its production affect the environment negatively. In order to overcome this drawback, full or partial replacement of cement is becoming applicable recently. A blend of pozzolans and cement is one of those materials which gets attention recently. In addition to environmental relevance, pozzolanic materials has an advantage of lower heat of hydration, Reduce alkali-aggregate reaction, Improve resistance from sulfate attack in soils and seawater, Improve extensibility, Lower susceptibility to dissolution and leaching, and Lower the cost of construction material. [5]

A pozzolana is a natural or artificial material containing silica in a reactive form. By themselves, pozzolanas have little or no cementitious value. However, in a finely divided form and in the presence of moisture they will chemically react with alkalis to form cementing compounds. Pozzolanas must be finely divided in order to expose a large surface area to the alkali solutions for the reaction to proceed. Examples of pozzolanic materials are volcanic ash, pumice, opaline shales, burnt clay and fly ash. [6]

In practice, it is important for cement to reach satisfactory strength within a short period of time. One obvious disadvantage of cement - pozzolan blends is their long setting time and slow strength development. Attempts have made to activate the potential reactivity of pozzolans and to increase the strength of pozzolan containing cement or concrete. Like calcination, acid treatment, prolonged grinding, elevated temperature curing of pozzolan-containing cement paste and concrete, and the addition of alkalis to pozzolan-containing cement paste and concrete. However, some methods are too expensive to be used practically, and some do not show a significant efficiency. [7]

In this study bagasse ash, one of artificial pozzolanic material is assessed in improving strength properties by using chemical activator.

### **2.1 Cement hydration**

The chemistry of concrete is essentially the chemistry of the reaction between Portland cement and water. [1] Since the weak zone in normal concrete is the Interfacial transition

zone, the strength of concrete is highly influenced by the bond between aggregates and cement.

Anhydrous Portland cement is a gray powder composed of angular particles typically in the size range from 1 to 50µm. It is produced by pulverizing a clinker with a small amount of calcium sulfate, the clinker is a heterogeneous mixture of several compounds produced by high-temperature reactions between calcium oxide and silica, alumina, and iron oxide. The chemical composition of the principal clinker compounds corresponds approximately to C<sub>3</sub>S, C<sub>2</sub>S, C<sub>3</sub>A, and C<sub>4</sub>AF. In ordinary Portland cement, their respective amounts usually range between 45 and 60, 15 and 30, 6 and 12, and 6 and 8 percent. [1]

The chemical composition of cement highly affects the hydration and setting of cement. As a result, it has a great influence on the chemical and physical and automatically mechanical properties of the concrete. The table below summarizes the recommended chemical content and how it controls the whole process of hydration.

**Table 2.1 Chemical ingredients of cement with their influence on the strength properties of cement<sup>3</sup>**

	Appropriate proportion (%)	When excess	In deficiency
Lime(CaO)	62(60-65)	makes the cement unsound	the strength of the cement is decreased, causes cement to set quickly
Silica(SiO <sub>2</sub> )	22(17-25)	Slow setting	lack of strength
Alumina(Al <sub>2</sub> O <sub>3</sub> )	(3-8)	weakens the cement	lack of quick setting property
Calcium Sulphate(CaSO <sub>4</sub> )	4		decrease the initial setting time of cement
Magnesia(MgO)	2(0.5-4)	Cracks, unsoundness	Affect hardness and color of cement
Sulfur	1	it causes the cement to become unsound	A very small amount makes sound cement.
Alkalis	1	efflorescence is caused	

---

<sup>3</sup> It is a short summary from note on BUILDING MATERIALS & CONSTRUCTION book(page 43-45) and table BUILDING MATERIALS book(page 146)

Bogue in 1929 developed formulas below for estimating the theoretical or the potential compound composition of Portland cement. If the chemical composition of cement is known the four clinker compounds that influence hydration products can be estimated.

$$\%C_3S = 4.071(\text{total CaO} - \text{free lime}) - 7.600\text{SiO}_2 - 6.718\text{Al}_2\text{O}_3 - 1.430\text{Fe}_2\text{O}_3 \quad (2.1)$$

$$\%C_2S = 2.867\text{SiO}_2 - 0.7544C_3S \quad (2.2)$$

$$\%C_3A = 2.65\text{Al}_2\text{O}_3 - 1.692\text{Fe}_2\text{O}_3 \quad (2.3)$$

$$\%C_4AF = 3.043\text{Fe}_2\text{O}_3 \quad (2.4)$$

From previous research [3] the chemical composition of Dangote cement is specified as:

**Table 2.2 Chemical composition of Dangote cement**

SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO
22.82	5.41	3.37	66.32	1.46

Clinker compounds can be determined by bogues method:

$$C_3S = 4.071*(66.32) - 7.600*22.82 - 6.718*5.41 - 1.430*3.37 = 55.4\%$$

$$C_2S = 2.867*22.82 - 0.7544*55.4 = 23.6\%$$

$$C_3A = 2.65*5.41 - 1.692*3.37 = 8.6\%$$

$$C_4AF = 3.043*3.37 = 10.3\%$$

The Bogue equations assume that the chemical reactions of formation of clinker compounds have proceeded to completion and that the presence of impurities such as MgO and alkalis can be ignored. In some cases the computed compound compositions, especially the amounts of C<sub>3</sub>A and C<sub>4</sub>AF in cement, are known to deviate considerably from the actual compound composition determined directly. [1]

Even though the calculated figures may not agree exactly with the proportions of the clinker minerals determined by quantitative X-ray diffraction or by microscopic point counting, they give a good guide to cement properties in terms of strength development, heat of hydration and sulfate resistance. [6]

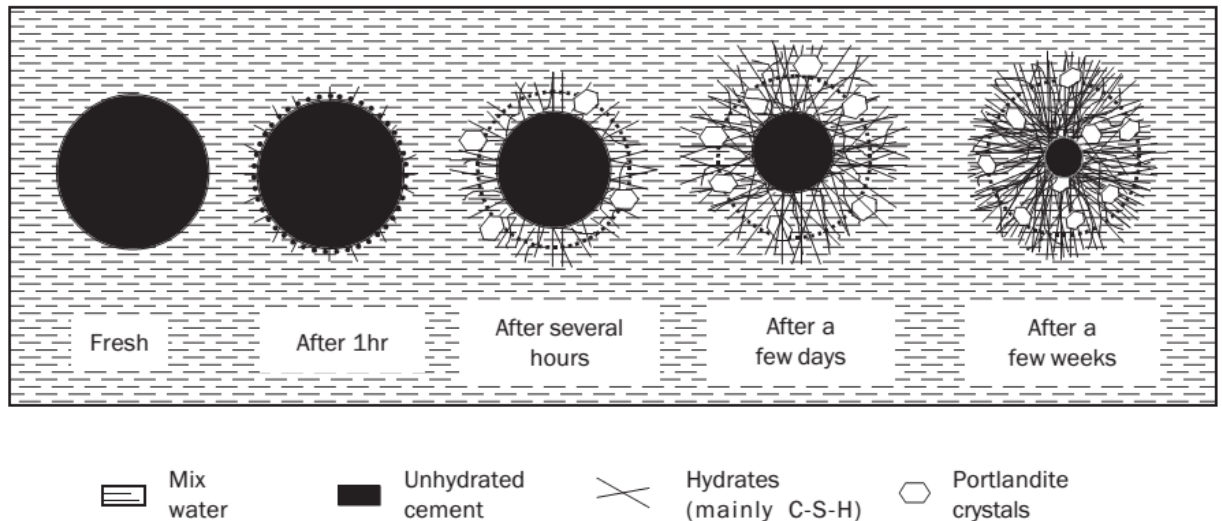
As Portland cement is composed of a heterogeneous mixture of several compounds, the hydration process consists of simultaneously occurring reactions of the anhydrous compounds with water. All the compounds, however, do not hydrate at the same rate. [1]

### **2.1.1 The process of hydration**

When Portland cement is dispersed in water, the calcium sulfate and the high-temperature compounds of calcium begin to go into solution, and the liquid phase gets rapidly saturated with various ionic species. As a result of interaction between calcium, sulfate, aluminate, and hydroxyl ions within a few minutes of cement hydration, the needle-shaped crystals of calcium trisulfoaluminate hydrate, called ettringite, first make their appearance. A few hours later, large prismatic crystals of calcium hydroxide and very small fibrous crystals of calcium silicate hydrates begin to fill the empty space formerly occupied by water and the dissolving cement particles. After some days, depending on the alumina-to-sulfate ratio of the Portland cement, ettringite may become unstable and will decompose to form monosulfoaluminate hydrate, which has a hexagonal-plate morphology. [1]

### **2.1.2 Solids in the hydrated cement paste**

*Calcium silicate hydrate:* The calcium silicate hydrate phase, abbreviated as C-S-H, makes up 50 to 60 percent of the volume of solids. The morphology of C-S-H also varies from poorly crystalline fibers to reticular network. The internal crystal structure of C-S-H also remains unresolved. It is sometimes called tobermorite gel. [1]



**Figure 2.1 Hydration of a single grain <sup>4</sup>**

The product of an ill-defined calcium silicate hydrate and crystalline calcium hydroxide (portlandite) is formed by the hydration of C<sub>3</sub>S at ambient temperatures. The equation may be written:



Where  $x + z = 3$  but  $x$ ,  $y$  and  $z$  are not necessarily integers. The calcium silicate hydrate formed in this reaction is poorly crystalline, yielding only two bands in its XRD pattern, a broad one peaking at 0.305 nm and a weaker, sharper one with a peak at 0.182 nm. [8]

Both C<sub>3</sub>S and C<sub>2</sub>S 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 aggregate particles together in concrete. C<sub>3</sub>S is much more reactive than C<sub>2</sub>S and under temperature conditions of 20°C, approximately half of the C<sub>3</sub>S present in typical cement will be hydrated by 3 days and 80% by 28 days. In contrast, the hydration of C<sub>2</sub>S does not normally proceed to a significant extent until ~14 days. The C–S–H produced by both C<sub>3</sub>S and C<sub>2</sub>S has a typical Ca to Si ratio of approximately 1.7.

**Calcium hydroxide:** Calcium hydroxide crystals (also called portlandite) constitute 20 to 25 percent of the volume of solids in the hydrated paste. In contrast to the C-S-H, calcium hydroxide is a compound with a definite stoichiometry, Ca(OH)<sub>2</sub>. It tends to form large crystals with distinctive hexagonal-prism morphology. Compared with C-S-H, the

<sup>4</sup> sited from a book ‘Construction materials their nature and behavior’ page 92

strength-contributing potential of calcium hydroxide is limited as a result of considerably lower surface area. [1]

Hydration of C<sub>3</sub>S produced higher calcium hydroxide than C<sub>2</sub>S. [6]



CH also contributes somewhat to concrete's inherent strength because it will form large crystals inside voids, thereby reducing porosity. However, CH is a soluble compound, it will move throughout the system in the presence of water and increase the concrete's porosity thus making less durable. [9]

**Calcium sulfoaluminates hydrates:** Calcium sulfoaluminate hydrates occupy 15 to 20 percent of the solid volume in the hydrated paste. During the early stages of hydration, the sulfate/alumina ionic ratio of the solution phase generally favors the formation of trisulfate hydrate, C<sub>6</sub>AS<sub>3</sub>-H<sub>32</sub>, also called ettringite. Ettringite eventually transforms to the monosulfate hydrate, C<sub>4</sub>AS-H<sub>18</sub>, which forms hexagonal-plate crystals. [1]

The aluminates are known to hydrate at a much faster rate than the silicates. The stiffening (loss of consistency) and setting (solidification) characteristics of a Portland cement paste are largely determined by the hydration reactions involving the aluminates. [1]

Tricalcium aluminate reacts rapidly with water to form crystalline hydration products with different lime/alumina ratios:[10]



The products in this reaction are formed as platelets with hexagonal symmetry. [8] The retardation of C<sub>3</sub>A hydration in the presence of calcium and sulfate ions in the aqueous phase has long been attributed to the formation of ettringite on its surface. Retardation is greater if calcium hydroxide is also present in solution. [10]

If unreacted C<sub>3</sub>A remains when the supply of sulfate ions runs out, then there is an outpouring in its hydration, and ettringite is progressively replaced by a monosulfate (AFm phase) C<sub>3</sub>A.CS.H<sub>12</sub>. If there is a sufficient excess of C<sub>3</sub>A, then C<sub>4</sub>AH<sub>13</sub> (C<sub>3</sub>A.CH.H<sub>12</sub>) is also produced in solid solution with the monosulfate. [7] [10]

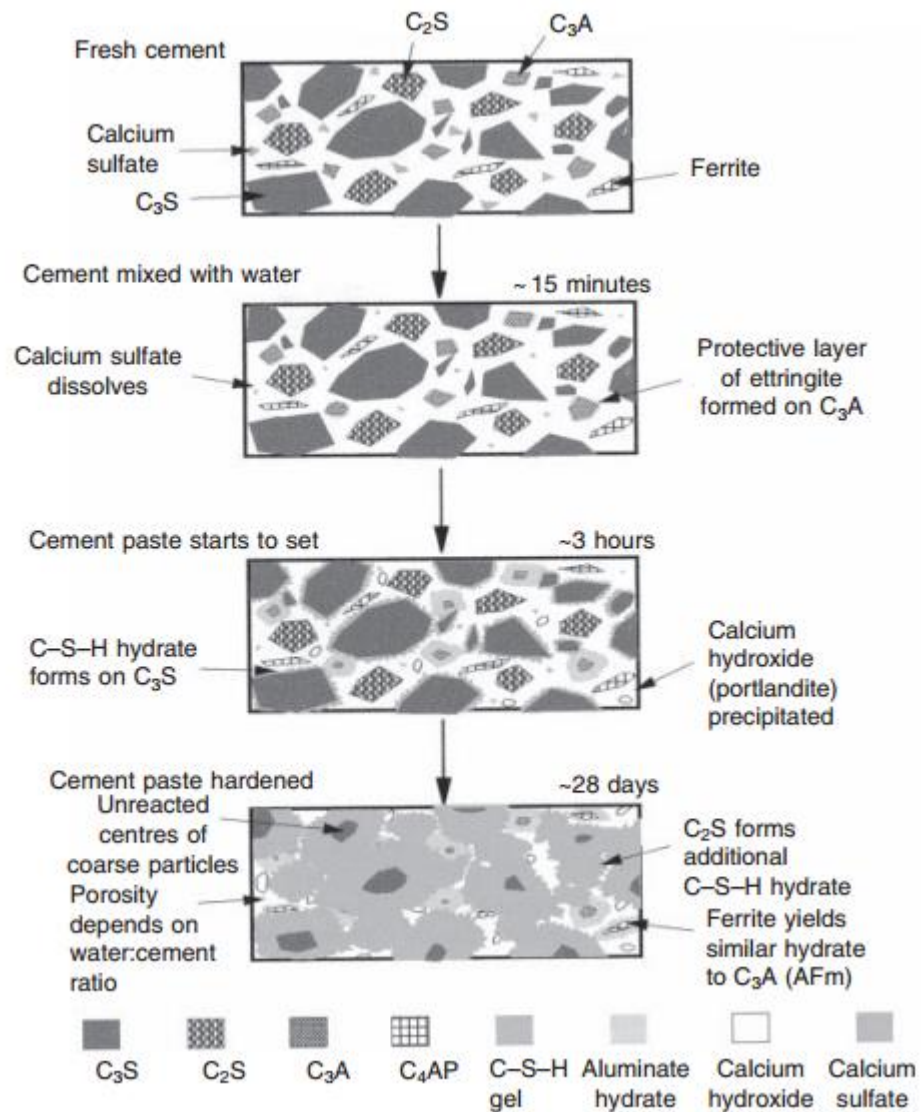


Figure 2.2<sup>5</sup>

Figure 2.3 The process of cement hydration<sup>6</sup>



**Unhydrated clinker grains:** Depending on the particle size distribution of the anhydrous cement and the degree of hydration, some unhydrated clinker grains may be found in the microstructure of hydrated cement pastes, even long after hydration.[1]

<sup>5</sup> sited from a book 'Construction materials their nature and behavior' page 92

<sup>6</sup> The picture is taken from 'Advanced Concrete Technology' book page 1/18

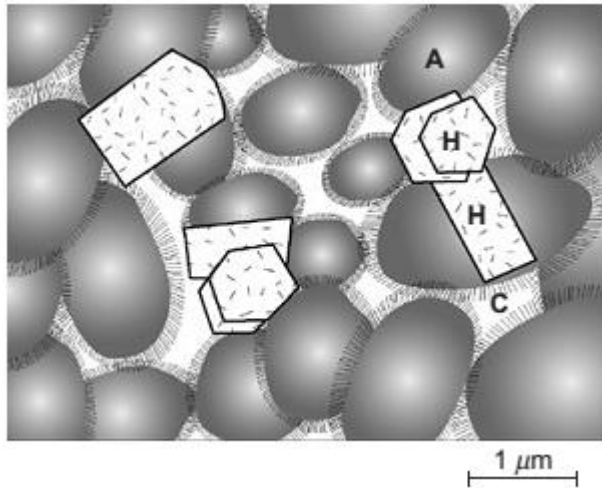


Figure 2.4 Model of a well-hydrated Portland cement<sup>7</sup>

## 2.2 Bagasse ash and its Pozzolanic activity

Bagasse is the residue from a plant or part of a plant (cane, fruits, and seeds) after its juice has been extracted. Sugarcane is the largest crop by production quantity in the world. The sugar juice is extracted from cane stalks. After extraction of the sugarcane juice, a large amount of wet bagasse is produced (30% to 34% by mass of collected sugarcane). [11] And by means of combustion, the sugar cane bagasse can be transformed into ash which can be used as a construction material with ordinary Portland cement. In sugar industry to produce supplementary power the sugar cane is combusted and SCBA waste dumped on the area. Thus the usage of consuming industrial wastes such as bagasse ash is twofold, environmental protection and economical advantage.

When mixed with ordinary Portland cement the silica of the pozzolana combines with the free lime released during the hydration of cement. This action is called pozzolanic action. The silica in the pozzolana reacts with the lime produced during hydration of Portland cement and contributes to the development of strength. Slowly and gradually additional

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<sup>7</sup>The Figure is taken from 'Microstructure and Properties of Hardened Concrete' book. "A" represents aggregation of poorly crystalline C-S-H particles. H represents hexagonal crystalline products such as  $\text{CH}=\text{C}_4\text{AH}_19=\text{C}_4\text{AS}-\text{H}_18$ . C represents capillary cavities or voids which exist when the spaces originally occupied with water do not get completely filled with the hydration products of cement.

Increasing compressive strength property of bagasse ash blended concrete by using chemical activator (NaSO<sub>4</sub>)

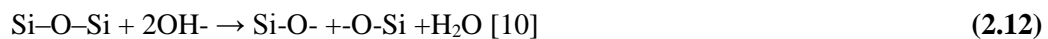
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calcium silicate hydrate is formed which is a binder and fills up the space, gives impermeability, durability and increasing strength. [5]



**The pozzolanic reaction (Eq 2.11) is are highly dependent on the hydration of portland cement(Eq 2.10)**

The basic pozzolanic reaction involves the separating of Si–O–Si and Si–O–Al bonds by hydroxyl ions. The reaction can be schematically represented by:



Kinetic analyses based on the degree of reaction of Ca(OH)<sub>2</sub> indicated that the pozzolanic reaction process in lime-pozzolan pastes could be divided into three phases: Phase I, controlled by the pozzolanic reaction rate. Phase II, controlled by the diffusion of reactants through a layer of porous hydration products; and Phase III, controlled by the diffusion of reactants through a layer of dense products. [7]

The pozzolanic reactivity of a material is predominantly depend on Physical and chemical properties of the material [11]

The most important parameters that influence the reactivity of bagasse ash are the calcination temperature, the particle size, and the presence of organic/unburned matter and soil contaminants. [11]

Good pozzolanic properties are obtained in BA with enough amount of amorphous silica, low carbon content, and high specific surface area. Burning temperature does not affect Chemical composition but it has an influence on reactive chemical content. The chemical compositions of BA showed similar result whether laboratory-controlled burning or an open-air burning is done. However, the amount of amorphous phases obtained from the controlled samples increased significantly after controlled burning when compared to uncontrolled burning conditions. [11]

Past studies reported the chemical composition of bagasse ash sample taken from wonji sugar factory.

**Table 2.3 Chemical composition of bagasse from previous studies**

	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O
Mihret G.	66.92	7.06	6.12	3.6	1.96	4.28
Biruk H.	65.58	5.87	4.32	1.78	1.23	1.02
	MnO	P <sub>2</sub> O <sub>5</sub>	TiO <sub>2</sub>	H <sub>2</sub> O	SO <sub>3</sub>	K <sub>2</sub> O
Mihret G.	0.2	0.02	0.05	0.01	0.25	4.92
Biruk H.	0.05	1.35	0.25	0.2	0.18	6.41
	LOI					
Mihret G.	3.65					
Biruk H.	10.48					

Except loss of ignition the reported amount is nearly similar. The difference in loss of ignition is may be due to unburned carbon content of the ash.

### 2.3 Activating pozzolanic reaction

To accelerate the pozzolanic reactivity of supplementary cementitious materials, different mechanisms are being studied. The methods below are prevalent.

- Increasing fineness: by prolonged grinding pozzolanic material become small in their particle size and the crystalline behavior is changed to amorphous state. Thus, reactive material is generated.
- Calcination: by controlling burning temperature when the ash is processed, pozzolanic activity can be enhanced.
- Thermal activation: curing the blended concrete in elevated temperature. Especially if Portland cement is not present or if the amount is very low, higher temperature curing with proper chemical activator results in good reactivity and high strength gain.
- Acid treatment: the precursor material will be treated before mixing. Mostly hydrochloric acid is used. Activate the chemical reaction the pozzolanic material by increase the PH OF chemical system. But it is uneconomical.
- Chemical activation: activation is held by the addition of chemicals into the mix. The reaction mechanism, the reaction time, and even the product formed can be controlled by the activator type and dosage. the type of activator used has a direct impact on the secondary products precipitating and on reaction kinetics (essentially through the pH generated in the medium), accelerating or retarding the precipitation of the main reaction products.[12] Usually, caustic

alkalis or alkaline salts are used as alkaline activators of alkali-activated cements and concretes.

### 2.3.1 Alkaline activation

Glukhovskiy et al. (1980) classified Alkali activators into six groups according to their chemical compositions:

- Caustic alkalis: MOH;
- Non-silicate weak acid salts: M<sub>2</sub>CO<sub>3</sub>, M<sub>2</sub>SO<sub>3</sub>, M<sub>3</sub>PO<sub>4</sub>, MF, etc.
- Silicates: M<sub>2</sub>O · nSiO<sub>2</sub>;
- Aluminates: M<sub>2</sub>O · nAl<sub>2</sub>O<sub>3</sub>;
- Aluminosilicates: M<sub>2</sub>O · Al<sub>2</sub>O<sub>3</sub> · (2-6) SiO<sub>2</sub>;
- Non-silicate strong acid salts: M<sub>2</sub>SO<sub>4</sub>

M represents the alkali metal element like sodium and potassium. Of all these activators, NaOH, Na<sub>2</sub>CO<sub>3</sub>, Na<sub>2</sub>O · nSiO<sub>2</sub> and Na<sub>2</sub>SO<sub>4</sub> are the most widely available and economical chemicals.[4] The alkaline activation can be grouped into two depending on the alkaline environment created namely, High alkaline activators and moderate alkaline activators.

#### 2.3.1.1 High alkaline activation

involves the breaking down of the glass phases in an elevated alkaline environment to accelerate the reaction.[4] The high alkalinity of these solutions (with pH values of over 13) favors speedy ash dissolution and favors the formation of N-A-S-H/ (N, C)-A-S-H gels to the damage of C-S-H gels and inhibits Portlandite formation. highly alkaline activators appear to adversely affect C-S-H gel stability, the kinetics of clinker calcium silicate hydration or both.[12]

The type of products formed and their characteristics depended heavily on the pH in the synthesis medium and the initial Ca/Si and Si/Al ratios. While medium-high lime content favored the formation of C-A-S-H gels, the presence of a high alumina and silica content led to the formation of an N-C-A-S-H gel. [13]

the addition of high alkaline activators breaking the Si-O and Al-O bonds and thus accelerates the rate of dissolution of Si and Al ions into the liquid phase. [12] The dissolution process is the breaking up of ionic (Ca-O) and covalent (Si-O-Si, Al-O-Al and Al-O-Si) bonds. The higher degree of ionicity of the bonds, the easier the substance is

hydrated by water.[13] Some of the chemicals that are commonly used for high alkaline activation are Ca(OH)<sub>2</sub>, NaOH, KOH and SiO<sub>2</sub> with NaOH. High alkaline activation is possible in low (less than 20%) or no cement system.

The activation mechanism is highly influenced by type of activator and mass of activator, silicon to Aluminium ratio of the precursor element, curing temperature and curing time. Bagasse ash shown an optimum result in NaOH activated mix but the concentration of the chemical is very high and also the curing temperature is not reliable on site. So that uneconomical and unsafe mix may results. [14] The advantage of alkaline activation is high strength achievement with the use of (60% to 100%) pozzolanic material. But it has its own drawbacks like not reliable curing temperature, expensive cost of activator and hostile environment when mixing.

### **2.3.1.2 Moderate alkaline activation**

C–S–H gel formation is favored by milder alkalinity. Advantage of inorganic salts over highly alkaline activators (such as NaOH) is that they have a lower impact on the hydration reaction of the clinker component in hybrid cements. In these systems, the clinker must first react with water to generate Portlandite, which then reacts with the inorganic salt to generate the respective insoluble calcium salt and sodium hydroxide, as it is indicated on the equation below. The heat released during initial OPC hydration favors and advances the dissolution of supplementary cementitious materials at high pH. [12]



The increase in pH of reaction environment is generated because activators can react with Ca(OH)<sub>2</sub> arising in cement hydration. Solid products of the reaction are precipitated CaSO<sub>4</sub> for the case of or NaSO<sub>4</sub> activated system or CaCO<sub>3</sub> for the case of NaCO<sub>3</sub> activated system and alkaline hydroxide (e.g., NaOH in the case of sodium salts) is formed.[15]

The Ettringite formed at the early stage of hydration in fly ash–cement pastes is increased with the addition of Na<sub>2</sub>SO<sub>4</sub> and K<sub>2</sub>SO<sub>4</sub> since the SO<sub>4</sub><sup>2-</sup> ions will react with tricalcium aluminate, C<sub>3</sub>A. [16]

Sulfate activation is based on the ability of sulfates to react with aluminium oxide in the glass phase of fly ash to form sulfates (AFt) that contributes to strength at early ages. [17]

Increasing compressive strength property of bagasse ash blended concrete by using chemical activator ( $\text{Na}_2\text{SO}_4$ )

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Alkali sulphates are efficient and cost-effective activators when Portland cement or cement clinker content is  $>20\%$ . [4]

### **Sodium sulphate activation**

Sodium sulphate, also known as disodium sulphate ( $\text{Na}_2\text{SO}_4$ ), in its natural form is found in two principal minerals: thenardite (anhydrous  $\text{Na}_2\text{SO}_4$ ) and mirabilite ( $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ ). Thenardite contains 43.68%  $\text{Na}_2\text{O}$  and 56.32%  $\text{SO}_3$ . It ranges from colourless to white and may be tinted shades of grey or brown. It has a specific gravity of 2.67 and a solubility of 15.9% by mass in water at  $20^\circ\text{C}$ . It commonly occurs in the massive form without visible crystals. Its crystals are frequently tabular pyramids of the orthorhombic system. It has a melting point of  $882^\circ\text{C}$  and decomposition temperature of  $1100^\circ\text{C}$ . Its pH values range from 6.0 to 9.0 for 1% solution.

Increasing compressive strength property of bagasse ash blended concrete by using chemical activator (NaSO<sub>4</sub>)

Table 2.4 Summary of sodium sulphate bearing minerals<sup>8</sup>

Mineral	Chemical formula	% Na <sub>2</sub> SO <sub>4</sub>
Thenardite (anhydrous)	Na <sub>2</sub> SO <sub>4</sub>	100
Hanksite	9Na <sub>2</sub> SO <sub>4</sub> · 2Na <sub>2</sub> CO <sub>3</sub> · KCl	81.7
D'ansite	9Na <sub>2</sub> SO <sub>4</sub> · MgSO <sub>4</sub> · 3NaCl	81.2
Lecontite	(Na, NH <sub>4</sub> , K) <sub>2</sub> SO <sub>4</sub> · 2H <sub>2</sub> O	<79.8
Vanthoffite	3Na <sub>2</sub> SO <sub>4</sub> · MgSO <sub>4</sub>	78
Hectorfloresite	4Na <sub>2</sub> SO <sub>4</sub> · CaClO <sub>3</sub>	74.1
Sulphohalite	2Na <sub>2</sub> SO <sub>4</sub> · NaCl · NaF	73.9
Burketite	Na <sub>6</sub> (SO <sub>4</sub> ) <sub>2</sub> (CO <sub>3</sub> )	72.8
Eugsterite (Fritzsche's salt)	2Na <sub>2</sub> SO <sub>4</sub> · CaSO <sub>4</sub> · 2H <sub>2</sub> O	62.3
Darapskite	NaNO <sub>3</sub> · Na <sub>2</sub> SO <sub>4</sub> · H <sub>2</sub> O	58.0
Hydro-glauberite	5Na <sub>2</sub> SO <sub>4</sub> · 3CaSO <sub>4</sub> · 6H <sub>2</sub> O	57.9
Glauberite	Na <sub>2</sub> SO <sub>4</sub> · CaSO <sub>4</sub>	51.1
Loeweite	MgSO <sub>4</sub> · Na <sub>2</sub> SO <sub>4</sub> · 2.5H <sub>2</sub> O	46.2
Ferrinatrite	3Na <sub>2</sub> SO <sub>4</sub> · Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> · 6H <sub>2</sub> O	45.6
Mirabilite (Glauber's salt)	Na <sub>2</sub> SO <sub>4</sub> · 10H <sub>2</sub> O	44.1
Bleodite (Astrakanite)	MgSO <sub>4</sub> · Na <sub>2</sub> SO <sub>4</sub> · H <sub>2</sub> O	42.5
Kroehnkite	CuSO <sub>4</sub> · Na <sub>2</sub> SO <sub>4</sub> · 2H <sub>2</sub> O	42.1
Nickelbloedite	Na <sub>2</sub> Ni(SO <sub>4</sub> ) <sub>2</sub> · 4H <sub>2</sub> O	40.3
Sideronatrite	Na <sub>2</sub> Fe(SO <sub>4</sub> ) <sub>2</sub> · (OH) · 3H <sub>2</sub> O	38.9
Caracolite	Pb(OH)Cl · Na <sub>2</sub> SO <sub>4</sub>	35.4
Palmierite	(K, Na) <sub>3</sub> Na(SO <sub>4</sub> ) <sub>2</sub>	<31.9
Tychite	2MgCO <sub>3</sub> · 2Na <sub>2</sub> CO <sub>3</sub> · NaSO <sub>4</sub>	27.2
Aphthitalite (glaserite)	(K, Na) <sub>3</sub> · Na(SO <sub>4</sub> ) <sub>2</sub>	21–38
Tamarugite	Na <sub>2</sub> SO <sub>4</sub> · Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> · 12H <sub>2</sub> O	20.3
Natrochalcite	Cu <sub>4</sub> (OH) <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> · Na <sub>2</sub> SO <sub>4</sub> · 2H <sub>2</sub> O	18.8
Almeriite	Na <sub>2</sub> SO <sub>4</sub> · Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> · 5Al(OH) <sub>3</sub> · H <sub>2</sub> O	15.9
Mendozite (soda alum)	Na <sub>2</sub> SO <sub>4</sub> · Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> · 24H <sub>2</sub> O	15.5
Natrojarosite	Na <sub>2</sub> Fe <sub>6</sub> (OH) <sub>12</sub> (SO <sub>4</sub> ) <sub>4</sub>	14.7
Noselite	3Na <sub>2</sub> Al <sub>2</sub> Si <sub>2</sub> O <sub>8</sub> · Na <sub>2</sub> SO <sub>4</sub>	14.3
Slavikite	(Na, K) <sub>2</sub> SO <sub>4</sub> · Fe <sub>10</sub> (OH) <sub>6</sub> (SO <sub>4</sub> ) <sub>12</sub> · 63H <sub>2</sub> O	<4.6

The main sodium sulphate deposits are in China, Mexico, Canada, the United States, the former USSR and Spain. Less important are Argentina, Chile, Iran and Turkey.

Na<sub>2</sub>SO<sub>4</sub> increased the production of ettringite in fly ash – cement pastes at early age—a result of the sulfate reaction between SO<sub>4</sub><sup>2-</sup> and C<sub>3</sub>A. [18]

The addition of Na<sub>2</sub>SO<sub>4</sub> to fly ash cement increases the alkalinity of the solution and the dissolution of fly ash during initial stages, and accelerates the pozzolanic reaction between lime and fly ash. Also it results in the formation of more ettringite, which results in a significant solid volume increase, a less porous structure and higher strength. [17]

<sup>8</sup> The table is taken from a book 'Alkali-Activated Cements and Concretes'

Increasing compressive strength property of bagasse ash blended concrete by using chemical activator ( $\text{Na}_2\text{SO}_4$ )

The sulfate activation mechanism is as follows: (1) incorporating sulfate activators into pozzolan-cement pastes accelerates the reduction of  $\text{Ca}(\text{OH})_2$  at early ages. (2) The amount of ettringite (AFt) produced in pozzolan-cement pastes containing activators increases at early ages by breaking down the glass phases in an elevated alkaline environment. (3) The addition of sulfate activators into pozzolan-cement pastes changes the pore distribution, resulting in smaller pore size and lower porosity. The addition of activators increases the early-age strength of fly ash mortar; however, later-age strength is not increased when compared to fly ash mortar without activators. [16]

The addition of  $\text{Na}_2\text{SO}_4$  mainly accelerated the consumption of lime during the first day and did not affect pozzolanic reaction thereafter. [7]

The following figures are representative results which show the development of strength in sodium sulphate activated cement fly ash blend. Also indicates the chemical activation promotes reactivity and achieve higher strength than the reactivity gain by grinding the ash. However if both activations are operational it results higher strength gain as it is seen on the figure.

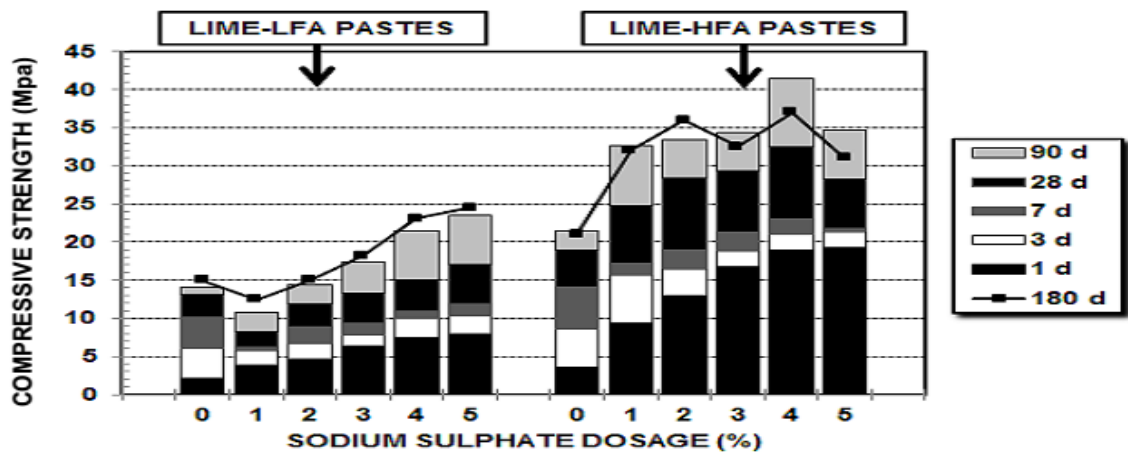


Figure 2.5 The strength development of cement fly ash blended paste<sup>9</sup>

<sup>9</sup> Sited from a journal 'The effect of various chemical activators on pozzolanic reactivity: A review' The abbreviations LFA and HFA are stands for low volume fly ash and high volume fly ash respectively

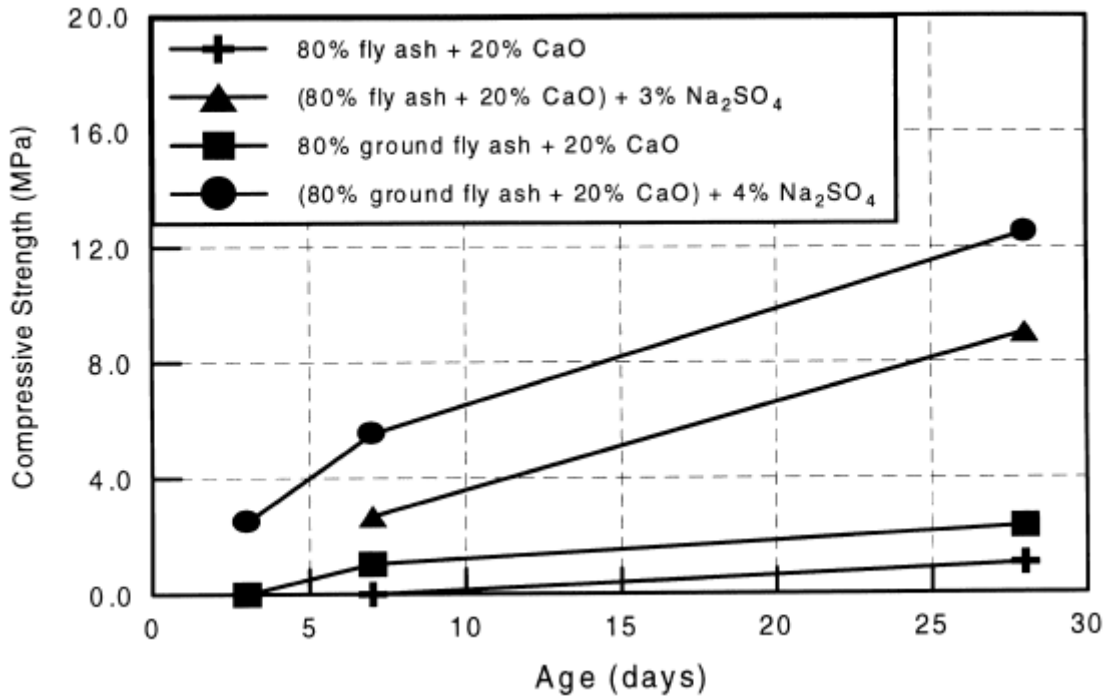


Figure 2.6 The strength development of cement fly ash blended paste<sup>10</sup>

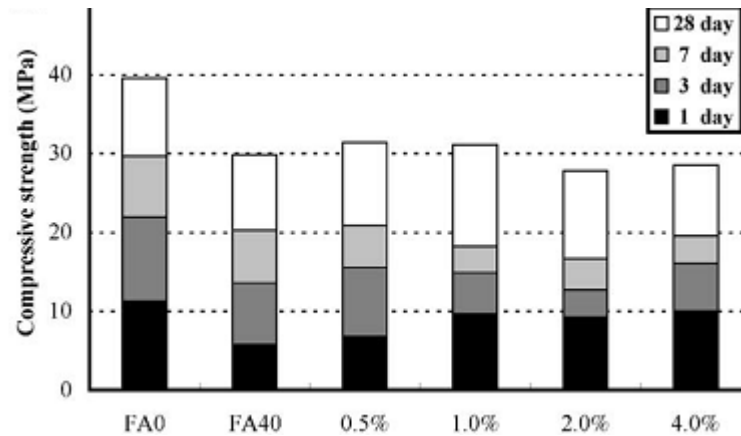


Figure 2.7 Compressive strength of chemically activated fly ash mortars with  $\text{Na}_2\text{SO}_4$ <sup>11</sup>

<sup>10</sup> Sited from a journal 'Activation of blended cements containing fly ash'

<sup>11</sup> Sited from a journal 'Strength and microstructural characteristics of chemically activated fly ash-cement systems' the chart indicate the strength of a control mortar as well as fly ash blended mortar with no activator addition, with addition of sodium sulfate 0.5%, 1%, 2%, 4% by weight of binder.

## CHAPTER 3 MATERIAL USED AND THEIR RESPECTIVE MATERIAL PROPERTIES DETERMINATION

The materials used are ordinary Portland Cement (OPC), bagasse ash, chemical activator (sodium sulfate), aggregate (coarse and fine) and water.

### 3.1 Ordinary Portland cement (OPC)

Ordinary Portland cement of grade 42.5 manufactured by Dangote cement factory is used for cement paste, mortar and concrete casting. The blain air fineness test is held in accordance with ASTM C 204[19] in AAiT chemical laboratory. The weight of the cement used for the test was 2.91g. Surface area and time of standard cement are 3774cm<sup>2</sup>/g and 37.8second. And the fineness results 5940cm<sup>2</sup>/g. Normal consistency and setting time of the cement is also done following the procedure of ASTM C 187[20] and ASTM C191[21] respectively. Consistency results 25%, initial setting time is 135 minutes and the final setting time is 240 minutes. Thus it the fulfill the minimum and the maximum required time of set greater than 60 min and less than 600min specified on ASTM.



Figure 3.1 Determination of fineness by blain air apparatus

### 3.2 Sugar cane bagasse ash

The bagasse ash used for this research was taken from Wonji Sugar factory. It was exposed to rainwater during the storage. In order to avoid the moisture, the bagasse is dried in oven for more than 24hour at 105<sup>0</sup>C. And after it is sieved to pass 300µm, blain air fineness and density tests are done according to ASTM C 204[19] and ASTM C 188[22] respectively. For air permeability test 1.85g bagasse is used and for density test 42g is used. Chemical test is done at geological survey of Ethiopia. Test result is seen on the table below. Xrd analysis test is done on Addis Ababa Science and Technology University chemical lab, from Xrd analysis test result it can be understood the bagasse contains some amount of crystalline silcon oxide.

**Table 3.1 Chemical and physical properties of bagasse ash**

Chemical composition							
Fineness	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O
1895.9cm <sup>2</sup> /g	75.98	11.54	2.28	1.12	0.6	0.64	1.92
Density	MnO	P <sub>2</sub> O <sub>5</sub>	TiO <sub>2</sub>	H <sub>2</sub> O	LOI		
2.0g/cm <sup>3</sup>	<0.01	0.42	0.09	1.1	5.81		

### 3.3 Aggregate

Ordinary sand washed and sieved to pass 4.75mm is used for mortar and concrete mixes. The sand is washed because the silt content was above the acceptable range. And coarse aggregate of nominal maximum size 25mm is used for concrete casting. Silt content, dry rodded mass, sieve analysis, and specific gravity tests are done to determine various



**Figure 3.2 Specific gravity test for fine aggregate**

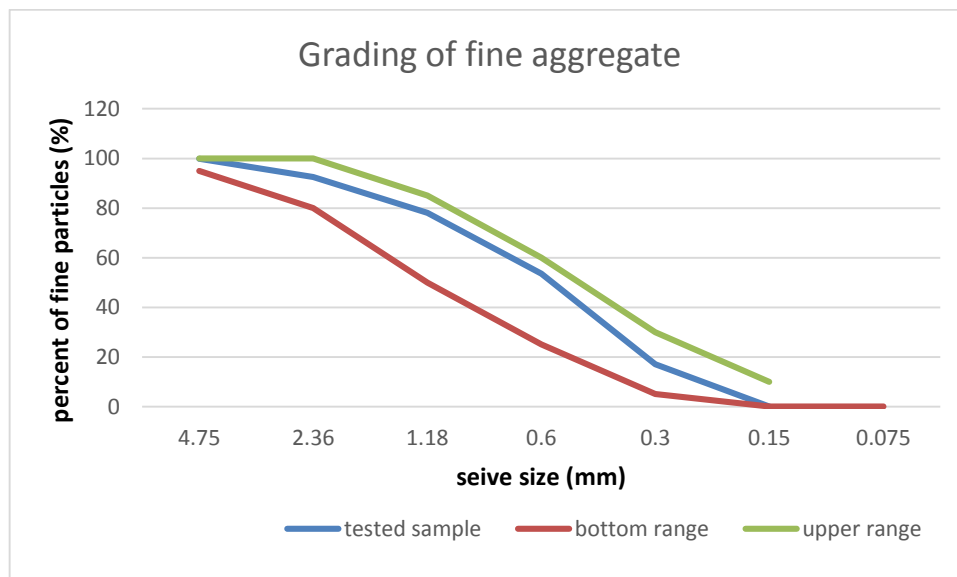
Increasing compressive strength property of bagasse ash blended concrete by using chemical activator (NaSO<sub>4</sub>)

material properties of both fine and coarse aggregates. The results are indicated on the table and the figures below.

**Table 3.2 Physical properties of fine and coarse aggregate**

Test		Coarse aggregate	Fine aggregate	The specification used
specific gravity	Bulk	2.48	2.19	ASTM C 127[23] (for CA) and ASTM C 128 (for FA)[24]
	Bulk (SSD)	2.5	2.3	ASTM C 127[23] (for CA) and ASTM C 128(for FA)[24]
	Apparent	2.53	2.4	ASTM C 127[23] (for CA) and ASTM C 128(for FA)[24]
Absorption		0.86	6.22	ASTM C 127[23] (for CA) and ASTM C 128(for FA)[24]
Silt content			3%	
Fineness Modulus		7.6	3.57	ASTM C 136[25]
Dry rodded Unit weight (Kg/m <sup>3</sup> )		1340		ASTM C 29

The higher FM of fine aggregate indicate the sand become courser because when the sand is washed to avoid the silt, very fine size particles are washed in the process.



**Figure 3.3 Particle size distribution of fine aggregate**

Increasing compressive strength property of bagasse ash blended concrete by using chemical activator ( $\text{NaSO}_4$ )

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### 3.4 Water

Tap water of Addis Ababa university institute of Technology was used in all mixes

### 3.5 Activator

A white powder sodium sulfate anhydrous is used as an activator. The product is imported and packed by Ranchem industry and Trading Company. From the information specified on the product it is known that the chemical contain 0.05% substances insoluble in Nitric acid, 0.005% Antimony and 0.0002%.

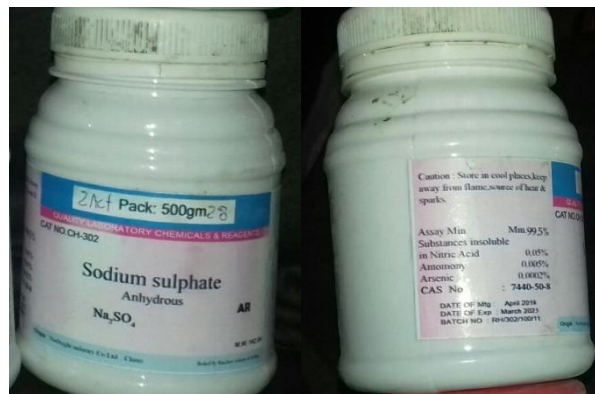


Figure 3.4 Chemical activator

## CHAPTER 4 EXPERIMENTAL PROCEDURE

### 4.1 Mix design

In order to prepare compressive strength cube samples and Xrd test powdered sample, mix design of cement paste, mix design of mortar and mix design of concrete is done. Mix design of cement paste was done for 7 mixes and each mix is done for 3 cubes size 70\*70\*70mm<sup>3</sup>. Mix design of mortar is done for 7 mixes and each mix is done for 3 cubes size 70\*70\*70mm<sup>3</sup>. Mix design of concrete is done for 7 mixes and each mix is done for 9 cubes size 100\*100\*100mm<sup>3</sup>.

#### 4.1.1 Mix design of paste

Amount of cement and water is calculated by the formula below. The selected water to cementitious material ratio is much more than consistency demand. i.e 0.4. Because for lesser water to cementitious material ratio, the mix becomes stiff and the mixer cannot mix properly.

$$V = \frac{mc}{3150} + \frac{0.4mc}{1000} \quad (4.1)$$

V is the total volume for one mix and since water to cementitious material ratio is 0.4, mw = 0.4mc. The first part of the equation stands for volume of cement and the second part stands for volume of water. After determining mass of cement, mass of water is determined. Following the procedure of ASTM C 305[28] mixes are prepared. Bagasse and cement are mixed in a sack prior to mixing. For mixes with activator, before adding the cementitious material, sodium sulfate is diluted in the mixing water first.

When mixing is over, the specimen was molded in 70\*70\*70mm cube and vibrated for 5second on a vibration table. A total of 54 cubes casted. After 24 hours the cubes were demolded and cured in water bath until tested.



**Figure 4.1 Mortar mixing**

**Table 4.1 Mix ratio of cement paste**

	Wt of water(g) For 3 cubes	Wt of cement (g) For 3 cubes	Wt of bagasse (g) For 3 cubes	Wt of activator (g) For 3 cubes
Mix 1(control)	632	1580	0	0
Mix 2(10BA0AC)	632	1475.7	104.3	0
Mix 3(10BA2AC)	632	1475.7	104.3	31.6
Mix 4(20BA0AC)	632	1363.5	216.5	0
Mix 5(20BA2AC)	632	1363.5	216.5	31.6
Mix 6(30BA0AC)	632	1241.9	338.1	0
Mix 7(30BA2AC)	632	1241.9	338.1	31.6



**Figure 4.2 Molded fresh cement paste**

#### **4.1.2 Mix design of mortar**

Mortar mix is done by selecting water to cementitious material ratio and sand to cementitious material ratio on the basis of ASTM recommendation for strength index calculation, i.e. 0.485 and 2.75 respectively. From Physical test specific gravity of fine aggregate is found. And By using the formula below the proportion of cement, sand and water is determined.

$$v = \frac{mc}{3150} + \frac{0.485mc}{1000} + \frac{2.75mc}{2200} \quad (4.2)$$

The first part of the equation stands for volume of cement, the second part stands for volume of water and the third is for volume of sand. Bagasse ash replacement is done by using the formula above (Equation 13). A total of 54 cubes of dimension 70\*70\*70mm<sup>3</sup> is casted. Mixing and curing is done in the same manner as to the paste.

**Table 4.2 Mix ratio of mortar**

	Wt of fine aggregate (g) For 3 cubes	Wt of water(g) For 3 cubes	Wt of cement (g) For 3 cubes	Wt of bagasse (g) For 3 cubes	Wt of activator (g) For 3 cubes
Mix 1(control)	1516.6	267.5	551.5	0	0
Mix 2(10BA0AC)	1516.6	267.5	515.1	36.4	0
Mix 3(10BA3AC)	1516.6	267.5	515.1	36.4	16.5
Mix 4(20BA0AC)	1516.6	267.5	475.9	75.6	0
Mix 5(20BA3AC)	1516.6	267.5	475.9	75.6	16.5
Mix 6(30BA0AC)	1516.6	267.5	433.5	118	0
Mix 7(30BA3AC)	1516.6	267.5	433.5	118	16.5

#### **4.1.3 Mix design of concrete**

The trial mix is prepared according to ACI mix design procedure.

From physical tests, fine and coarse aggregate material properties below are determined.

Specific gravity of CA = 2.48

Absorption of CA = 0.86%

Dry rodded Unit weight of CA = 1340Kg/m<sup>3</sup>

Nominal maximum size of CA = 25mm

Specific gravity of FA = 2.19

Absorption of FA= 6.22%

Fineness modulus of FA = 3.57

And the concrete intended to withstand 30Mpa compressive load at 28 days. The slump of the control mix is intended to be higher (greater than 75mm), in order to have a workable mix on a higher replacement of cement.[26]

Increasing compressive strength property of bagasse ash blended concrete by using chemical activator (NaSO<sub>4</sub>)

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Following the procedure of ACI standard practice mix proportion is calculated on an absolute volume basis, and a trial mix is prepared. Slump test and compressive strength test at 7day are done. Little modification is made towards the mix in order to fix the slump and finally the desired strength and slump is achieved for the control mix. One day prior to casting moisture content determination is done for both fine and coarse aggregate according to ASTM and Moisture adjustment is done on each mix. Proportion of bagasse is done by substituting 10, 20 and 30 percent by volume of cement. ACI recommends the formula below to change the volume substitution into weight percentage.



**Figure 4.3 Slump of the control concrete and 30%BA concrete**

$$Fw = \frac{1}{1 + \left(\frac{3.15}{Gp}\right) * \left(\frac{1}{Fv} - 1\right)} \quad (4.3)$$

Fw is pozzolan percentage by weight of the total weight of cement plus pozzolan expressed as a decimal factor

Gp is specific gravity of pozzolanic material, 2.0

And Fv pozzolan percentage by absolute volume of the total absolute volume of cement plus pozzolan expressed as a decimal factor.

Increasing compressive strength property of bagasse ash blended concrete by using chemical activator (NaSO<sub>4</sub>)

Thus, 10% by volume is equal to 6.6% by weight; similarly for 20% by volume will be 13.7% by weight and 30% by volume will be 21.4% by weight.

**Table 4.3 Conversion factor of bagasse ash volume in mass**

	Percent replacement of cement	coefficient of bagasse ash	Activator Addition for paste (in percent of binder)	Activator Addition for mortar and concrete (in percent of binder)
Mix 1(control)	0%	0	0	0
Mix 2(10BA0AC)	10%	0.066	0	0
Mix 3(10BA2/3AC)	10%	0.066	2	3
Mix 4(20BA0AC)	20	0.137	0	0
Mix 5(20BA2/3AC)	20	0.137	2	3
Mix 6(30BA0AC)	30	0.214	0	0
Mix 7(30BA2/3AC)	30	0.214	2	3

In determining the water to cementitious material ratio equivalent weight approach is used even though it compromises the issue of workability. Because, equivalent absolute volume approach influences the strength property, by varying the amount of water or by reducing the total weight of cementitious material in a mix. In equivalent weight approach, the total weight of pozzolanic materials remains the same  $w/(c + p) = w/c$  and the total absolute volume of cement plus pozzolanic materials will normally be slightly greater.

Concrete mixes are prepared on the basis of the procedure of ASTM C 192[27]. For sodium sulfate activated mixes, after adding some water into coarse aggregate, the remaining water is mixed to the activator thoroughly until the activator is fully diluted. And after, cement, sand and the water with the activator mixed for 1 minute. Cube specimen of size 100\*100\*100mm<sup>3</sup> were prepared for compressive strength test. The molds were vibrated in a vibration table and after 24hour they are demoulded and kept cured in water curing tank until tested.

**Table 4.4 Mix ratio of concrete**

	Wt of coarse aggregate (kg)	Wt of fine aggregate (kg)	Wt of water (kg)	Wt of cement (kg)	Wt of bagasse (kg)	Wt of activator (kg)
Mix 1(control)	31.23	21.25	5.46	11	0	0
Mix 2(10BA0AC)	31.23	21.25	5.46	10.274	0.726	0
Mix 3(10BA3AC)	31.23	21.25	5.46	10.274	0.726	0.33
Mix 4(20BA0AC)	31.23	21.25	5.46	9.493	1.507	0
Mix 5(20BA3AC)	31.23	21.25	5.46	9.493	1.507	0.33
Mix 6(30BA0AC)	31.23	21.25	5.46	8.646	2.354	0
Mix 7(30BA3AC)	31.23	21.25	5.46	8.646	2.354	0.33

## **4.2 Compressive strength tests**

A total of 54 cubes bagasse ash blended cement pastes were casted to study the compressive strength of blended paste with and without activator. Similarly a total of 54 cubes to study the compressive strength behavior of blended mortar and also a total of 54 concrete cubes casted to study the compressive strength blended concrete. A 3day,7day and 28 day compressive strength test is done for cement paste, mortar and concrete cubes.



**Figure 4.4 Cubes for compressive strength determination**

The tests for the determination of the compressive strength of paste and mortar cubes were carried out according to methods specified by ASTM C 109 [29] by AUTOMAX5 Controls Model 51 machine. For mortar cubes, strength activity index is calculated according to ASTM C311. As specified on ASTM C311, The test for strength activity index is used to determine whether fly ash or natural pozzolan results in an acceptable level of strength development when used with hydraulic cement in concrete. Since the test is performed with mortar, the results may not provide a direct correlation of how bagasse ash or the activator will contribute to strength in concrete.

The tests for the determination of the compressive strength of concrete cubes were carried out according to methods specified by ASTM C 39 by AUTOMAX5 Controls Model 51 machine



**Figure 4.5 Compressive strength test for mortar cube**

### **4.3 X-ray diffraction tests**

Bagasse ash cement blended paste is casted and molded and after curing for 7 days and 28 days it is crushed and grinded to  $32\mu\text{m}$  sieve size to determine X ray diffraction curve. A total of 4 samples prepared to compare the chemical reaction with and without the presence activator. The samples were scanned by BTX model 528 Xrd machine in the range of  $5-50^\circ 2\theta$  and the integration time was 150 seconds for each sample.



**Figure 4.6** Crushed cement sample for Xrd analysis

All samples had the same water to binder ratio and the same bagasse to cement ratio. The controlled parameters are activator amount and curing days.

**Table 4.5** Xrd test samples

	Activator to binder ratio (%)	Curing days
Sample 1	0	7
Sample 2	2	28
Sample 3	0	7
Sample 4	2	28



**Figure 4.7** Xrd test of grounded hydrated cement

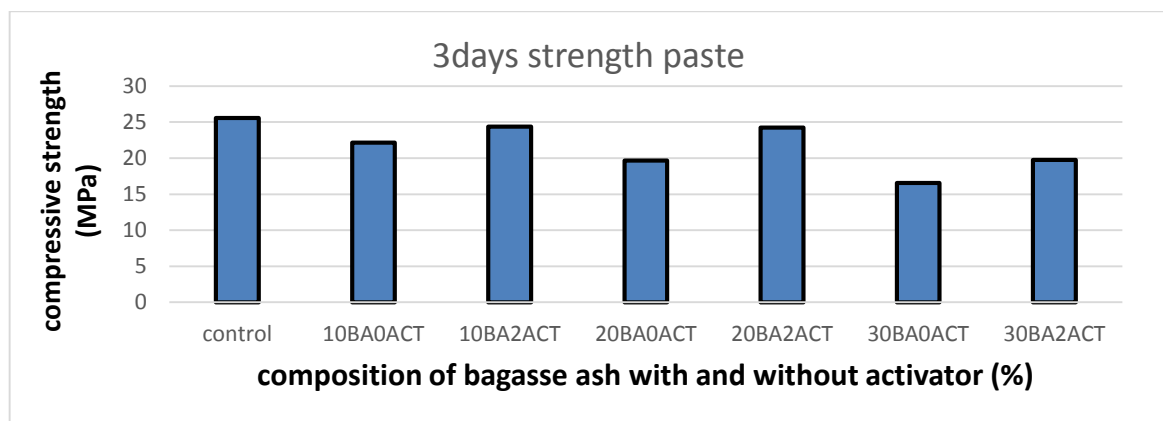
Using the pure calcium hydroxide Xrd result as reference data the amount of calcium hydroxide in blended cement pastes was comparatively observed.

## CHAPTER 5 RESULT AND DISCUSSION

### 5.1 Compressive test result

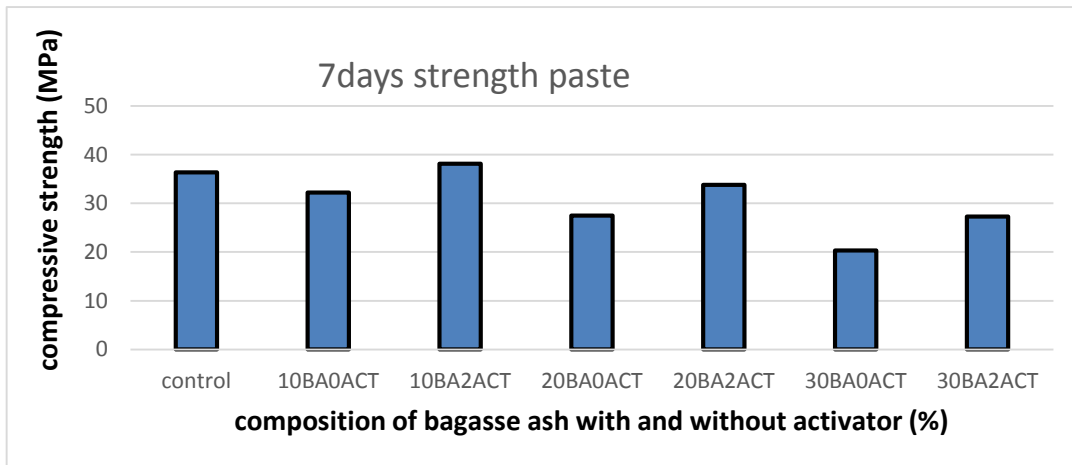
Graphs below show the effect of Na<sub>2</sub>SO<sub>4</sub> on compressive strength development of 10% 20% 30% bagasse ash blended cement paste, mortar, and concrete cube at different ages. It is observed that the addition of activator increases the compressive strength of paste, mortar and concrete cubes. From previous researches the replacement of 10% of cement by bagasse ash results little increment[2][3]. But in this study, the result has shown a little reduction in strength. This may be due to the fineness of the bagasse used (the bagasse is coarser). As researches discuss the fineness of bagasse influence the chemical reaction of pozzolan because the finer the bagasse, the higher the amorphous silica content and results in C-S-H formation by promoting a reaction between calcium hydroxide from cement hydration and silicon oxide from the bagasse.

#### Percent increment of paste.



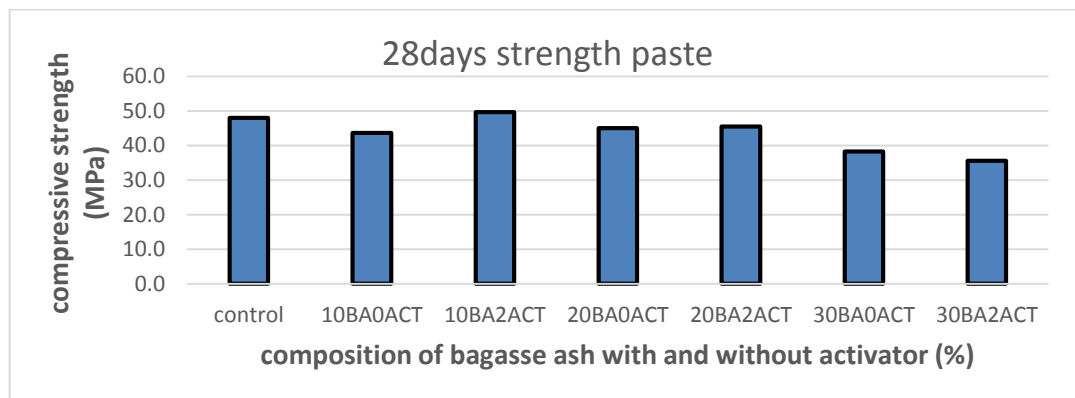
**Figure 5.1 Average 3day compressive strength of cement paste**

At 3days age, the addition of 2% activator by weight of binder has a 12.5% increase on 10% replacement of bagasse ash mix, 23.2% increase on 20% replacement of bagasse ash mix, 19.3% increase on 30% replacement of bagasse ash mix.



**Figure 5.2 Average 7day compressive strength of cement paste**

At 7days age, the addition of 2% activator by weight of binder has 12.2% increase on 10% replacement of bagasse ash mix, 22.9% increase on 20% replacement of bagasse ash mix, 34.2% increase on 30% replacement of bagasse ash mix.

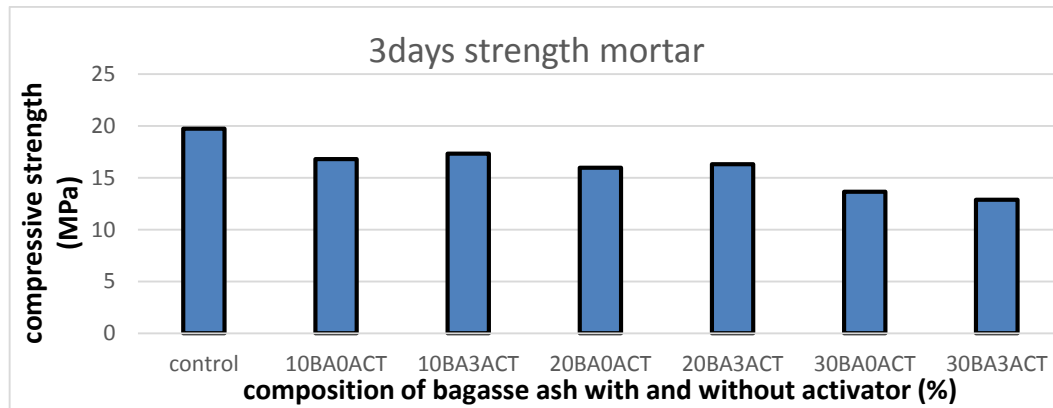


**Figure 5.3 Average 28day compressive strength of cement paste**

At 28days age, the addition of 2% activator by weight of binder has an 13.7% increase on 10% replacement of bagasse ash mix, 1% increase on 20% replacement of bagasse ash mix, 7.1% decrease on 30% replacement of bagasse ash mix.

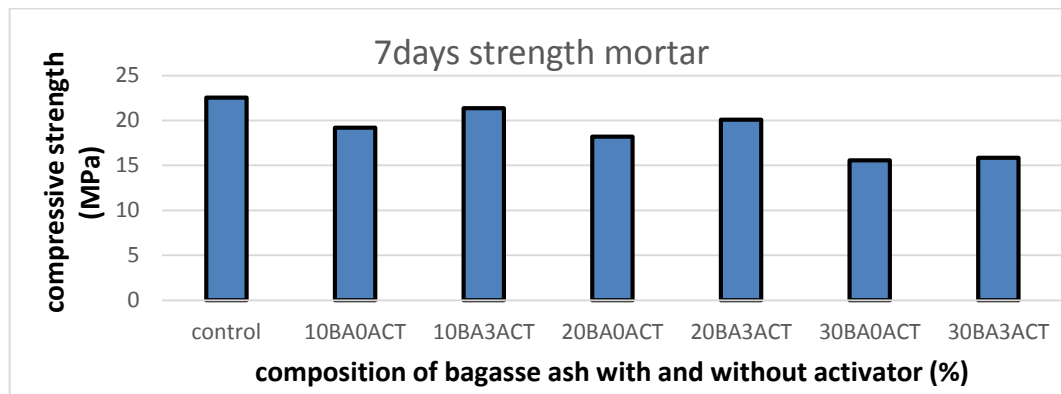
The presence of activator enhances the compressive strength of paste especially at early age. This is due to the increase in ettringite formation because of reaction of Aluminates in cement and sulfate ion from the activator and the increased formation of C-S-H gel by the reaction of bagasse and calcium hydroxide in high PH environment created by the activator at early ages.

### Percent increment of Mortar



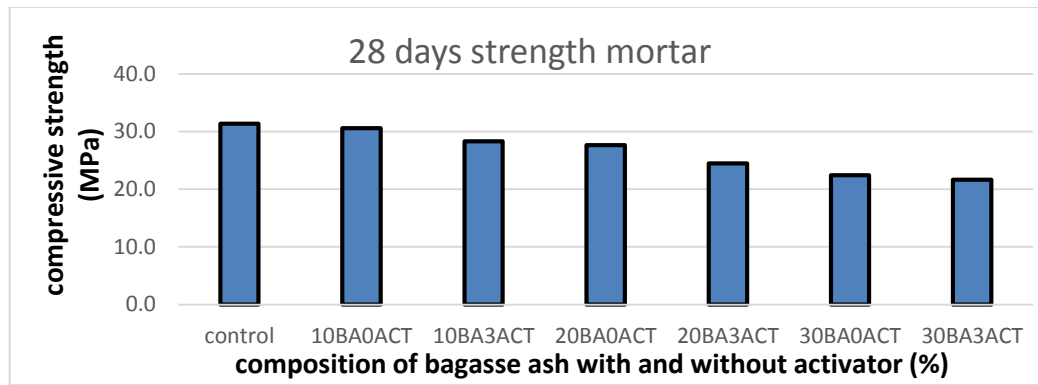
**Figure 5.4 Average 3day compressive strength of mortar**

At 3days age, the addition of 3% activator by weight of binder has a 3.1% increase on 10% replacement of bagasse ash mix, 10.6% increase on 20% replacement of bagasse ash mix, 6.1% decrease on 30% replacement of bagasse ash mix.



**Figure 5.5 Average 7day compressive strength of mortar**

At 7days age, the addition of 3% activator by weight of binder has a 16.5% increase on 10% replacement of bagasse ash mix, 10.3% increase on 20% replacement of bagasse ash mix, 2.0% increase on 30% replacement of bagasse ash mix.



**Figure 5.6 Average 28day compressive strength of mortar**

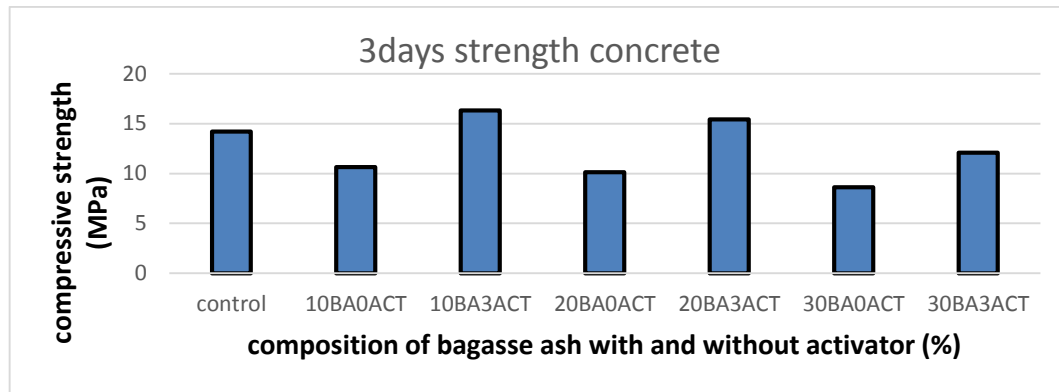
At 28days age, the addition of 3% activator by weight of binder has a 7.5% decrease on 10% replacement of bagasse ash mix, 11.4% decrease on 20% replacement of bagasse ash mix, 3.4% decrease on 30% replacement of bagasse ash mix.

**Table 5.1 Strength activity index**

Strength activity index calculation according to ASTM C311					
	7days strength			28days strength	
	MPa	SAI		MPa	SAI
control	22.5		control	31.4	
10BA0ACT	18.3	81.4	10BA0ACT	30.6	81.4
10BA3ACT	21.4	94.8	10BA3ACT	28.3	75.3
20BA0ACT	18.2	80.8	20BA0ACT	27.7	73.6
20BA3ACT	20.1	89.1	20BA3ACT	24.5	65.2
30BA0ACT	15.6	69.0	30BA0ACT	22.4	59.6
30BA3ACT	15.9	70.4	30BA3ACT	21.7	57.6

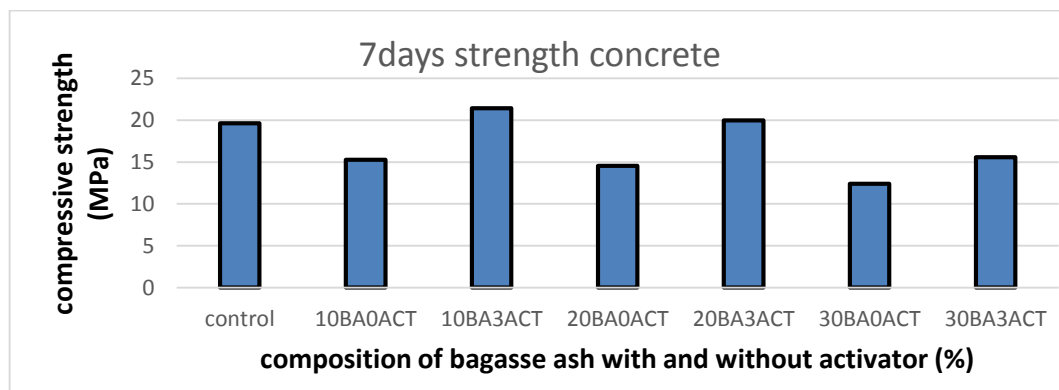
At early age the presence of activator show positive affection but at later age the presence of activator affect the compressive strength of mortar cubes negatively, this is due to the ettringite transformation into mono sulphate at later ages.

### Percent increment of Concrete



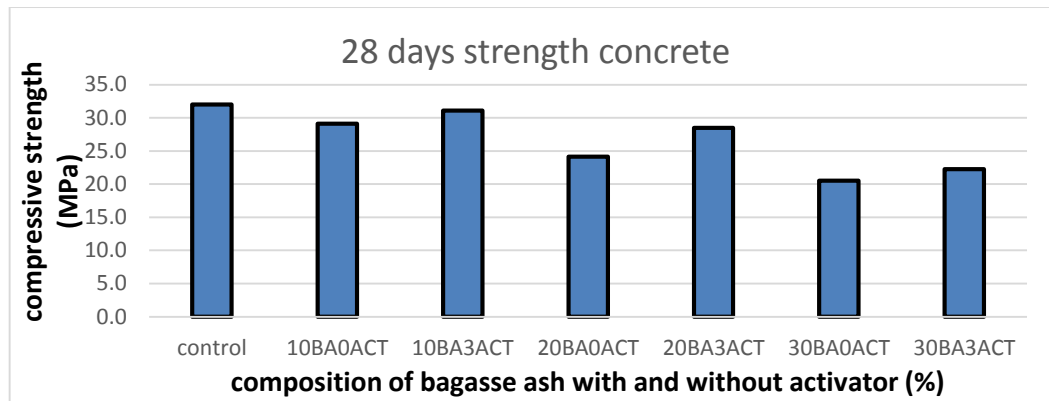
**Figure 5.7 Average 3day compressive strength of concrete**

At 3days age, the addition of 3% activator by weight of binder has a 49.4% increase on 10% replacement of bagasse ash mix, 44.8% increase on 20% replacement of bagasse ash mix, 40.1% increase on 30% replacement of bagasse ash mix.



**Figure 5.8 Average 7day compressive strength of concrete**

At 7days age, the addition of 3% activator by weight of binder has a 18.4% increase on 10% replacement of bagasse ash mix, 14.8% increase on 20% replacement of bagasse ash mix, 25.3% increase on 30% replacement of bagasse ash mix.



**Figure 5.9 Average 28day compressive strength of concrete**

At 28days age, the addition of 3% activator by weight of binder has a 40.3% increase on 10% replacement of bagasse ash mix, 6.9% increase on 20% replacement of bagasse ash mix, 8.6% increase on 30% replacement of bagasse ash mix. Generally the compressive strength of concrete cubes is increased significantly when 3% sodium sulphate by mass of binder is used and the variation is greater at early ages.

## 5.2 X – Ray diffraction analysis test result

As it is indicated on appendix F, on the ranges of pure calcium hydroxide Xrd patterns peak pastes cured for 28 days show lesser peaks compared to the pastes cured for 7 days. And with the presence of activator decrement of peaks were shown. This indicates the pozzolanic reaction of bagasse ash is increased with increase of curing day and also with the presence of activator.

### **6.1 Conclusion**

This study has investigated the early strength development of bagasse ash blended cement containing 10%, 20%, and 30% bagasse ash content by volume of cement in the presence of sodium sulfate as an activator. The reaction of sugar cane bagasse ash in a solution of moderate alkaline environments is found to be one of the principal ways in which the pozzolanic reaction can be activated.

The following conclusions are discovered based on the experimental results:

Compressive strength of blended cement without activator has a little reduction as compared to previous researches because of the bagasse coarseness. The coarser the bagasse, the lower the strength of blended cement.

Sodium sulfate is found out to be the appropriate chemical activator on bagasse ash blended concrete.

The presence of activator has positive impact on compressive strength at early ages.

In all ages, the presence of activator has positive impact on compressive strength of blended concrete. Up to 3 days the effect is rising in increasing manner but, after that its effect increasing on slow manner.

Compressive strength increase with the increase of dosage of activator. This indicates bagasse ash pozzolanic reaction is promoted by the alkali environment.

The Xrd test result verified the increase in reactivity of calcium hydroxide and silica of bagasse ash in the presence of activator.

With sodium sulfate activation (3% mass of binder), 20% bagasse replacement by volume of cement is optimum replacement for concrete mix.

## **6.2 Recommendation**

To confirm the conclusions stated, further studies need to be done to observe the morphology and nature of the generated hydration products as well as the formed microstructure.

Further research should be conducted to study the tensile and shear strength properties of chemically activated bagasse ash concrete.

The effect of fineness of precursor material on chemical activation of blended concrete should be studied.

Also the effect of chemical activation on durability, shrinkage and other properties of bagasse ash blended concrete should be studied.

The influence of activator on other pozzolanic materials should be studied

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**APPENDIX A**

Specific gravity and absorption test Coarse Aggregates — ASTM Designation: C 127		
	Sample 1	Sample 2
(A) Wt. oven-dry sample (Kg)	4	4
(B) Wt. SSD sample (Kg)	4.04	4.03
(C) Wt. saturated sample in water (Kg)	3.879	3.815
Bulk specific gravity	2.52	2.43
Apparent specific gravity	2.58	2.48
Bulk specific gravity (SSD)	2.54	2.45
Absorption (%)		
<i>Bulk specific gravity = 2.48</i> <i>Bulk specific gravity (SSD) = 2.5</i> <i>Apparent specific gravity = 2.53</i> <i>Absorption = 0.86%</i>		

Specific gravity and absorption test Fine Aggregates — ASTM Designation: C 128		
	Sample 1	Sample 2
(A) Wt. oven-dry sample (g)	473.8	467.6
(B) Wt. pycnometer + water to calibration mark (g)	1310	1310
(C) Pycnometer + water + sample to calibration mark (g)	1595	1595
Bulk specific gravity	2.2	2.17
Apparent specific gravity	2.51	2.56
Bulk specific gravity (SSD)	2.3	2.3
Absorption (%)	5.52	6.93
<i>Bulk specific gravity = 2.19</i> <i>Bulk specific gravity (SSD) = 2.3</i> <i>Apparent specific gravity = 2.4</i> <i>Absorption = 6.22%</i>		

**APPENDIX B**

Rodded unit weight of Coarse aggregates (ASTM Designation: C 29)			
	Sample 1	Sample 2	Sample 3
Combined mass of the oven-dry aggregate and the bucket(kg)	9.125	8.835	8.9
Mass of the bucket alone (kg)	0.91	0.91	0.91
Mass of the bucket and water (kg)	6.09	6.09	6.09
Volume of the bucket (m <sup>3</sup> )	0.006	0.006	0.006
Dry rodded density	1369.2	1320.8	1331.7
Average dry rodded density = 1340kg/m <sup>3</sup>			

**APPENDIX C**

Sieve Analysis for Fine and Coarse Aggregates (ASTM C136)

Sample Number 1				
Sieve Size	Weight Retained (g)	% Retained	% Passing	cum retained
37.5		0	100	0
25	1003.3	9.351465215	90.64853478	9.351465215
19	1882.3	17.54436656	73.10416822	26.89583178
12.5	5907.9	55.06580419	18.03836403	81.96163597
9.5	1512.8	14.10036537	3.937998658	96.06200134
4.75	422.5	3.937998658	0	100
2.36	0	0	0	100
1.18	0	0	0	100
600	0	0	0	100
300	0	0	0	100
150	0	0	0	100
	10728.8		FM	814.2709343

Sample Number 2				
Sieve Size	Wt Retained (g)	% Retained	% Passing	cum retained
37.5		0	100	0
25	0	0	100	0
19	1.02	11.84256357	88.1574364	11.84256357
12.5	1.995	23.16266109	64.9947753	35.00522466
9.5	3.05	35.41158714	29.5831882	70.4168118
4.75	1.645	19.09903634	10.4841519	89.51584814
2.36	0.903	10.48415186	0	100
1.18		0	0	100
600	0	0	0	100
300	0	0	0	100
150	0	0	0	100
	8.613		FM	706.7804482

Fineness modulus of CA = 7.6

Increasing compressive strength property of bagasse ash blended concrete by using chemical activator (NaSO<sub>4</sub>)

Sample Number 1				
Sieve Size	Wt Retained (g)	% Retained	% Passing	Cumm retained
4.75	0.6	0.112296463	99.88770354	0.112296463
2.36	33.8	6.326034063	93.56166947	6.438330526
1.18	61.4	11.49167135	82.06999813	17.93000187
600	153.4	28.71046229	53.35953584	46.64046416
300	204.8	38.33052592	15.02900992	84.97099008
150	80.3	15.02900992	0	100
75		0	0	100
	534.3		FM	356.0920831

Sample Number 2				
Sieve Size	Wt Retained (g)	% Retained	% Passing	Cumm retained
4.75	0.8	0.168634064	99.8313659	0.168634064
2.36	34.6	7.293423272	92.5379427	7.462057336
1.18	68.4	14.41821248	78.1197302	21.88026981
600	116.6	24.57841484	53.5413153	46.45868465
300	173.1	36.48819562	17.0531197	82.94688027
150	80.9	17.05311973	0	100
75		0	0	100
	474.4		FM	358.9165261

Fineness modulus of FA= 3.57

## APPENDIX D

### Compressive strength test results

Compressive strength of concrete (ASTM Designation: C 39)					
	days	strength			Average
control	3	13.7	14.9	14.0	14.2
	7		22.0	21.2	21.6
	28	32.1		31.9	32.0
10BA0ACT	3	12.4	13.4	12.7	12.8
	7		19.5	18.8	19.2
	28	29.2		29.0	29.1
10BA3ACT	3	18.7	19.0	19.8	19.2
	7		21.5	23.3	22.4
	28	31.9	32.5	28.9	31.1
20BA0ACT	3	10.9	10.4	9.5	10.3
	7	18.2	17.3	14.9	16.8
	28	23.6	24.4	24.5	24.2
20BA3ACT	3	14.5	14.7	15.3	14.9
	7		20.1	21.7	20.9
	28	29.3	29.8	26.5	28.5
30BA0ACT	3	9.2	8.8	8.0	8.6
	7	13.5	12.8	11.0	12.4
	28	20.0	20.7	20.8	20.5
30BA3ACT	3	11.8	12.0	12.5	12.1
	7		16.3	17.6	16.9
	28	22.9	23.3	20.7	22.3

Increasing compressive strength property of bagasse ash blended concrete by using chemical activator (NaSO<sub>4</sub>)


<b>Compressive strength of Mortar (ASTM Designation: C 109)</b>					
	days	strength			Average
control	3	18.7	20.3	20.3	19.7
	7	21.2	23.6	22.8	22.5
	28	30.3	32.3	31.6	31.4
10BA0ACT	3	16.6	16.3	17.6	16.8
	7	18.8	16.4	19.8	18.3
	28	31.9	29.6	30.3	30.6
10BA3ACT	3	18.4	16.8	16.8	17.3
	7	20.1	21.5	22.5	21.4
	28	28.4	29.5	27.0	28.3
20BA0ACT	3	14.3	12.8	12.0	13.0
	7	20.0	17.9	16.7	18.2
	28	25.8	30.3	26.8	27.7
20BA3ACT	3	14.5	14.3	14.5	14.4
	7	20.2	19.9	20.2	20.1
	28	23.0	25.9	24.7	24.5
30BA0ACT	3	13.1	13.2	11.7	12.7
	7	16.1	16.2	14.4	15.6
	28	22.8	22.3	22.1	22.4
30BA3ACT	3	14.9	12.4	12.9	13.4
	7	17.6	14.7	15.3	15.9
	28	22.7	19.3	23.0	21.7

Increasing compressive strength property of bagasse ash blended concrete by using chemical activator (NaSO<sub>4</sub>)

<b>Compressive strength of cement paste (ASTM Designation: C 109)</b>					
	days	strength			Average
control	3	24.5	24.8	27.3	25.6
	7	34.4	38.1	36.6	36.4
	28	41.5	46.3	56.1	48.0
10BA0ACT	3	23.2	23.4	22.6	23.1
	5	27.7	28.1	25.8	27.2
	7	32.4	32.6	31.6	32.2
	28	39.1	45.0	46.8	43.6
	3	27.6	25.9	24.4	25.9
	5	31.4	32.5	30.0	31.3
10BA2ACT	7	38.4	36.0	34.0	36.1
	28	51.6	54.5	42.8	49.6
	3	19.9	20.7	18.5	19.7
20BA0ACT	7	29.1	28.3	25.1	27.5
	28	45.4	44.7	45.1	45.1
	3	23.9	24.6	24.2	24.3
20BA2ACT	7	33.5	32.6	35.3	33.8
	28	46.4	44.8	45.2	45.5
	3	17.3	15.3	17.0	16.5
30BA0ACT	7	20.1	21.5	19.5	20.4
	28	38.2	38.6	38.0	38.3
	3	19.8	20.1	19.3	19.7
30BA2ACT	7	27.1	26.1	28.8	27.3
	28	34.7	36.5	35.4	35.5

**APPENDIX E**

Chemical composition of bagasse ash

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

Customer Name:- Destaye Haile Adero  
 Issue Date: -19/07/2019  
 Request No:- GLD/RN/475/19  
 Report No:- GLD/TR/416/19  
 Sample Preparation: - 200 Mesh  
 Number of Sample:- One (1)


Sample type:- wonji bagasse Ash  
 Date Submitted: - 10/07/2019


Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides  
 Analytical Method: LiBO<sub>2</sub> FUSION, HF attack, GRAVIMETRIC, COLORIMETRIC and AAS


Collector's code	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	MnO	P <sub>2</sub> O <sub>5</sub>	TiO <sub>2</sub>	H <sub>2</sub> O	LOI
Wonji-SCBA	75.98	11.54	2.28	1.12	0.60	0.64	1.92	<0.01	0.42	0.09	1.10	5.81


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

Analysts  
 Yirgalem Abriham  
 Tihitna Belerkachew  
 Tizita Zemene  
 Yohannis Getachew  
 Bethelhem Tefera

Checked By  
  
 Dessie Abebe

Approved By  
  
 Gosa Halle

Quality Control  
  
 Negish Worku



## APPENDIX F

### Xrd test results

