

**PROBING OPTIMAL BLENDS OF POZZOLANS TO DEVELOP  
SUPPLEMENTARY CEMENTING MATERIAL WITHIN BUSIA  
COUNTY, KENYA**

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Award of the Degree of Masters in Science (Chemistry) in the School of  
Pure and Applied Sciences of Kenyatta University.**

**APRIL, 2024**

**DECLARATION**

I declare that this thesis is my original work and has not been presented in any other university for a degree award.

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**DEDICATION**

To my beloved father, the late Maurice Okumu Duke (of blessed memory). Your love and support is highly appreciated. Rest in Peace Daddy.

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May God who recompense all with mighty folds.

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**ACRONYMS AND ABBREVIATIONS**

ASTM	American Society for Testing and Materials
BA	Bagasse Ash
BB	Broken Bricks
BBC	Broken Bricks, Bagasse Ash, Clay
Bs En	British Standards European Norm
ITZ	Inter-facial Transaction Zone
LPC	Lime Pozzolana Cement
MDD	Maximum Dry Density
OPC	Ordinary Portland cement
PC	Portland cement
RBC	Rice Husk Ash, Broken Bricks, Clay
RBBC	Rice Husks Ash, Broken Bricks, Bagasse Ash, Clay
RHA	Rice Husk Ash
XRF	X-Ray Fluorescence
CEN	European Committee for Standardization

## ABSTRACT

Usage of pozzolanic materials in cement production has increased in the recent past years. This is because of the high expense of material, high energy requirement and high emission of green-house gases accompanied with manufacture of Ordinary Portland Cement (OPC). Utilization of pozzolanic material is advantageous because it utilizes local agricultural waste materials. This work focused on the use of natural pozzolans within Busia County, that is; broken bricks (BB), rice husks ash (RHA), clay and bagasse ash (BA), to make Pozzolana Cement (PC). These materials contain active Silica and Alumina necessary for a pozzolanic reaction to take place. BA was obtained as a by-product of controlled burning of Bagasse and limestone in a kiln. The lime obtained in this process was slaked to get calcium hydroxide. RHA was produced by burning rice husks at temperatures of 700 - 900 °C. Using different ratio, we prepared RBC, BBC and RBBC samples. RBC comprised of RHA, BA and clay. BBC was made of BB, BA and Clay. RBBC comprised of RHA, BA, ground BB and Clays. The binder was made by mixing each Pozzolana ash with lime at different intervals. Mortar was prepared and tested for physical cement tests. Chemical composition tests demonstrated that the Pozzolans studied met pozzolanicity standards for use in supplementary cement production, with a total percentage of Iron(iii) Oxide ( $\text{Fe}_2\text{O}_3$ ), Alumina ( $\text{Al}_2\text{O}_3$ ) and Silica ( $\text{SiO}_2$ ) being greater than 70%.  $\text{SiO}_2$  had the highest percentage. The levels of MgO were less than 2.8% which comply with ASTM C (618) specifications. The electrical conductivity test showed that RHA had the highest rate of decrease in the electrical conductivity by 77% followed by BB 64%, Clay 56% and least was BA 26%. RHA had the highest pozzolanicity value and BA had the least though all of them had great change in electrical conductivity an indication that they are active pozzolans. In addition, optimal Pozzolana: Lime ratio was 2:1, and the best blend of the pozzolana ashes was RBC comprising of RHA, BB and Clay which gave a 28 days compressive strength of  $2.88\text{N/mm}^2$  cured in air. The optimal blend obtained, for instance RBC falls under cement type CS ii as classified by BS EN 998-1; Classification For Hardened Rendering and Plastering Mortar. The others; BBC and RBBC fall under cement type CS i. The optimal Pozzolan: Lime binder had 677 minutes final setting time with 139 minutes initial setting time demonstrating that the binder takes a prolonged duration reaching peak hydration temperature comparing with Lime Pozzolana Cement. It implies that compared to PPC cements hydration, the binder hydration is very low. The study provides an alternative method for making cement which is ecofriendly, of low cost and uses locally available materials in Kenya. It also has positive input on solving waste disposal problem which is of great environmental and health concerns.

**Key words:** cement, lime, pozzolana, RHA, BA, BB.

## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background Knowledge

Alternative cementitious substances are materials used as pozzolana cement or used together with Portland cement. Usage of supplementary cementitious materials is affordable and improves concrete properties. These materials include silica fume, limestone, dust and natural or calcined pozzolans. Using them in blended cements is advantageous because it increases blended cement plant capacity, reduces the amount of fuel used, lowers the emission of greenhouse gases and makes cement durable or controls alkali–silica reactivity (Gartner, 2004).

Pozzolans are silicate-based materials that consume the calcium hydroxide which is formed by hydration of cement to make additional cementitious materials. The pozzolan are mixed with lime to produce more calcium silicate hydrate, which is important for binding concrete. When more lime is consumed, it causes an increase in the strength of the concrete, decrease in its density, decrease in pozzolan efflorescence, decrease or elimination of the propensity for alkali-silica reaction (Girard, 2011).

Limestone is the most prevalent form of calcium carbonate used to manufacture cement. Limestone powder generates carbon-aluminates, stabilizes the ettringite and thus reduces the porosity of cement-based materials. For effective use the limestone quality must have; a minimum of 75% calcium carbonate ( $\text{CaCO}_3$ ) by mass, the mass of the clay content

should not be more than 1.2% and any organic material present should be less than 0.2% by mass (Mehta & Monteiro, 2014).

Ordinary Portland cement has 60% - 65% of CaO, part of which is given out during hydration as free Ca(OH)<sub>2</sub>. Calcium hydroxide makes Portland cement concrete predisposed to destruction in acid environments (Gambhir, 2013).

Use of rice husks ash in cement eliminates segregation, though it has similar strength characteristics as it contains 20% CaO, which upon hydration no free lime is formed as calcium hydroxide (Ca(OH)<sub>2</sub>). This is because calcium silicate hydrates and silica gel are obtained on hydration which makes the rice husks concrete to be more resistant to acidic environment (Mansha *et al.*, 2011).

This study aimed at making cementitious materials using a blend of rice husks ash, bagasse ash, broken bricks and clays as pozzolana within Busia County, Kenya. In Busia County, Kenya, there are potential pozzolanic clays which have been used for pottery and brick making for long. Rice husks and bagasse are agricultural wastes also found within the region, Limestone is found in Tororo, 25 km from the Kenyan border. A blend of these may lead to production of pozzolana cement that is processed with lesser energy than Portland cement and may therefore avail an affordable binder. The binder made using local materials reduces emission of green-house gases associated with production of Portland cement. Bagasse Ash (BA) and Rice Husk Ash (RHA) are agricultural wastes and adopting them for use in making cement will help to reduce cost and also positively

contribute to redress the problem of waste disposal which is of great environmental and health concerns.

## **1.2 Problem Statement**

Rapid population increase has led to urbanization and high demand to expand infrastructure which has necessitated the increase in demand for use of cement for construction. Use of ordinary portland cement as a major classical binder in construction industry is costly, involves consumption of a lot of energy and also emits of a lot of carbon (IV) oxide to the atmosphere. Production of high energy for the process of making ordinary Portland cement is costly and carbon (IV) oxide produced is harmful to the environment as it causes global warming. Due to this undesirable cost of production and emission of harmful carbon (IV) oxide to the atmosphere, there was urge to source and develop sustainable binding materials suitable for construction using ecofriendly and readily available raw materials. The process envisaged in this study aimed at reducing amount of energy used to make cement, which is cheaper and also ecofriendly. The binder made using this blend is ecofriendly due to reduction of emission of green-house gases associated with production of Portland cement. In addition, it will amend the decrease of the world's most vital fossils energy and decrease the undesirable effects involved in manufacture of cement on the environment.

In Busia County, Kenya, there are potential pozzolanic clays, rice husks and bagasse are agricultural wastes. Limestone is found in Tororo, 25 km from the Kenyan border. A blend of these may lead to production of pozzolana cement that is processed with lesser

energy than Portland cement and may therefore avail an affordable binder. Bagasse Ash (BA) and Rice Husk Ash (RHA) are agricultural wastes and adopting them for use in making cement will help to reduce cost and also positively contribute to redress the problem of waste disposal which is of great environmental and health concerns.

### **1.3 Hypothesis**

Clays within Busia County blended with bagasse ash, rice husk ashes and broken bricks, then mixed with Limestone can be used to make pozzolana.

### **1.4 Objectives**

#### **1.4.1 General Objective**

To develop and characterize potential supplementary cementing material using clays, sugarcane and rice husks wastes in Busia County, Kenya.

#### **1.4.2 Specific Objectives**

- i. To characterize pozzolanic activity for clays within Busia County
- ii. To determine the cementing properties of a blend of Rice Husks Ash, Bagasse Ash, Broken Bricks and Clays within Busia County
- iii. To determine the optimal blend of pozzolan for making cementitious materials.

### **1.5 Research Significance**

A study on developing an ecofriendly binder using pozzolanic materials (RHA, BA, Clay) is vital due to numerous advantages of using pozzolanic materials in cement. Using

these materials does not only reduce the cost for production of cement but also improves the durability of the cement. Providing an alternative way to use these waste materials to replace cement will make scientists explore a suitable durable method of material saving, specifically cement and also lessening the discharge of  $\text{CO}_{2(g)}$  to the atmosphere. Utilizing these waste materials increases the desirable properties of cement and there will be minimal wastes. In addition, we will be able to get an environmentally friendly binding material.

The intention of this work is to explore chances of creating an alternative binder putting to use a blend of RHA, BA, waste bricks and clay by mechano-thermal (grinding-heating) activation technique.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Composition of cement

Cement is a binder, with cohesive and adhesive properties. It hardens and sets independently binding other materials. The frequently used cements are the hydraulic ones, which means they set when mixed with limes in the presence of water (Allen, 2015). Silica, lime and iron (II) oxide are the primal matter in the process of manufacturing cement. These substances are obtained from unrefined rock and minerals such as shale, sand, iron ore and clay.

Manufacture of cement begins with mining then grinding the raw materials to a powdery form which is then subjected to a temperature of  $1350^{\circ}\text{C}$  -  $1550^{\circ}\text{C}$  in a kiln. The chemical bonds of the raw materials are broken due to the heat, and they recombine to form new compounds. These results to a product called clinker which is pulverized to a flimsy powder in a cement mill then mixed with gypsum to produce cement. (Darrel Leetham, 2015). The compounds formed in the burning process have the properties of setting and hardening in the presence of water known as 'Bogues compounds'. These compounds are namely; dicalcium silicates (belite), tricalcium silicates (alite), tricalcium aluminates (Celite) and tetra-calcium alumino ferrite (Felite).

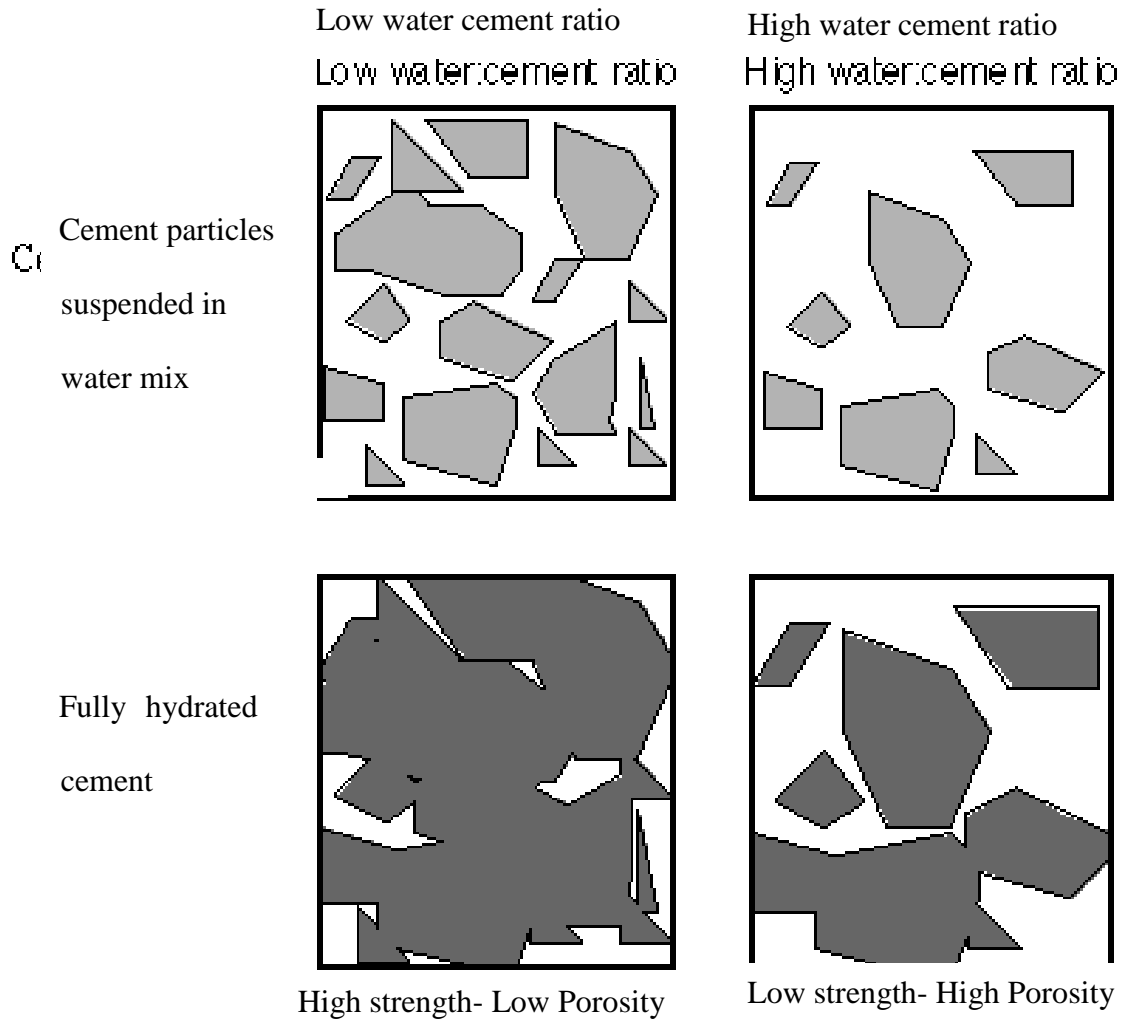
**Table 2.1: Composition of Portland cement**

CEMENT COMPOUND	% BY WEIGHT	FORMULAR
Tricalcium silicate	50%	$3\text{CaO} \cdot \text{SiO}_2$
Dicalcium silicate	25%	$2\text{CaO} \cdot \text{SiO}_2$
Tricalcium aluminate	10%	$3\text{CaO} \cdot \text{Al}_2\text{O}_3$
Tetracalcium-alumino ferrite	10%	$4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$
Gypsum	5%	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$

### 2.1.1 Hydration of cement

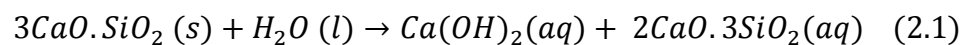
Hydration of cement is a process which involves several chemical reactions of water and cement leading to formation of the binding material. Hydration determines the strength of concrete. The amount of water used during hydration is vital because concrete strength is amplified when less amount of water is used to make it. The reaction between aluminates ( $\text{C}_3\text{A}$  and  $\text{C}_4\text{AF}$ ) and silicates ( $\text{C}_3\text{S}$  and  $\text{C}_2\text{S}$ ) with water in the hydration process leads to formation of a firm and hard solid (the hydrated cement paste) with time. Though, some pores will still exist as shown in Fig. 2.1. The formation of Calcium Hydroxide and Calcium Silicate Hydrates provide “seeds” upon which more C-S-H can form.

NB: Hydration will continue as long as there is water plus anhydrated compounds in the cement paste.



**Figure 2.1: A diagram showing the connection of porousness and water/cement**

Generally, cement compounds react with water in two major ways. One way of reaction is the direct addition of the water molecules which is a true hydration reaction (Aïtcin, 2011). The other way of reaction involves hydrolysis which is depicted in the equation 2.1 of the reaction of C<sub>3</sub>S with water below;



Though C<sub>3</sub>S reaction with water continues, when lime is saturated in the solution, crystals of lime are precipitated Ca(OH)<sub>2</sub>(s). When it is in contact with the solution saturated with lime Calcium silicate hydrate remains constant (Bullard *et al.*, 2011)

Calcium silicate hydrate undergoes hydrolysis when in water leading to formation of lime and the process lasts till the solution becomes saturated with lime. When calcium silicate is kept in touch with water it tends to form a hardened compound of hydrate silica only because of the hydrolysis of all the lime (Abel *et al.*, 2009). Though, the main compounds undergo different rates of reaction.

### **2.1.2 Aluminates**

The aluminates start reacting with water at the start of the reaction causing an effect to the pathway of the chemical reactions at early stages of hydration. The hydration of calcium aluminates takes place in three stages. In the first step, the anhydrous grains contained in calcium aluminate hydrate reacts instantly upon adding water dissolving simultaneously. Barrent and Bertandie 2004, claimed that this was due to the fact that small quantities of alumina gel precipitate out of the solution at the time of hydration. During this stage, the reaction attains a nucleation stage upon reaching a stage of super saturation of  $\text{Ca}^{2+}$  and  $\text{Al}(\text{OH})_4^-$ . In the second stage, the solution remains super saturated with ions. Dissolution and hydrate formation occur slowly which maintains a high concentration of  $\text{Ca}^{2+}$  and  $\text{Al}(\text{OH})_4^-$ . During the last stage, considerable precipitation and growth of hydrate species occur.

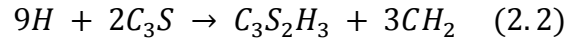
### **2.1.3 Silicates**

Silicates tend to influence the later stages of the chemical reactions.

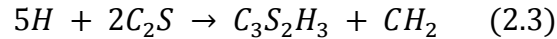
During hydration the vital hydrates formed are:

- 1. Calcium silicates hydrate**, which include the products of  $\text{C}_3\text{S}$  and  $\text{C}_2\text{S}$ .

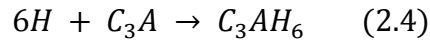
Tricalcium silicate reacts rapidly upon addition of water to form calcium silicate hydrates as depicted in the equation 2.2



Dicalcium silicate reacts with water in a similar manner like tricalcium silicate but more slowly



## 2. Tricalcium aluminate hydrate.



Though,  $C_3A$  in most of the cement is usually in minor quantities compared to other major compounds, it is of great interest in cement making due to its properties and how it interacts with other phases in the cement.

The final strength of the hardened cement is determined by calcium silicates;  $C_3S$  and  $C_2S$  which are the major composite of cement as they take up almost 75% of cement by weight (Dodson, 2013)

Time is a major factor to consider during hydration because the rate of hydration decreases steadily/continuously with time (Lothenbach *et al.*, 2011). Furthermore, the sizes of anhydrated cement particles decrease with time. For instance, cement particles have been found to have hydrated to an expanse of  $4\mu\text{m}$  after 28 days in contact with water, and  $8\mu\text{m}$  after about a year as observed using an X- ray nano computed tomography (Nano-CT).

The main reasons for this observation were:

- i. Hydration products tend to accumulate around the anhydrated cement grains thus preventing water from directing to them.
- ii. The amount of water tends to decrease due to chemical reactions or by evaporation.
- iii. The amount of cement also decreases due to chemical reaction.

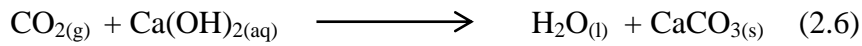
Various ways for determining the progress of hydration of cement include: The heat evolved by hydration (Lothenbach *et al.*, 2011), measuring the amount of  $\text{Ca(OH)}_2$  in the paste resulting silicate hydration (Mozaffaridana, 2011), determining the specific gravity of the paste (Perry *et al.*, 2017), determining the amount of chemically combined water and measuring the quantity of anhydrated cement present by use of X-ray quantitative analysis (Sun, 2015). Rate of hydration of cement may also be found indirectly from the strength of the hydrated paste (Buffo-Lacarrière 2011).

## **2.2 Lime in Construction**

Lime exists in two major forms namely: hydrated lime and quicklime. Generally, quicklime is formed when stone or rock which has calcium carbonate (chalk, marble, shells, limestone etc.) is heated for many hours at high temperatures of  $1000^\circ\text{C}$  in a process called 'calcining' (Varghese, 2015). Chemically, lime is calcium oxide ( $\text{CaO}$ ) which is formed by decomposing calcite ( $\text{CaCO}_3$ ) to form  $\text{CaO}$  and carbon (IV) oxide ( $\text{CO}_2$ ). Calcium oxide is unstable and hazardous. To handle it easily and safely it is hydrated /slaked by mixing it with water making it to be more stable. The reaction of calcium oxide with water is exothermic. The equation of the reaction to form the hydrate is shown in equation 2.5.



In the building industry, water, fine aggregate and hydrated lime are mixed to produce mortar (Allen, 2015). Basic lime-sand mortars are delicate; early adherent strength develops from drying up, carbonation causes extended stiffening.



In the past, animal hair was blended with lime renders and plasters to enhance cohesion. Nowadays, pozzolans or gypsum is added to boost durability and give faster setting time (Rodríguez-Navarro, 2012).

Limestone produces the main raw material for lime. It mainly consists of 99% pure calcium carbonate ( $\text{CaCO}_3$ ) (Elert *et al.*, 2002). Limestone undergoes a cycle in which the first step is incineration. During incineration, limestone is incinerated at temperatures between  $900^\circ\text{C}$  and  $1200^\circ\text{C}$ . This leads to formation of quick lime  $\text{CaO}$  or magnesium oxide. Carbon (IV) oxide ( $\text{CO}_2$ ) and water vapor formed are emitted to the atmosphere. The second step of the cycle is slaking of the quick lime. During slaking, quicklime is combined with water forming calcium hydroxide or magnesium hydroxide. This reaction is exothermic and leads to generation of a lot of heat.

The third step, the slaked lime also known as hydrated lime which is in form of putty is combined with other additives and aggregates forming grouts, plaster and mortars. Lime putty is a moist, elastic material whereas hydrated lime is a hydrate powder which is dry. Addition of surplus water in the time of slaking leads to formation of putty. Generally, lime putty is kept for a certain duration to mature before being used to make motors

(Hansen *et al.*, 2008). Setting and hardening of plastic calcium hydroxide takes place during carbonation. Exposing calcium hydroxide to air increases dehydration and in addition the atmospheric carbon (IV) oxide reacts slowly with calcium or magnesium hydroxide leading to formation of crystalline calcium or magnesium carbonate (Ruiz-Agudo & Rodriguez-Navarro, 2010). For effective results, the reaction needs best optimum level of moistness and temperature. The process of carbonation takes place very slowly and may take a long duration, and it will not take place if the material is inaccessible to air.

### **2.3 Pozzolans**

Pozzolan can be described as an alumino-siliceous or a siliceous material that contains small quantities or lacks binding value but when ground to fine form, reacted with alkaline or alkaline earth hydroxides at room temperature in presence of moisture will lead to formation of or will assist in formation of compounds with cementitious properties (Habeeb & Fayyadh, 2009).

A cementitious material is defined by ASTM as a substance which sets and builds up strength by reacting with water to produce hydrates in a reaction that takes place underwater (ASTM C618, 1993). The advantage of using pozzolanic supplements in lime-based mortar is that they make them to increase the strength and durability in absence of atmospheric carbon (IV) oxide.

### 2.3.1 Classification of Pozzolans

Several materials containing silica can be considered as pozzolans and may be split in two major classes: artificial and natural pozzolans. Natural pozzolans are formed naturally and are found in the nature. Natural pozzolans to be active may or may not need to be incinerated (Rogers, 2011). Those pozzolans that are industrial made and/or ought to be calcined for them to change to pozzolanic are classified as artificial. Further classification of pozzolans into different categories may be done depending on their source/origin and elemental composition:

- i. Those that occur in nature- this pozzolans are volcanic ashes. They acquired their name from their location. They were found at a place called the 'Puzzioli' Volcanic ash pozzolans are often called "true pozzolana". They are ousted from volcanoes and contain elevated amounts of silica and alumina in a glass-like, fine particulate.
- ii. The second group is of clay soil and crushed rock which tend to contain sufficient minerals to enable moderate pozzolanic reaction.
- iii. Calcined clay products- they contain aluminates and silicates. They include ceramic bricks and tiles. When these materials are crushed into flimsy powder, they have pozzolanic reaction with lime. To show pozzolanic properties, these materials must be ground and heated at low temperature. Grinding increases the surface area for the reaction. Currently, in the modern way for preparation of bricks a lot of heat is involved to make them hence they are not pozzolanic.

### **2.3.2 Chemistry of Pozzolans**

Pozzolanic materials have two basic properties; their tendency of reacting with lime and capability of forming by-products able to bind when combined with lime (Juenger *et al.*, 2011). Properties of pozzolans depend mostly on the major components which are alumina and silica. Alumina and silica combine with calcium hydroxide and form cementitious substances, particularly the calcium aluminum hydrates and calcium silicate hydrates.

Diversity of pozzolanic materials leads to formation of a variety of products. Though, some siliceous substances are not pozzolanic, there is no prescribed way or extend to settle on which siliceous materials will bring about a pozzolanic reaction and which one will not. Regarding the hydraulic lime, the quantity of silica which is dissolvable or able to combine is vital in envisioning the production of C-S-H (Alavéz-Ramírez *et al.*, 2012).

### **2.3.3 Clay Mineralogy**

Clay is defined as a finely-ground natural rock or soil substance made of tiny grains of non-clay and clay minerals. Clay mineral is comprised majorly of hydrous aluminum silicates and sometimes has components like iron and magnesium instead of aluminum. Some Alkaline and alkaline earth elements are also found in some clay minerals as well. The Clay minerals are divided to six major classes namely: illite, smectite, kaolin, chlorite palygorskite- sepiolite and mixed-layered clays. This classification is based on their diverse chemical makeup and crystalline structures. The different classes may

include several different clay minerals. Most clays contain non-clay minerals like dolomite, quartz, mica, and the rest (Murray, 2006).

**Table 2.2: Chemical Composition of Clay**

Clay Mineral	Theoretical formula
Kaolin	$\text{Al}_4\text{Si}_4\text{O}_{10}(\text{OH})_8$
Smectite	$(\text{OH})_4\text{Si}_8\text{Al}_4\text{O}_{20}\cdot\text{NH}_2\text{O}$
Illite	Variable – contains Potassium
Chlorite	$(\text{OH})_4(\text{SiAl})_8(\text{MgFe})_6\text{O}_{20}$
Palygorskite	$(\text{OH}_2)_4(\text{OH})_2\text{Mg}_5\text{Si}_8\text{O}_{20}\cdot 4\text{H}_2\text{O}$
Sepiolite	$(\text{OH}_2)_4(\text{OH})_4\text{Mg}_8\text{Si}_{12}\text{O}_{30}\cdot 8\text{H}_2\text{O}$

Kaolin is commonly known as the pure clay. It is made from kaolinite clay minerals and is the purest of all clays. Precisely, it is a hydrous aluminum silicate (Chamley, 2013). Kaolin (metakaolinite) proved to successfully bring about a pozzolanic reaction with lime when fired. Currently, bricks being made possess small packaging of kaolinite and are contained mainly of minerals like calcite, feldspar, quartz, and sodic plagioclase with minor amounts of mica and clay minerals (Alexander & Mindess, 2010). Modern bricks tend to show insignificant pozzolanic activity when blended with lime. In the modern world, common clay is frequently used in brick production. The phrase “common clay” depicts glacial clays, shales and soil clays which are utilized mainly for structural clay products. Common clays are powder like and often mouldable when moist and they have a wide-ranging mineral composition (Reeves *et al.*, 2006).

The major clay mineral detected in common clay is illite (Murray, 2006). Most of the clays used in brick production meet the Brazilian and ASTM set standards of

specifications of containing not less than 70% by weight of a sum of (  $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ ) (Claus, 2008).

#### **2.3.4 Brick as a Pozzolanic Substance**

Bricks are formed from different clays and additives like sand and subsidiary minerals. Production of bricks undergoes seven steps whereupon unprocessed clay is transformed to structural ceramic units. Clay is mined by opencast method then it is cleaned to remove stone, vegetable matter and pebbles. The second step involves air drying the clay in sheds with open sides. The dry clay is crushed or ground, pugged (mixed with water), then squeezed-out to shape the brick. Finally, the clay is dried in air and then fired in a kiln at high temperatures to form a hardened structural unit (Murray, 2006). The quality, characteristics of the clay and its ability to act as pozzolan are determined by the mineralogy composition of the brick clay. Clays that have 50-60% silica and 20-30% alumina and the remaining percentage by mass comprising of calcium carbonate, magnesium carbonate, and iron oxide are rated fit for making bricks and pottery. The composition of clay is completely non identical through diverse seedbeds, and composition may differ greatly even within the same beds (Rogers, 2011).

#### **2.3.5 Durability of Bagasse Ash in Cement**

Bagasse is a fibrous residue from juice extraction from sugarcane. Normally utilized as a source of heat in boilers in industries. Compared to before when it was burnt as a way of disposing solid waste, now it is burnt under controlled temperatures for future use. The Bagasse ash (BA) has a quantity of unburnt matters, calcium, aluminium and oxides

silicon. BA has been identified as a possible pozzolanic material with the prime aspect that affect reactivity being the silica crystallinity in the ash and existence of impurities like unburnt material and Carbon (Sua-Iam & Makul, 2013).

BA depicts good pozzolanic properties when subjected to heat between 800°C and 1000°C for up to 20 minutes or calcined at 600°C for three hours (Morales *et al.*, 2009). The good pozzolanic qualities are tagged to presence of high specific surface area, low carbon content and amorphous silica (Cordeiro *et al.*, 2009). The scholar proved that BA pozzolanic activity can be improved substantially by mechanical grinding in a vibratory mill. Alavéz-Ramírez *et al.* (2012) affirms that many studies show that, BA depicts good properties in blended cementitious materials in concrete. Zhang *et al.* (2016) showed that, increasing BA by 10% tends to increase the cement paste's compressive strength at all hydration ages. While there has been extensive research on using cement and other stabilizing agents to stabilize soil, only a limited number of researchers have investigated the impact of using BA on soil stabilization.

### **2.3.6 Strength of RHA Blended Cements**

Rice husk is berlignoselulosa. Chemically, rice husks contain 50% cellulose, 25%–30% lignin, 15%-20% silica. Rice husks ash (RHA) produced from burning rice husks at 500°C -800°C temperatures becomes amorphous silica and at higher temperatures it becomes crystalline silica.

Rice husk is an agricultural bi-product obtained from production of rice. When incinerated into ash, the rice husk is accepted as a pozzolana because it contains 67-70% silica, 4.9% Aluminium and 0.956% Iron Oxide (Oyetola & Abdullahi, 2006). The rice husk ash has amorphous silica that can react with calcium hydroxide ( $\text{Ca}(\text{OH})_2$ ) during hardening. Using RHA specifically with coarser average particle decreases amount of water consumed surpassing fly ash mixtures (Givi *et al.*, 2010a). The workability observed from 50% -100% for RHA proportionate replacement from 5% - 20%. This may be explained that, the cement particles are evenly distributed hence could entrap high quantity of water leading to decline of water needs to the system to attain desirable consistency.

The fresh concrete workability for both 95 $\mu\text{m}$  and 5 $\mu\text{m}$  particle size was enhanced by the partially replacing cement with RHA. RHA with average particle size of 95 $\mu\text{m}$  increased slump values for relative cases. Ultimately it was found that 10% ultra-fine RHA blended concrete could be regarded as the best formulation because of its acceptable workability, low water permeability and compressive strength value. From the literature, it has been ascertained that substituting cement partially with RHA enhances concrete workability and compressive strength and reduces its water permeability. On top of that, reducing RHA average particle size results to desirable effects on the water permeability and compressive strength of hardened concrete but reveals fresh concrete workability is negatively affected.

Mostafa *et al.* (2010) concluded in their investigation that the clinker hydration rate regulates the pozzolanic reaction rate contribution to the strength if high reactivity pozzolanic materials are used. Devoid of a super plasticizer, strengthening of blended cements is owed to the pozzolanic reaction and morphology advancement and the hydration products structure despite the sticky agglomerates.

### **2.3.7 Previous Studies on Lime: RHA Cements**

Investigations on lime's cementitious properties: RHA blends depict existence of contradiction concerning the value of compressive strength obtained by a blend of lime: RHA mortar blends and with respect to the optimum lime: RHA blend ratio for maximum strength gain. Pitt & Mehta, (2010) studied Lime's compressive strength properties; RHA cements using a Lime: RHA blend of 20:80 and they found that mortar strength above  $10 \text{ N/mm}^2$  was attained after 3 days and a strength above  $35 \text{ N/mm}^2$  was achieved at 28 days.

A controlled kiln was used by Cook & Suwanvitaya (1983) to burn RHA at  $600^\circ\text{C}$  to make RHA: Lime mortars with cement: sand ratio of 1:3 and evaluated it conforming to ASTM C618 (1993). The ratios of the cement were 1:4; 1:1.5; 1:0.67 and 1:0.25 limes: RHA. Mortars were fog-room cured for 1 or 2 days and then cured in lime water at  $200^\circ\text{C}$ . Cube strength and shrinkage were determined in conformance with ASTM C311-11b., (2011). The optimal strength of  $8.5 \text{ N/mm}^2$  at 28 days was attained with the 40:60 Lime: RHA blend, this blend also demonstrated the lowest shrinkage. However, all

mortars were over 4 N/mm<sup>2</sup> strength level; a carbon content of up to 20% by mass in the ash did not significantly influence the strength development.

In Kenya several experiments on pozzolanic activity of RHA have been done. Mitullah & Wachira (2003) investigated RHA's pozzolanic activity with commercially hydrated lime (CHL) and was able to prove the best results when a ratio of 2:1 lime: RHA was used. Waswa-Sabuni *et al.* (2003) tested the pozzolanic activity of RHA obtained from rice husks from Mwea rice mills (Kenya) using controlled burning of rice husks (500-700°C) to make lime: RHA mortar and concrete cubes. The ratios of the cement were 50:50, 60:40, 70:30, 80:20 and 100:0 lime: RHA. Chemical analysis of the rice husks ash exhibited elevated amounts of silica content (above 70%) denoting high pozzolanic property (Table 2.3). It was ascertained that RHA greatly enhanced lime's compressive strength with the strength building up with increasing RHA. Amongst the lime: 50:50 lime ratio was used for RHA: RHA blend yielded excellent outcomes with 2.8 N/mm<sup>2</sup> mortar strength and 12.7 N/mm<sup>2</sup>, concrete cube strength, setting times and workability were detected to reduce with a rise in the amounts of RHA.

**Table 2.3: Comparison of Chemical Properties of Rice from Different Countries**

Country/ Constituents	Malaysia	Brazil	Netherlands	Kenya
<b>Silica</b>	93.1	92.9	86.9	75.8
<b>Alumina</b>	0.21	0.18	0.84	1.15
<b>Fe<sub>2</sub>O<sub>3</sub></b>	0.21	0.43	0.73	0.86
<b>MgO</b>	1.59	0.35	0.57	0.23
<b>LoI</b>	2.36	-	5.14	10.2
<b>Total%(silica+alumina + Fe<sub>2</sub>O<sub>3</sub>)</b>	<b>93.52</b>	<b>93.51</b>	<b>88.47</b>	<b>77.81</b>

In summary, the enhancement in the compressive strength of cement-based materials, stemming from the addition of RHA to OPC, arises from the pozzolanic interaction between RHA and unreacted lime during cement hydration. Free Ca<sup>2+</sup> and OH<sup>-</sup> ions within the hydrated cement is restricted, primarily linked to the calcium silicates hydration process. For instance, the hydration of tricalcium silicate proceeds in water as follows:



These investigations demonstrate that because of increased specific RHA surface area, incorporating RHA into OPC concrete results in a reduction in workability. This explains why a significant portion of the published studies utilized relatively higher water-to-cement ratios in attaining a workable concrete mixture.

### **2.3.8 Rice Husks in Brick Kilns**

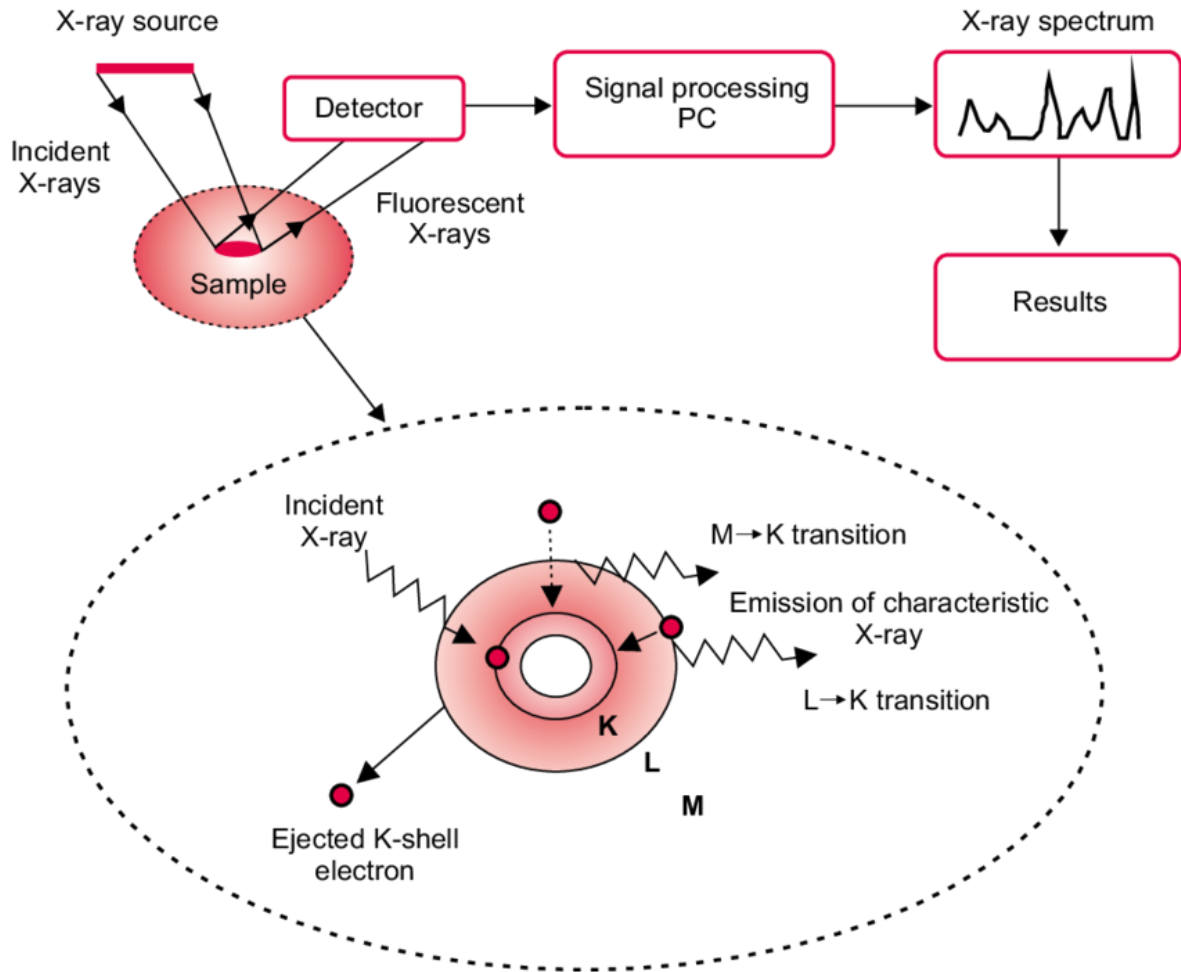
In Sri Lanka, rice husk has traditionally been utilized as a fuel for firing bricks; however, the resulting rice husk ash (RHA) has not been effectively repurposed. Adekunle (2012) conducted research indicating that RHA, a byproduct of brick kiln operations, could be harnessed to enhance the structural characteristics of fired clay bricks. RHA was obtained from a brick kiln situated in the Embilipitiya area, while clay was sourced from Dankotuwa, an area known for its established brick manufacturing industry. The collected RHA underwent sieve analysis to determine its particle size distribution. Clay was manually mixed with varying RHA percentages: 0%, 2%, 4%, 6%, 8%, and 10%. The RHA addition at all percentages improved the clay mixture for brick production. The optimal compressive strength of 3.55 N/mm<sup>2</sup> was achieved with a 4% addition of RHA.

This represented a 32.7% enhancement in compressive strength compared to control bricks (fired clay bricks containing 0% RHA). These findings suggest that RHA, previously considered waste from brick kiln operations, can be effectively utilized to enhance the structural integrity of fired clay bricks.

## **2.4 Analytical Techniques**

### **2.4.1 X-Ray Fluorescence Spectroscopy**

The elemental composition of solid materials is determined using a non-destructive technique called X-Ray Fluorescence spectroscopy. XRF analyzers work by determining the chemistry of material fluorescent X-rays emitted from a sample upon excitation by primary X-rays are measured. It has been demonstrated that each element within the sample generates a distinct set of characteristic fluorescent signals, akin to a unique fingerprint for that element (Temitope et al., 2019). This process sequentially analyzes each X-ray, albeit at a rapid pace. Modern XRF machines are equipped with detectors capable of handling 1 million counts per second, facilitating quasi-simultaneous measurements. Despite the brief measurement duration, the spectrum obtained provides ample data to compute intensities, enabling the determination of the sample's composition (<http://www.spectro.com>, 2019). The working principle of XRF and its detection arrangement are shown on Fig. 2.2.



**Figure 2.2: Illustration for the principle of XRF Spectroscopy**

(Source: Papachristodoulou, 2002)

### 2.4.2 Electrical Conductivity Test

The purpose of conducting electric conductivity tests is to monitor pozzolanic activity. It is cheap and exists as a time-efficient method. Uzal *et al.* (2010) utilized electrical conductivity test in determining pozzolanicity by measuring lime decrease from a lime-pozzolan solution as a cause to fix calcium hydroxide being fixed by a pozzolan. primary approach pioneered by Fratini involves utilizing chemical titration to ascertain the  $\text{Ca}^{2+}$  and  $\text{OH}^-$  concentrations within a solution with cement for assessment. A simplified

rendition of the Fratini method is the saturated lime test, wherein it is assumed that the pozzolan is mixed with saturated lime instead of water and cement. This method serves as the foundation for NP EN 196-5 (Testing method for cement - Part 5; pozzolanicity tests for pozzolanic cements'). The calcium hydroxide quantity derived from the pozzolan is deduced through examining dissolved residual calcium.

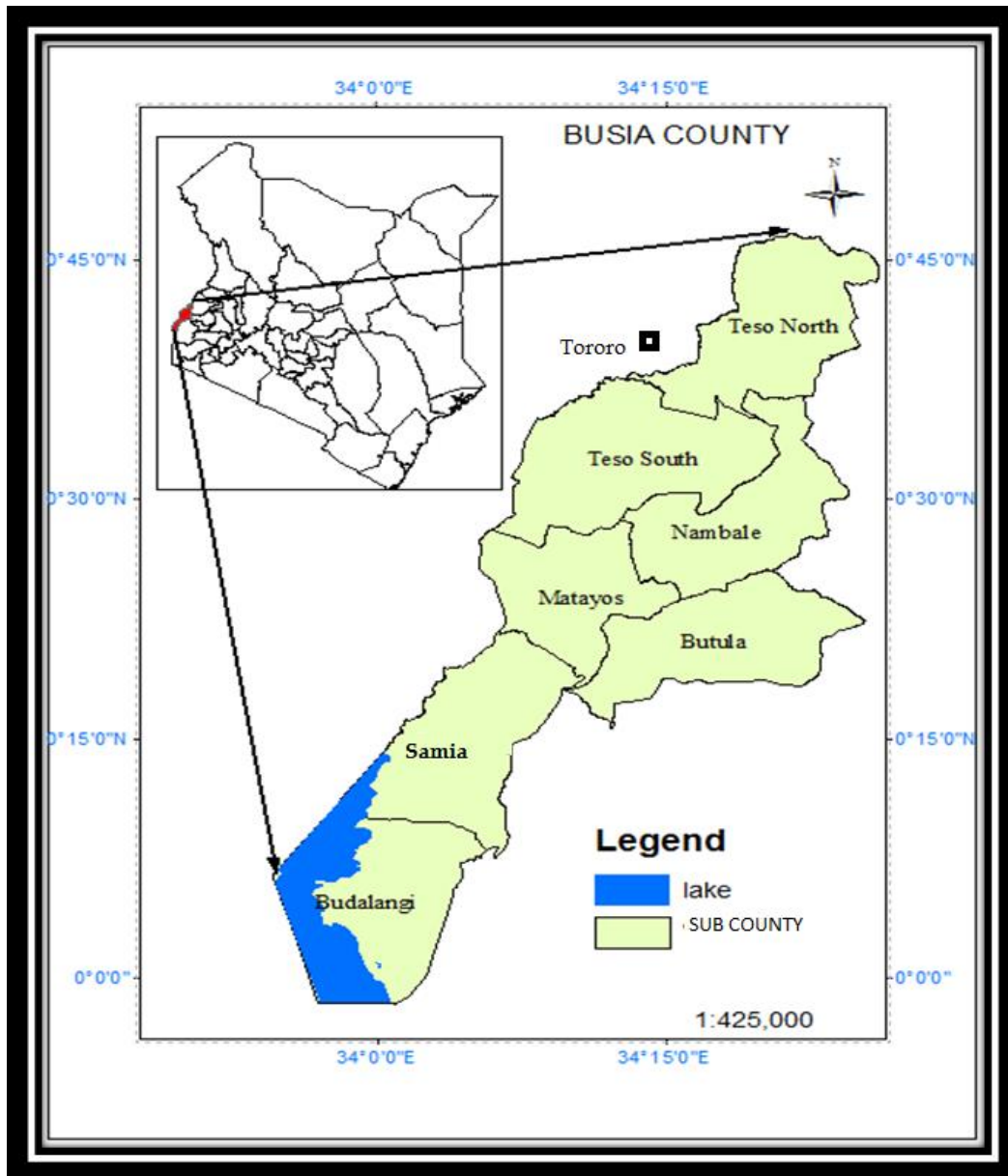
Indirect testing methods rely on the properties of analyses, which can potentially correlate with the activity level of the pozzolanic material being studied. These analyses may encompass investigations into electrical conductivity, mechanical strength, or the heat of hydration evolution. For instance, monitoring the solutions conductivity with pozzolanic materials serves as a robust indicator of pozzolanic activity degree (Felipe *et al.*, 2016).

## **CHAPTER THREE**

### **METHODOLOGY**

#### **3.1 Sampling**

In this study, Lime, broken bricks (BB), BA, RHA Clay samples and Standard Sand were used to make the cementations material. Convenience sampling method was used. Waste bricks were collected from construction and demolition sites within Busia County. Bagasse was collected from the local sugar industries around Nambale Sub County. Limestone was collected from Tororo Uganda. Rice husks were collected from paddy fields in Bunyala Sub County. The Clay samples were collected from pottery sites in Butula Sub County.



**Figure 3.1: Study Area Map**

([kcsepdf.co.ke/busia-county-profile](http://kcsepdf.co.ke/busia-county-profile))

### 3.2 Sample Pre-Treatment

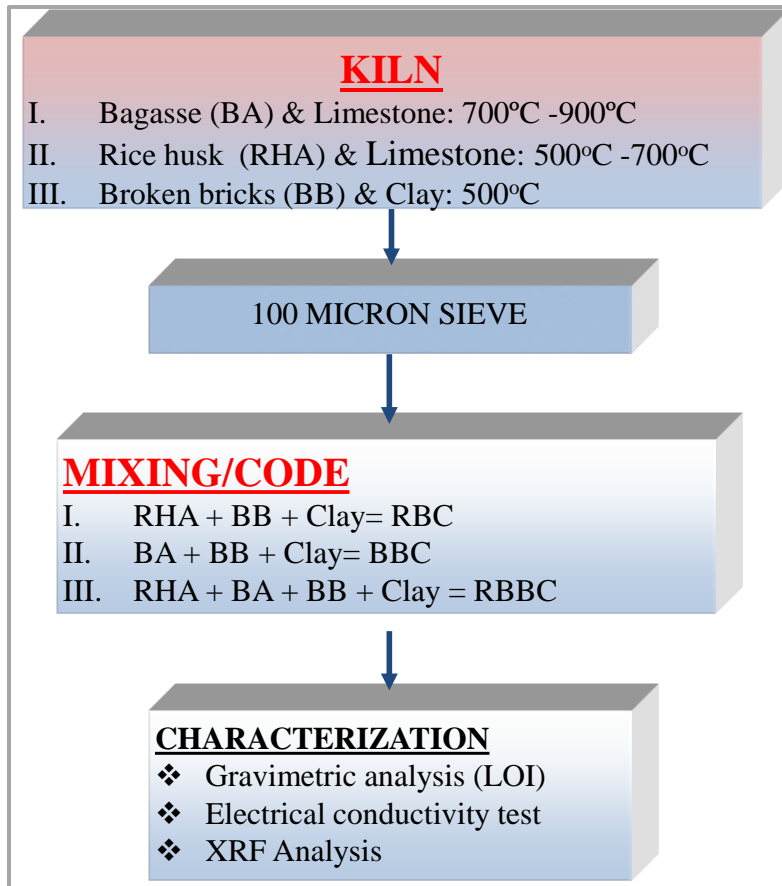
Bagasse was used as fuel to burn limestone. Bagasse and limestone were heated together in a kiln represented in Fig.3.2 at controlled temperatures between 700°C -900°C. The kiln was constructed at Mundika in Busia County, Kenya. It's measurements were 1.5m x

1.5m and 1.75m high. The walls of the kiln were made of bricks and a metallic chimney at the top. The kiln temperature was regulated by closing and opening of the holes on its walls.



**Figure 3.2: Kiln**  
(Okoya, 2013)

BA obtained was sieved through a 100micron mesh, and the lime produced was slaked. The same process was repeated with rice husks but the temperatures were between 500°C -700°C and the time for burning was 6 hours (Chandrasekha & Pramada, 2006). The procedure is illustrated on the flow chart on Fig. 3.3.



**Figure 3.3: The procedure to prepare different pozzolana samples; BA, RHA and BB**

Broken bricks and clay samples were ground using a Denver Crusher Serial no: OTT 775951/ TG 36773 and pulverized using a Herzog's Pulverize type HSM 250, Serial no; MA 16384-1-2 (Fig. 3.4) at a temperature of 500°C. Each sample was passed through 100micron sieve. RHA, ground BB and Clay were homogeneously mixed (RBC). Another mixture was made of BA ground BB and Clay (BBC). Lastly RHA, BA, ground BB and Clay were mixed (RBBC). Percentage by mass of each pozzolana ash was recorded in a table. Each pozzolana ash was characterized and tested by electrical conductivity test, and XRF analysis.



**Figure 3.4: Pulverizer**

(photo by Mary Assumptor)

### **3.3 Pozzolanicity Tests**

#### **3.3.1 Electrical Conductivity Test**

This was carried out according to a method described by Vu *et al.* (2001). Distilled water (200 ml) was put in a 500 ml glass beaker then put on a hot magnet plate and then heated at  $40 \pm 1^\circ\text{C}$ . Solid  $\text{Ca}(\text{OH})_2$  was added to the deionized water till saturation point. Magnetic stirrer was used to mix the solution after addition of calcium hydroxide for two minutes. To determine the conductivity of electricity in this mix, 5.0g of the pozzolana sample added to saturated solution maintaining it at a temperature of  $42 \pm 1^\circ\text{C}$ . Contents

in the beaker were shaken continuously for two minutes. After preparation samples were left in an oven at 42°C. The solution's electrical conductivity yielded was recorded daily for 9 days. Loss in conductivity of the mix was determined as a measurement of the sample's pozzolanic activity. The process was carried out thrice for every pozzolana sample thereafter the mean was noted.

### **3.3.2 XRF Analysis**

Solid samples of pozzolana ashes were irradiated with high energy X-rays from a controlled X-ray tube from Brucker Company, Model S1 Titan 600N Germany in origin. The powdered samples were placed into a plastic support film, ensuring a flat surface for the X-ray analyzer and support the sample over the X-ray beam. A finer grind of the sample enhances homogeneity and minimizes void spaces, resulting in a more effective analysis. 15g of sample materials were utilized in ensuring infinite thickness was gotten for all of the interested elements. The results of the elemental composition of the pozzolans were then tabulated in a table.

### **3.3.3 Loss on Ignition (LoI)**

This was done to ascertain the organic contents in the sample. The muffle furnace was turned on and the control dial was set. This was done 2 hours earlier so as to bring the temperatures of the furnace to the desired temperature of 900°C. Using forceps, the clean and dry crucible was weighed on a calibrated electronic balance and the weight recorded ( $W_C$ ). Exactly 1g of the sample was added to the crucible and the weight recorded as  $W_S$ . The muffle was placed in the furnace then gradually heated to 900°C and the temperature

kept constant for 30 minutes. After cooling, the crucible was weighed ( $W_A$ ). LoI was measured to be a percentage of initial sample weight. The calculations were carried out as follows;

Weight of the Crucible and Sample before heating  $W_S$

Weight of the Crucible  $W_C$

Weight of Sample and Crucible after heating  $W_A$

$$(LoI = (WS - WC / WS - WA) \times 100)$$

The results were then represented on a table.

### **3.4 Development of Pozzolanic Cement**

The binder was made by mixing Pozzolana Lime ratios of 1:2, 1:1 and 2:1. Mixing was done in accordance to ASTM C305 using a Hobart mixer. Firstly, all the mixing water was put in the bowl, cement added and allowed 30 seconds to absorb water. The mixer was started at low speed (14065 r/min) for 30 seconds. The mixer was then stopped for 15seconds, any paste collected on sides of the bowl during this time is scrapped down. The mixer is again started at a medium speed (285610 r/min) and was allowed to mix for 60seconds.

### **3.5 Physical characterization Tests**

#### **3.5.1 Standard Consistency**

To determine the standard consistency of the pozzolana binder, the Vicat method as prescribed by the European Standards EN 196-3:2000 was used. The vicat apparatus was kept on a level base. The dashpot top was unscrewed then the dashpot oil of viscosity

filled and was screwed to top. The plunger used to assess standard consistency was connected to the adjustable rod, 450g of the binder was gauged with water to form a cement paste. The Vicat Apparatus-Farnell model (Fig. 3.5) was kept on a non-porous plate and was filled with the cement paste. The mould was then slightly shaken to remove air spaces. The surface of the paste was smoothed off making it level with the moulder top. The cement paste was the test block which was then placed on the non-porous plate under the movable rod, bearing the needle. The plunger was gently lowered to touch the cement paste surface and was released quickly to allow it sink into the paste. Extend of penetration was measured and noted. The room temperature was kept constant. The paste's water content was computed as a percentage of the dry Pozzolana mass: Lime cement and noted as water necessary for standard consistence.



**Figure 3.5: Vicat apparatus**

### **3.5.2 Setting Time Test**

#### **3.5.2.1 Initial Setting Time**

The initial setting time was also determined using the Vicat method. Exactly 450 g of cement was used to prepare a neat cement paste using the water percentage noted for the standard consistency. Gauging time was kept 3 to 5 minutes and done in the Vicat mould. The paste, confined in the mould and placed on the base plate, was put under the rod bearing the needle of the Vicat Apparatus. The needle was gently lowered in contact with the test block surface and released quickly to sink in. The method was redone until the needle was not able to go through the block 4mm from the bottom of the mould. Initial setting time from when water was poured into the cement and at that instance when 1mm<sup>2</sup> needle failed to penetrate test block.

#### **3.5.2.2 Final Setting Time**

To determine the final setting time, replacement of the needle was done by a needle with an annular attachment. For this test, the test block was inverted. The cement is deemed to have set if when the needle is applied gently to the test block's surface, it will make an impression while the attachment did not. Final setting time is the period from gauging and the time when 5mm<sup>2</sup> needle failed to pierce the test block.

### **3.5.3 Strength of Lime: Pozzolana Binder**

Mortar compressive strength test was carried out on each blend of Pozzolana and lime to provide a demonstration of the resulting binder's strength. The procedure followed the ASTM C109 standards, employing the standard mortar prism test. The prismatic test specimens measured 160mm x 40 mm x 40 mm and were produced from a mortar batch

with a pozzolana cement to standard sand mass ratio of 1:3, maintaining a water-to-binder ratio of 0.9. While the typical water-to-binder ratio for mortar compressive tests is 0.5, a higher ratio of 0.9, determined from the standard consistency, was utilized for the Lime:Pozzolan binder mix due to its elevated water demand.

Each mortar cube materials were separately mixed. Exactly 450g of each binder was mixed with 1350g of standard sand in a motorized mixer: ELE 1616-6-6-1088. Thereafter, the water required was added and mixed for 4 minutes.



**Figure 3.6: Jolting table**

The mortar cubes were moulded in average room temperature of 25°C. During moulding, the mortar was tamped 60 times and was vibrated on a Jolting table; Contrals 00104051(20063 Cermisco S/N) machine for 2 minutes (Fig.3.6). After gauging, the moulds were kept in a moist closet for 24 hours . Thereafter the pozzolana cement cubes taken off from their moulds and left to cure in air at a temperature of 25 ±2°C and 65±5

relative humidity for 28 days. This is because lime cement does not harden in water and it takes a longer duration to cure therefore the 3 and 7 days strength was not able to be determined.

After curing the cubes were tested for compressive strength by applying the load steadily and uniformly on the cube side with a compressive strength testing machine; [Walter + Bai DB 3000/100/200/15(FL50C(CH)MB-2SGK] until fracture appeared. First the cement cubes were placed on the compression test machine's lower platen. The upper platen was gently lowered, applying no pressure to the sample. The compression testing apparatus operated at a speed ranging from 200 to 400 pounds/sec until the sample experienced a fracture. The force exerted by the compression tester was then quantified, and the strength determined by dividing the maximum measured force by the cross-sectional area. Three samples were tested and the average data recorded in  $\text{N/mm}^2$ .



**Figure 3.7: Compressive Strength Testing Machine**

### **3.6 Analysis of Data**

The data obtained was graphically represented, then analysed using the student's t-test.

**CHAPTER FOUR**  
**RESULTS AND DISCUSSION**

**4.1 Elemental Composition**

Analysis for elemental composition was done using XRF spectroscopy as presented in Table 4.1. The analysis showed highest content of SiO<sub>2</sub> followed by Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, CaO and least was MgO in all the samples analyzed. According to ASTM C618 Standards, a material qualifies for pozzolana if the total percentage of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub> in its composition exceeds 70%. These analyses indicate that, a mixture of clay, BA, BB and RHA could be used up as cementitious material as they contain high amounts of SiO<sub>2</sub>, a major component of cement.

**Table 4.1: XRF Analysis for Elemental Composition**

<b>Property in %</b>	<b>SiO<sub>2</sub></b>	<b>Al<sub>2</sub>O<sub>3</sub></b>	<b>Fe<sub>2</sub>O<sub>3</sub></b>	<b>CaO</b>	<b>MgO</b>
<b>RBC</b>	77.95± 2.34	13.060±0.998	3.719±0.763	1.53±1.002	1.469±0.872
<b>BBC</b>	66.929±1.88	22.737±1.322	5.730±1.112	1.604±0.024	0.753±0.025
<b>RBBC</b>	80.199±1.65	11.643±0.967	3.490±0.856	1.096±0.054	0.972±0.104
<b>CLAY</b>	58.597±1.43	27.017±1.293	8.708±0.897	2.884±0.682	0.691±0.008
<b>BB</b>	70.795±2.01	21.305±1.171	2.916±4.324	0.934±0.016	0.905±0.102
<b>BA</b>	65.791±1.87	13.523±1.658	5.719±1.113	9.951±1.215	0.000
<b>RHA</b>	94.873±3.22	0.511±0.002	0.708±0.012	0.902±0.002	0.000

In all the samples used, Silicon (IV) oxide had the highest percentage. SiO<sub>2</sub> was highest in RHA with a percentage of 94.9% and lowest in clay with a percentage of 58.6%. The

percentage of  $\text{Al}_2\text{O}_3$  was highest in the clay, followed by BB, BA and least in RHA. In studies carried out by other researchers using the same pozzolans but from different regions, their elemental composition shown a similar trend. For instance, Tavakoli *et al.* (2007) used BA from Nzoia sugar company and its elemental composition had  $\text{SiO}_2$  highest with 66.23%,  $\text{Al}_2\text{O}_3$  1.90%,  $\text{Fe}_2\text{O}_3$  3.02% and MgO 1.54%. Okoya (2013) studied RHA from Mwea irrigation scheme, he found out that the elemental composition was  $\text{SiO}_2$  70.55%,  $\text{Al}_2\text{O}_3$  4.76%,  $\text{Fe}_2\text{O}_3$  0.96% and MgO 0.76%. John (2013) worked with the Ugweri clays, their elemental composition was  $\text{SiO}_2$  62.90%,  $\text{Al}_2\text{O}_3$  24.64%,  $\text{Fe}_2\text{O}_3$  6.64% and MgO 2.07%. In this study despite different pozzolans being blended the results yielded were similar.

A proper amount of silica must exist in cement for the creation of tricalcium silicate and dicalcium silicate. Silica contributes to the cement strength. The necessary quantity of alumina adds the property of quick setting to the cement, but an excessive amount of alumina can weaken it. Iron (III) oxide serves as a flux and, under high temperatures, initiates a chemical reaction with calcium and aluminum, resulting in the formation of tricalcium alumino-ferrite. This compound enhances the hardness and strength of the cement.

#### **4.2 Chemical properties**

Chemical analysis of the clays used was done and tabulated in table 4.2. Silicon (IV) oxide had the highest percentage in all the clays used; Clay 1, 2 and 3. Clay 1 had high percentage of  $\text{SiO}_2$  only. Clay 3 had high percentage of calcium oxide, iron (iii) oxide and

aluminum oxide. Magnesium oxide was only present in Clay 2. The composition of this clay met the Brazilian NBR and ASTM C 618 standards of specification for pozzolans that pozzolans should have more than 70% by aluminum oxide ( $\text{Al}_2\text{O}_3$ ) weight, silica ( $\text{SiO}_2$ ) and iron oxide ( $\text{Fe}_2\text{O}_3$ ). This provides the necessary glass-like content that reacts with added lime at room temperature in the water to obtain the cementing materials.

**Table 4.2: Chemical properties of Clays used**

Property in %	Clay 1	Clay 2	Clay 3	Mean Results
<b>SiO<sub>2</sub></b>	67.593±1.624	59.482±1.678	48.716±1.043	<b>58.597</b>
<b>Al<sub>2</sub>O<sub>3</sub></b>	23.260±0.886	23.672±0.989	34.119±0.994	<b>27.017</b>
<b>Fe<sub>2</sub>O<sub>3</sub></b>	5.414±0.642	5.730±0.736	14.979±0.945	<b>8.708</b>
<b>CaO</b>	1.147±0.004	7.261±0.034	0.244±0.002	<b>2.884</b>
<b>MgO</b>	0.000	2.072±0.004	0.000	<b>0.691</b>

Chemical composition of broken bricks (BB 1, BB 2 and BB 3) also showed the most prevalent was  $\text{SiO}_2$ . BB 3 had the lowest amount of  $\text{SiO}_2$  though it had the highest amount of  $\text{Al}_2\text{O}_3$ . The results are presented in table 4.3. Magnesium oxide had highest percentage of 2.072% in clay 2. These indicated the amount of magnesium in all the samples was lower than the highest limit of 5% in accordance to ASTM C593 specifications. Normally, the level of MgO in commercial cement should be less than 2.8% (ASTM C150). High amount of MgO is not recommended because it will cause destructive expansion of the concrete. MgO has the ability of reacting with water in concrete to form expansive  $\text{Mg}(\text{OH})_2$ .

**Table 4.3: Chemical properties of Broken Bricks used**

<b>Property in %</b>	<b>Results BB 1</b>	<b>Results obtained BB 2</b>	<b>Results obtained BB 3</b>	<b>Mean Results</b>
<b>SiO<sub>2</sub></b>	75.735±1.348	76.610±1.868	60.040±1.250	<b>70.795</b>
<b>Al<sub>2</sub>O<sub>3</sub></b>	16.15±0.942	17.030±0.587	30.734±0.969	<b>21.305</b>
<b>Fe<sub>2</sub>O<sub>3</sub></b>	0.046±0.001	2.640±0.103	6.062±0.081	<b>2.916</b>
<b>CaO</b>	1.456±0.446	0.785±0.016	0.560±0.002	<b>0.934</b>
<b>MgO</b>	1.612±0.003	1.104±0.036	0.000	<b>0.905</b>

Comparative analysis was done between the properties of the lime used and the composition of commercial lime. Table 4.4. has the results

**Table 4.4: Chemical properties of Lime**

<b>Property in %</b>	<b>Lime used</b>	<b>Commercial Lime</b>
<b>SiO<sub>2</sub></b>	0.000	0.000
<b>Al<sub>2</sub>O<sub>3</sub></b>	1.092±0.47	1.948
<b>Fe<sub>2</sub>O<sub>3</sub></b>	2.599±0.000006	0.345
<b>CaO</b>	93.353±0.432	96.342
<b>MgO</b>	0.000	0.000

$$\text{Al}_2\text{O}_3 T_{\text{cal}}=1.621$$

$$T_{\text{tab}} = 4.303$$

$$T_{\text{cal}} < T_{\text{tab}}$$

Hence no significant difference

$$\text{Fe}_2\text{O}_3 T_{\text{cal}} = 650,673$$

$$T_{\text{tab}} = 4.303$$

$$T_{\text{cal}} > T_{\text{tab}}$$

Hence there is significant difference

$$\text{CaO } T_{\text{cal}} = 1.9004$$

$$T_{\text{tab}} = 4.303$$

$$T_{\text{cal}} < T_{\text{tab}}$$

Hence no significant difference

From the calculation above, it clearly shows there is no significant variation between the chemical properties of lime used and the commercial lime at 95% confidence level.

### 4.3 Loss of Ignition

Analysis of loss of ignition was done and the outcomes obtained are shown in table 4.5

**Table 4.5: Loss on Ignition Results**

<b>RBC</b>	<b>BBC</b>	<b>RBBC</b>	<b>CLAY</b>	<b>BB</b>	<b>BA</b>	<b>RHA</b>
<b>8.50%</b>	<b>6.34%</b>	<b>8.28%</b>	<b>9.58%</b>	<b>3.43%</b>	<b>15.62%</b>	<b>13.73%</b>

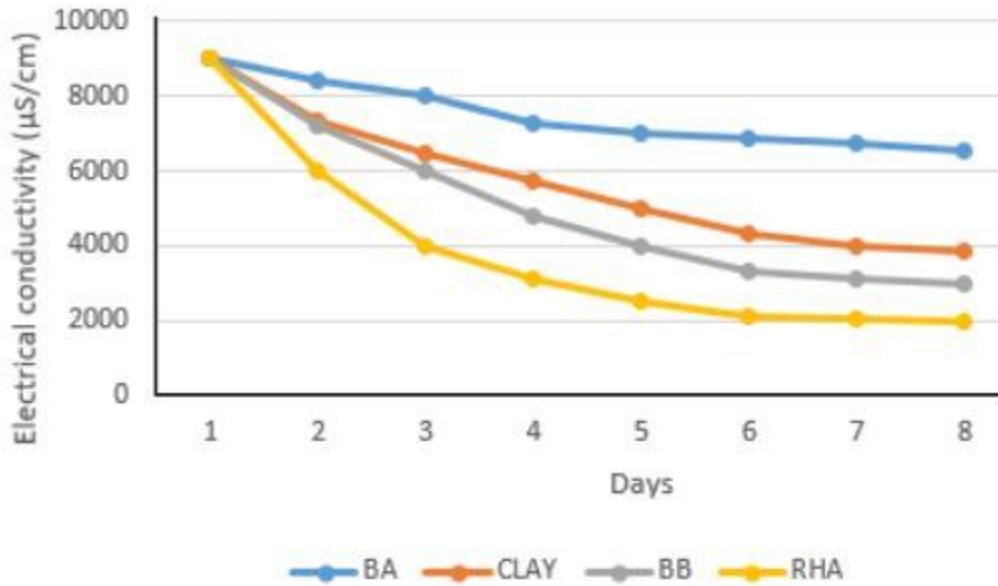
The BS EN 450 required a loss of ignition (LoI) of less than 7% for fly ash to be used in concrete, while the ASTM C 618-93 permits to 12% LoI (Adnan & Rahman, 2011). From the above results, BB met both the standards, clay met the ASTM standards. The LoI of 15.62% and 13.73% for BA and RHA was fairly above the other pozzolanas requirements utilized as alternative cementing materials. Maybe because of the presence of some unburnt material in ash. Though the ash was burnt approximately at 700°C, there is a possibility that some tiny materials turned up either partially burnt or unburnt. When

these pozzolanic materials were blended, it was found that RBC and RBBC conformed to the ASTM standards while BBC conformed to both the ASTM and BS EN 450 standards that requires a cementitious material to have an organic content of less than 12% and 7% respectively. (Parhizkar *et al.*, 2010). Organic matter in cementitious materials when in excess obstructs the pozzolanic reaction by coating the cement particles retarding their hydration.

#### **4.4 Decrease in Electrical Conductivity**

The results obtained for the pozzolans and calcium hydroxide reaction displayed a gradual decline in the system's electrical conductivity. This property is associated with the pozzolanic reaction of calcium hydroxide and amorphous silica to produce calcium silicate hydrate gels, with a related reduction in the calcium hydroxide concentration in the solution.

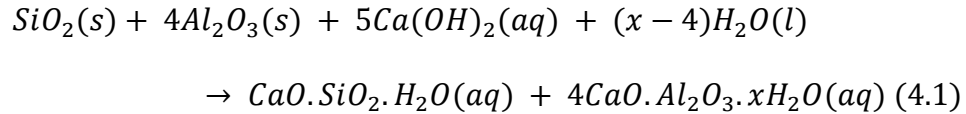
RHA had the highest rate of decrease in the electrical conductivity of 77% followed by BB 64%, Clay 56% and least was BA 26%. The change in electrical conductivity is shown in a pictogram in Fig. 4.1 Decrease of electrical conductivity because of  $\text{Ca(OH)}_2$  reduction when it reacts with amorphous silica in the pozzolana (Givi *et al.*, 2010b). The sample with the greatest change in electrical conductivity indicates it has the greatest value of pozzolanicity. Substances which show a great decrease in conductivity are good pozzolanic materials (Rosell-Lam *et al.*, 2011).



**Figure 4.1: Decrease in Electrical Conductivity**

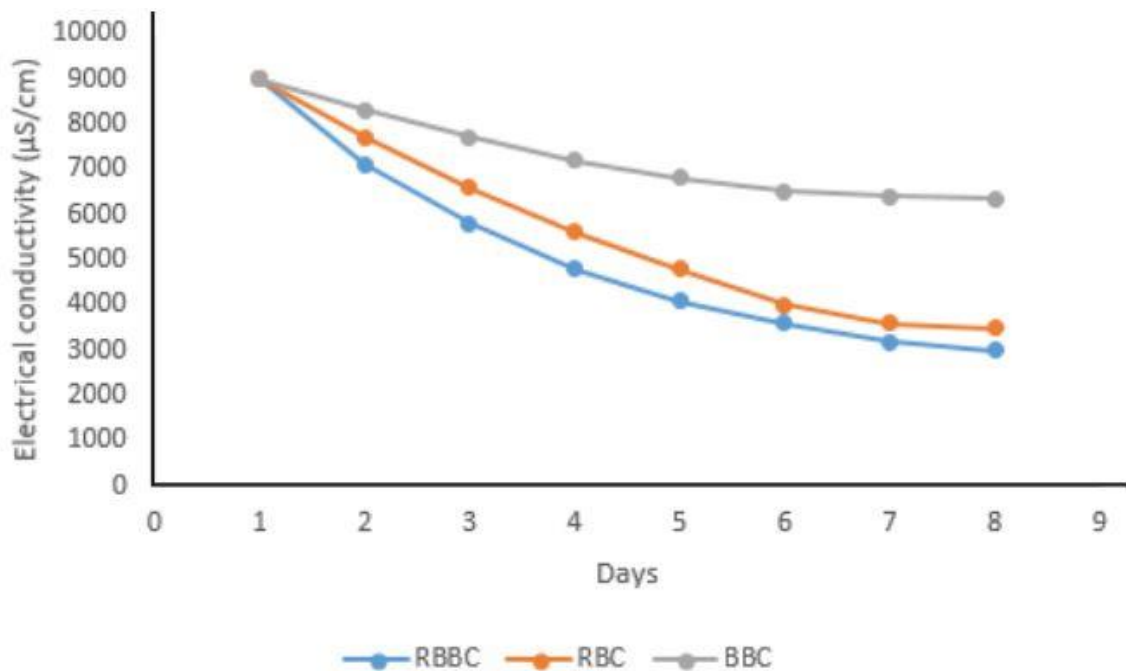
From the results, RBBC Showed a greater decrease of electrical conductivity with 66%, RBC 61% and BBC had the lowest decrease of 29%. This implies that the pozzolanic reaction was more in the RBBC Blend. A pH of above 12 and enough free  $\text{Ca}^{2+}$  are required to support the pozzolanic reaction. At this pH, the solubility of  $\text{Si}^{2+}$  and  $\text{Al}^{3+}$  is high enough to sustain the reaction (Cherian & Arnepalli, 2015).

During the pozzolanic reaction, water in the highly alkaline solution protonically attacks the pozzolanic particles, this makes the Si – OH at the particle's surface to dissociate to  $\text{SiO}_4^{4-}$  and  $\text{H}_3\text{O}^+$ , subsequently, the surface of the particle acquires a negative charge hence absorbing  $\text{Ca}^{2+}$  from calcium hydroxide  $\text{Ca}(\text{OH})_2$  triggering the detachment of the pozzolans into the liquid phase. Besides,  $\text{Ca}^{2+}$  at the surface of the particle reacts with alumina and silica forming a coat that becomes thicker gradually.



with x being an integer between 9 and 13 inclusive (Griffin, 2004)

John (2013) found that the electrical conductivity for Rice Husks Ash decreased by 1.3ms/cm whereas from the above data the RHA electrical conductivity decreased by 5ms/cm. The higher decrease was due to the high percentage of Silica (98%) in the composition.



**Figure 4.2: Decrease in Conductivity of the blends**

#### 4.5 Standard Consistency

The standard consistency of cement represents the lowest amount of water needed to trigger the chemical reaction between cement and water. The standard consistency for these binders was 0.9. The water demand increase can be accredited to the miniature size of the Pozzolana: Lime binder which increased the whole blend's surface area resulting

to higher water volume to form a workable paste (Memon *et al.*, 2012). An increased amount of water enhances the concrete's workability; however, it also results in issues like segregation and bleeding, negatively impacting the strength of the concrete. Conversely, a reduced water quantity reduces workability and prevents the formation of a uniform concrete structure.

#### 4.6 Setting Time

The setting time of the samples are shown in table 4.6 below.

**Table 4.6: Setting Time Data in Minutes**

Pozzolana:Lime Ratio		RBC	BBC	RBBC
<b>1:2</b>	<b>Initial</b>	$250 \pm 0.000^d$	$509.667 \pm 1.527^i$	$285.333 \pm 1.527^e$
	<b>Final</b>	$1302.667 \pm 1.527^l$	$2657 \pm 0.000^o$	$1485 \pm 0.000^k$
<b>1:1</b>	<b>Initial</b>	$204.667 \pm 1.527^b$	$435.333 \pm 0.577^h$	$425.333 \pm 1.527^g$
	<b>Final</b>	$1068.333 \pm 2.517^k$	$2226.667 \pm 2.517^n$	$2213.667 \pm 2.517^n$
<b>2:1</b>	<b>Initial</b>	$129 \pm 0.0^a$	$394 \pm 0.0^f$	$239.667 \pm 0.577^c$
	<b>Final</b>	$676.667 \pm 2.517^j$	$2057.667 \pm 1.527^m$	$1250.667 \pm 4.041^l$

- i. Means in the above table then same superscripted letter are not significantly different at 95% confidence level.
- ii. Means in the above table then different superscripted letter are significantly different (Tukey's test  $P < 0.05$ ) p values

**Table 4.7: ASTM Specifications C91 for Masonry Cement**

Masonry Cement type / Setting time	N	S	M
Initial Setting time (Minutes)	120	90	60
Final Setting time (Minutes)	1440	1440	1440

**Table 4.8: Kenyan Standards (KS EAS 18) for Portland Pozzolanic Cement**

<b>Initial Setting time (minutes)</b>	<b>Final Setting Time (minutes)</b>
Minimum 75	Maximum 600

All the samples had significant differences in setting time.

Setting is a word used to explain how cement paste stiffens and generally indicates transformation to a rigid state from a fluid state due to selective of tricalcium aluminate ( $C_3A$ ) and tricalcium silicate ( $C_3S$ ). Initial set correlates to a constant temperature rise whereas final set correlates with highest attainable temperature (Gambhir, 2013). The setting time results show that the optimal binder slightly exceeds the initial setting time's minimum requirement but conforms to the pozzolanic cement final setting time's maximum requirement according to ASTM requirements for Masonry Cements C91.

Findings report that the binder takes a prolonged duration to get to peak hydration temperature; the final setting time is estimated to 677 minutes comparing to the required maxima of 600 minutes for Portland Pozzolanic Cement (PPC). Implying that, compared to PPC cements hydration period, the 11 hours binder hydration is very slow. Because cement paste setting is controlled by  $C_3A$  reaction with water, the high setting times may be because of high quantity of pozzolan leading to high silica content in the mix. (Collepari, 1996) found out that both the pozzolan and  $Ca(OH)_2$  had tendencies of slowing the hydration of  $C_3A$ . In order to obtain high early strengths, lower the setting times to the necessary limits and increase the degree at which hydration takes place, there is need to introduce an accelerating admixture.

In his study, Okoya (2013) observed that his optimal blend of 30% Lime with 70% RHA had a setting time of 285 and 1485 minutes final setting.

#### 4.7 Mortar comprehensive strength

Mortar comprehensive strength was determined for 28 days, results are as below:

**Table 4.9: Mortar Compressive Strengths for 28 Days Results**

Pozzolan: Lime Ratio	RBC (N/mm <sup>2</sup> )	BBC (N/mm <sup>2</sup> )	RBBC (N/mm <sup>2</sup> )
1:2	1.53 ± 0.016 <sup>d</sup>	0.75 ± 0.008 <sup>e</sup>	0.90 ± 0.008 <sup>g</sup>
1:1	1.88 ± 0.031 <sup>b</sup>	0.88 ± 0.016 <sup>g</sup>	1.35 ± 0.008 <sup>e</sup>
2:1	2.88 ± 0.008 <sup>a</sup>	0.97 ± 0.004 <sup>f</sup>	1.61 ± 0.0 <sup>c</sup>

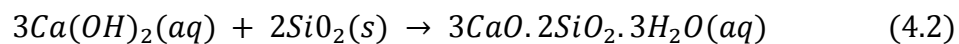
- i. Means in the above table then same superscripted letter are not significantly different at 95% confidence level.
- ii. Means in the above table then different superscripted letter are significantly different (Tukey's test  $P < 0.05$ ) p values

All the values were significantly different from the standard value (2N/mm<sup>2</sup>) of LP 20 Indian Standard specification for Lime Pozzolana mixture (IS 4098-1967). Only the comprehensive strength for RBC Poz: lime ratio 2:1 was greater than the standard value. The value for RBC the Poz: lime ratio 1:1 and RBBC Poz: lime ratio 1:1 were not significantly different.

Pozzolana's Compressive strength: Lime cement mixes generally rise with rising amount of Pozzolan, this is because there is adequate Silica, Alumina and Iron Oxide to act on Ca(OH)<sub>2</sub> forming additional cement compounds that is Calcium Silicates and Calcium Aluminates. Pozzolana decline in the mix leads to reduction of current Silica, Alumina,

and Iron Oxide reacting with  $\text{Ca(OH)}_2$  to get the C-S-H hence compressive strength of the binder reduces.

The requirement for air curing stems out of the reason that lime cement doesn't undergo hardening in water; instead, it solidifies when exposed to air, absorbing carbon (IV) oxide from the atmosphere to create calcium carbonate, thereby enhancing its strength. Consequently, both the solidification and hydration reactions are anticipated to impact the compressive strength of the mixture. The reaction between  $\text{SiO}_2$  and  $\text{Ca(OH)}_2$  from the Pozzolana is controlled by equation below



This relies on the presence of liquid water ( $\text{H}_2\text{O}$ ) that interacts with solid  $\text{CaO}$  to produce  $\text{Ca(OH)}_2$  in an aqueous form. The exothermic reaction between lime and silica from Pozzolana, as indicated in the equation, generates heat. This heat of hydration raises the overall temperature of the mixture, consequently accelerating the chemical reaction of hydration and enhancing strength gain, especially during the initial stages, when air curing is applied.

**Table 4.10: Classification for Hardened Rendering and Plastering Mortar Compressive Strength for 28 Days (BS En 998-1)**

TYPE	MEAN VALUE ( $\text{N/mm}^2$ )
CS i	0.4 – 2.5
CS ii	1.5 -5.0
CS iii	3.5 – 7.5
CS iv	>6.0

The optimal blend RBC had 28 day compressive strength between 1.53 to 2.88 N/mm<sup>2</sup> which falls under cement type CS ii as classified by BS En 998-1; Classification for Hardened Rendering and Plastering Mortar. The others; BBC and RBBC fall under cement type CS i.

## CHAPTER FIVE

### CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 Conclusions

The study aimed at characterizing potential supplementary cementing material within Busia County, Kenya. Characterization was done by determining the chemical composition of pozzolans. Chemical composition tests results validates that the RHA BA, BB and Clay studied have adequate pozzolanic material to utilize in producing supplementary cement, with Alumina ( $Al_2O_3$ ) Iron Oxide ( $Fe_2O_3$ ) and Silica ( $SiO_2$ ) total percentage greater than 70%, which was higher than ASTM C 618 minimum standards. The amount of MgO present was very low with the highest being in clay 2 which had 2.07%. This was in the standard range because the levels of MgO should not exceed 2.8%.

Cementing properties of RHA BA, BB and Clay were determined successfully. The data obtained shows decrease in all the pozzolans electrical conductivity used. RHA had the highest decrease rate in the electrical conductivity by 77% followed by BB 64%, Clay 54% and least was BA 26%. RHA had the highest pozzolanicity value and BA had the least though all of them had great change in electrical conductivity an indication that they can be used as pozzolan.

In addition, the study shows that, the optimal blend attained comprised of RHA, BB and Clay with air cured and a Pozzolan to Lime ratio of 2:1. The optimal Pozzolan: Lime binder had 677 minutes final setting time with 139 minutes initial setting time

demonstrating that the binder takes a prolonged duration reaching peak hydration temperature comparing with PPC cement. It implies that compared to PPC cements hydration, the binder hydration is very low.

The optimal blend RBC had 28 day compressive strength between 1.53 to 2.88 N/mm<sup>2</sup> which falls under cement type CS ii as classified by BS En 998-1; Classification For Hardened Rendering and Plastering Mortar. The others; BBC and RBBC fall under cement type CS i.

While the ideal binder doesn't meet the specified compressive strength standards for pozzolanic cements outlined in KS EAS 18, 2001, the attained strengths are still noteworthy and suitable for specific structural purposes. The 28-day mortar compressive strength of 2.88 N/mm<sup>2</sup> is sufficient for applications like plaster, floor screed, and masonry mortar rendering for use in low-cost housing as classified by BS EN 998-1.

## **5.2 Recommendations**

From this work the following recommended:

- i. Use of RHA and BA to make supplementary cementing material is recommended.
- ii. A feasibility study should be done to embrace the use of this binder as an alternative to Portland cement.

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## APENDICES

### Appendix I: Elemental composition of Pozzolans

#### RBC

<b>SiO</b>	77.95	77.91	77.98	77.947± 0.0875
<b>Al<sub>2</sub>O<sub>3</sub></b>	13.060	13.058	13.062	13.060±0.016
<b>Fe<sub>2</sub>O<sub>3</sub></b>	3.719	3.721	3.716	3.120+0.002
<b>CaO</b>	1.53	1.55	1.51	1.53±0.016
<b>MgO</b>	1.469	1.468	1.470	1.469±0.008

#### BBC

<b>SiO</b>	66.929	66.920	22.941	66.927±0.0086
<b>Al<sub>2</sub>O<sub>3</sub></b>	22.7373	22.733	22.740	22.737±0.003
<b>Fe<sub>2</sub>O<sub>3</sub></b>	5.730	5.735	5,727	5.731±0.033
<b>CaO</b>	1.604	1.607	1.601	1.604±0.0024
<b>MgO</b>	0.753	0.752	0.754	0.753±0.008

#### RBBC

<b>SiO</b>	80.199	80.190	80.211	80.200±0.0086
<b>Al<sub>2</sub>O<sub>3</sub></b>	11.643	11.641	11.646	11.643±0.0021
<b>Fe<sub>2</sub>O<sub>3</sub></b>	3.490	3.488	3.494	3.491±0.0025
<b>CaO</b>	1.096	1.099	1.093	1.096±0.0024
<b>MgO</b>	0.972	0.970	0.974	0.972±0.016

#### CLAY

<b>Property in %</b>	Trial 1	Trial 2	Trial 3	Mean
<b>SiO<sub>2</sub></b>	58.97	38.560	58.624	58.594±0.026
<b>Al<sub>2</sub>O<sub>3</sub></b>	27.017	27.002	27.035	27.018
<b>Fe<sub>2</sub>O<sub>3</sub></b>	8.707	8.704	8.711	8.704
<b>CaO</b>	2.884	2.882	2.886	2.884
<b>MgO</b>	0.691	0.692	0.690	0.691±0.008

#### BB

<b>Property in %</b>	Trial 1	Trial 2	Trial 3	Mean
<b>SiO<sub>2</sub></b>	70.795	70.802	70.781	70.792±0.0086
<b>Al<sub>2</sub>O<sub>3</sub></b>	21.305	21.301	21.309	21.305±0.00326
<b>Fe<sub>2</sub>O<sub>3</sub></b>	2.916	2.911	2.919	2.915±0.00326
<b>CaO</b>	0.935	0.934	0.933	0.934±0.008
<b>MgO</b>	0.905	0.908	0.903	0.905±0.0021

**BA**

Property in %	Trial 1	Trial 2	Trial 3	Mean
<b>SiO<sub>2</sub></b>	65.83	65.75	65.75	65.79±0.0034
<b>Al<sub>2</sub>O<sub>3</sub></b>	13.523	13.522	13.524	13.523±0.0013
<b>Fe<sub>2</sub>O<sub>3</sub></b>	5.719	5.717	5.718	5.718±0.008
<b>CaO</b>	9.951	9.955	9.948	9.951±0.0029
<b>MgO</b>	0.000	0.000	0.000	0.000

**RHA**

Property in %	Trial 1	Trial 2	Trial 3	Mean
<b>SiO<sub>2</sub></b>	94.873	94.905	94.852	94.876±0.0218
<b>Al<sub>2</sub>O<sub>3</sub></b>	0.511	0.512	0.513	0.512±0.008
<b>Fe<sub>2</sub>O<sub>3</sub></b>	0.707	0.709	0.708	0.708±0.008
<b>CaO</b>	0.902	0.903	0.901	0.902±0.008
<b>MgO</b>	0.000	0.000	0.000	0.000

**Chemical properties of Clays****CLAY 1**

Property in %	Trial 1	Trial 2	Trial 3	Mean
<b>SiO<sub>2</sub></b>	67.593	67.572	67.603	67.589±0.0129
<b>Al<sub>2</sub>O<sub>3</sub></b>	23.260	23.269	23.254	23.361±0.0062
<b>Fe<sub>2</sub>O<sub>3</sub></b>	5.414	5.410	5.418	5.414±0.00326
<b>CaO</b>	1.47	1.159	1.151	1.152±0.005
<b>MgO</b>	0.000	0.000	0.00	0.00

**CLAY 2**

Property in %	Trial 1	Trial 2	Trial 3	Mean
<b>SiO<sub>2</sub></b>	59.482	59.468	58.496	59.149±0.462
<b>Al<sub>2</sub>O<sub>3</sub></b>	23.672	23.668	23.680	23.673±0.106
<b>Fe<sub>2</sub>O<sub>3</sub></b>	5.730	5.722	5.739	5.730±0.0069
<b>CaO</b>	7.261	7.232	7.286	7.260±0.00146
<b>MgO</b>	2.072	2.045	2.096	2.071±0.0208

**CLAY 3**

Property in %	Trial 1	Trial 2	Trial 3	Mean
SiO <sub>2</sub>	48.716	47.724	48.712	48.717±0.00526
Al <sub>2</sub> O <sub>3</sub>	34.119	34.105	34.140	34.121±0.0144
Fe <sub>2</sub> O <sub>3</sub>	14.976	14.985	14.970	14.977±0.00755
CaO	0.244	0.236	0.254	0.245±0.00737
MgO	0.00	0.00	0.00	0.00

**Chemical Properties of Broken Bricks used****BB 1**

Property in %	Trial 1	Trial 2	Trial 3	Mean
SiO <sub>2</sub>	75.735	75.698	75.765	75.733±0.027
Al <sub>2</sub> O <sub>3</sub>	16.15	16.19	16.11	16.15±0.033
Fe <sub>2</sub> O <sub>3</sub>	0.046	0.047	0.045	0.046±0.008
CaO	1.456	1.457	1.454	1.456±0.0013
MgO	1.612	1.610	1.614	1.612±0.016

**BB 2**

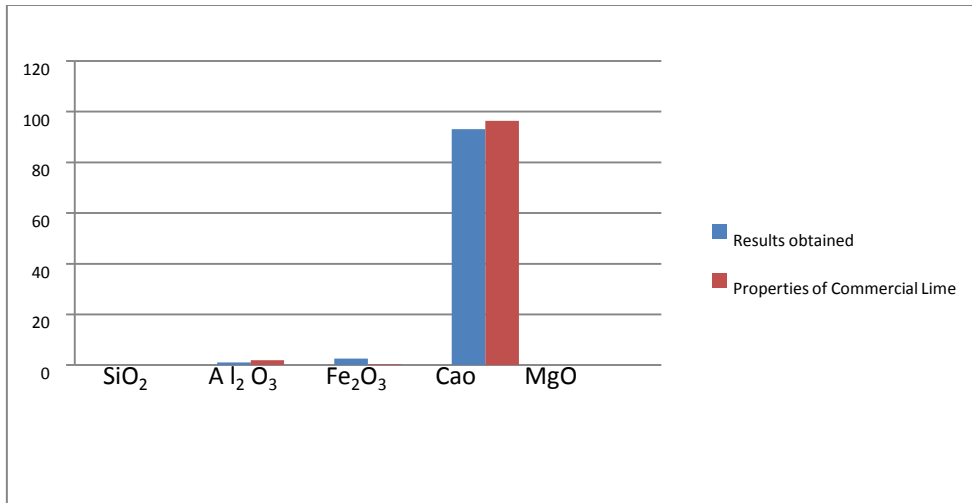
Property in %	Trial 1	Trial 2	Trial 3	Mean
SiO <sub>2</sub>	76.610	76.642	76.590	76.614±0.0124
Al <sub>2</sub> O <sub>3</sub>	17.030	17.026	17.035	17.030±0.004
Fe <sub>2</sub> O <sub>3</sub>	2.640	2.641	2.639	2.641±0.0013
CaO	0.785	0.788	0.783	0.785±0.003
MgO	1.104	1.103	1.105	1.104±0.013

**BB 3**

Property in %	Trial 1	Trial 2	Trial 3	Mean
SiO <sub>2</sub>	76.610	76.642	76.590	76.614±0.0124
Al <sub>2</sub> O <sub>3</sub>	17.030	17.026	17.035	17.030±0.004
Fe <sub>2</sub> O <sub>3</sub>	2.640	2.641	2.639	2.641±0.0013
CaO	0.785	0.788	0.783	0.785±0.003
MgO	1.104	1.103	1.105	1.104±0.013

**Chemical composition of Lime**

	1	2	3	mean
Al <sub>2</sub> O <sub>3</sub>	1.092	1.090	1.094	1.092±0.47
Fe <sub>2</sub> O <sub>3</sub>	2.596	2.599	2.602	2.599±0.000006



### Chemical Properties of Lime used

#### Setting Time Data

<b>1:02</b>		250	1303	510	2657	285	1485
<b>1:01</b>		205	1068	435	2267	425	2214
<b>2:01</b>		130	677	395	2058	240	1250
			<b>1:2</b>			<b>MEAN</b>	<b>STD</b>
<b>RBC</b>	<b>Initial</b>	249	250	251	250	250	1
	<b>Final</b>	1303	1301	1304	1302.667	1302.667	1.527525
<b>BBC</b>	<b>Initial</b>	508	510	511	509.6667	509.6667	1.527525
	<b>Final</b>	2657	2654	2660	2657	2657	3
<b>RBBC</b>	<b>Initial</b>	285	284	287	285.3333	285.3333	1.527525
	<b>Final</b>	1483	1485	1487	1485	1485	2
			<b>1:1</b>				
<b>RBC</b>	<b>Initial</b>	206	205	203	204.6667	204.6667	1.527525
	<b>Final</b>	1071	1068	1066	1068.333	1068.333	2.516611
<b>BBC</b>	<b>Initial</b>	435	436	435	435.3333	435.3333	0.57735
	<b>Final</b>	2267	2264	2269	2266.667	2266.667	2.516611
<b>RBBC</b>	<b>Initial</b>	424	425	427	425.3333	425.3333	1.527525
	<b>Final</b>	2211	2214	2216	2213.667	2213.667	2.516611
			<b>2:1</b>				
<b>RBC</b>	<b>Initial</b>	128	130	129	129	129	1
	<b>Final</b>	677	674	679	676.6667	676.6667	2.516611
<b>BBC</b>	<b>Initial</b>	393	396	395	394.6667	394.6667	1.527525
	<b>Final</b>	2059	2058	2056	2057.667	2057.667	1.527525
<b>RBBC</b>	<b>Initial</b>	239	240	240	239.6667	239.6667	0.57735
	<b>Final</b>	1247	1250	1255	1250.667	1250.667	4.041452

<b>1:2</b>	250	1303	510	2657	285	1485
<b>1:1</b>	205	1068	435	2267	425	2214
<b>2:1</b>	130	677	395	2058	240	1250
		<b>1:2</b>			<b>MEAN</b>	<b>SD</b>
<b>RBC</b>	<b>Initial</b>	249	250	251	250	1
	<b>Final</b>	1303	1301	1304	1302.667	1.527525
<b>BBC</b>	<b>Initial</b>	508	510	511	509.6667	1.527525
	<b>Final</b>	2657	2654	2660	2657	3
<b>RBBC</b>	<b>Initial</b>	285	284	287	285.3333	1.527525
	<b>Final</b>	1483	1485	1487	1485	2
		<b>1:1</b>				
<b>RBC</b>	<b>Initial</b>	206	205	203	204.6667	1.527525
	<b>Final</b>	1071	1068	1066	1068.333	2.516611
<b>BBC</b>	<b>Initial</b>	435	436	435	435.3333	0.57735
	<b>Final</b>	2267	2264	2269	2266.667	2.516611
<b>RBBC</b>	<b>Initial</b>	424	425	427	425.3333	1.527525
	<b>Final</b>	2211	2214	2216	2213.667	2.516611
		<b>2:1</b>				
<b>RBC</b>	<b>Initial</b>	128	130	129	129	1
	<b>Final</b>	677	674	679	676.6667	2.516611
<b>BBC</b>	<b>Initial</b>	393	396	395	394.6667	1.527525
	<b>Final</b>	2059	2058	2056	2057.667	1.527525
<b>RBBC</b>	<b>Initial</b>	239	240	240	239.6667	0.57735
	<b>Final</b>	1247	1250	1255	1250.667	4.041452

### Mortar Compressive Strength for 28 days

#### RBC

<b>POZ : LIME RATIO</b>	Trial 1	Trial 2	Trial 3	MEAN
1:2	1.53	1.51	1.55	1.53±0.016
1:1	1.88	1.90	1.85	1.876±0.031
2:1	2.88	2.89	2.87	2.88±0.008

#### BBC

<b>POZ : LIME RATIO</b>	Trial 1	Trial 2	Trial 3	MEAN
1:2	0.75	0.74	0.76	0.75±0.008
1:1	0.88	0.86	0.90	0.88±0.016
2:1	0.97	0.975	0.965	0.970±0.004

**RBBC**

<b>POZ : LIME RATIO</b>	Trial 1	Trial 2	Trial 3	MEAN
1:2	0.90	0.91	0.92	0.91±0.008
1:1	1.35	1.34	1.36	1.35±0.008
2:1	1.61	1.61	1.61	1.61±0.0



Jaw crusher



**Sample**

**Appendix II: Kenyatta University Research Authorization****KENYATTA UNIVERSITY  
GRADUATE SCHOOL**E-mail: [dean-graduate@ku.ac.ke](mailto:dean-graduate@ku.ac.ke)Website: [www.ku.ac.ke](http://www.ku.ac.ke)P.O. Box 43844, 00100  
NAIROBI, KENYA  
Tel. 8710901 Ext. 57530

Our Ref: I56/29971/2014

DATE: 10<sup>th</sup> October, 2017Director General,  
National Commission for Science  
& Innovation,  
P.O. Box 30623-00100,  
**NAIROBI**

Dear Sir/Madam,

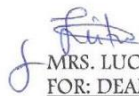
**RE: RESEARCH AUTHORIZATION FOR OKUMU MARY ASSUMPTOR – REG. NO.  
I56/29971/2014**

I write to introduce Ms. Okumu Mary Assumptor who is a Postgraduate Student of this University. She is registered for M.Sc degree programme in the Department of Chemistry.

Ms. Assumptor intends to conduct research for an M.Sc Proposal entitled, "Probing Optimal Blends of Pozzolans to Develop Supplementary Cementing Material within Busia County, Kenya".

Any assistance given will be highly appreciated.

Yours faithfully,

  
MRS. LUCY N. MBAABU  
FOR: DEAN, GRADUATE SCHOOL

JG/rwm



**KENYATTA UNIVERSITY  
GRADUATE SCHOOL**

E-mail: [dean-graduate@ku.ac.ke](mailto:dean-graduate@ku.ac.ke)

Website: [www.ku.ac.ke](http://www.ku.ac.ke)

P.O. Box 43844, 00100  
NAIROBI, KENYA  
Tel. 810901 Ext. 57530

Internal Memo

FROM: Dean, Graduate School

DATE: 10<sup>th</sup> October, 2017

TO: Okumu Mary Assumptor  
C/o Chemistry Department.

REF: 156/29971/2014

SUBJECT: APPROVAL OF RESEARCH PROPOSAL  
=====

This is to inform you that Graduate School Board, at its meeting of 27<sup>th</sup> September, 2017 approved your Research Proposal for the M.Sc Degree Entitled, "Probing Optimal Blends of Pozzolans to Develop Supplementary Cementing Material within Busia County, Kenya".

You may now proceed with data collection, subject to clearance with the Director General, Commission for Science, Technology & Innovation.

As you embark on your data collection, please note that you will be required to submit to Graduate School completed Supervision Tracking forms per semester. The form has been developed to replace the progress report forms. The supervision Tracking Forms are available at the University's website under Graduate School webpage downloads.

Thank you.

JULIA GITU  
FOR: DEAN, GRADUATE SCHOOL

c.c. Chairman, Department of Chemistry

Supervisors:

1. Dr. Karanja Thiong'o  
C/o Department of Chemistry  
Kenyatta University
2. Dr. Erick Masika  
C/o Department of Chemistry  
Kenyatta University

JG/rwm

### Appendix III: NACOSTI Research Authorization



#### NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone: +254-20-2213471,  
2241349, 3310571, 2219420  
Fax: +254-20-318245, 318249  
Email: dg@nacosti.go.ke  
Website: www.nacosti.go.ke  
When replying please quote

NACOSTI, Upper Kabete  
Off Waiyaki Way  
P.O. Box 30623-00100  
NAIROBI-KENYA

Ref. No. **NACOSTI/P/18/29263/20838**

Date: **23<sup>rd</sup> February, 2018**

Mary Assumptor Okumu  
Kenyatta University  
P.O. Box 43844-00100  
**NAIROBI.**

#### **RE: RESEARCH AUTHORIZATION**

Following your application for authority to carry out research on *“Probing optimal blends of pozzolans to develop supplementary cementing material within Busia County, Kenya,”* I am pleased to inform you that you have been authorized to undertake research in **Busia County** for the period ending **23<sup>rd</sup> February, 2019**.

You are advised to report to **the County Commissioner and the County Director of Education, Busia County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

*GP Kalerwa*

**GODFREY P. KALERWA MSc., MBA, MKIM  
FOR: DIRECTOR-GENERAL/CEO**

Copy to:

The County Commissioner  
Busia County.

The County Director of Education  
Busia County.

## REPUBLIC OF KENYA



## THE PRESIDENCY

MINISTRY OF INTERIOR AND CO-ORDINATION OF NATIONAL GOVERNMENT  
 ccbusia@gmail.com  
 Telephone: 055 - 22598  
 Fax No: 055 - 22231  
 When replying please quote

COUNTY COMMISSIONER'S OFFICE  
 BUSIA COUNTY  
 P.O. BOX 14  
 BUSIA (K)

Ref No. ADM 15/4 VOL.III/110  
 and Date

9<sup>th</sup> March, 2018

All Deputy County Commissioners  
BUSIA COUNTY

RESEARCH AUTHORIZATION

Following research authorization vide letter Ref. No. NACOSTI/P/18/29263/20838 dated 23<sup>rd</sup> February, 2018 by the National Commission for Science, Technology and Innovation on "Probing optimal blends of pozzolans to develop supplementary cementing material within Busia County, Kenya"

This is to inform you that Mary Assumptor Okumu has been authorized to carry out research in Busia County for the period ending 23<sup>rd</sup> February, 2019

F. O. Ayieko  
 For: County Commissioner  
BUSIA COUNTY

Copy to:

Mary Assumptor Okumu


**Appendix IV: NACOSTI Permit**

**THIS IS TO CERTIFY THAT:**  
**MS. MARY ASSUMPTOR OKUMU**  
**of KENYATTA UNIVERSITY, 0-50409**  
**NAMBALE, has been permitted to**  
**conduct research in Busia County**

**Permit No : NACOSTI/P/18/29263/20838**  
**Date Of Issue : 23rd February,2018**  
**Fee Received :Ksh 1000**

**on the topic: PROBING OPTIMAL**  
**BLENDS OF POZZOLANS TO DEVELOP**  
**SUPPLEMENTARY CEMENTING MATERIAL**  
**WITHIN BUSIA COUNTY, KENYA.**

**for the period ending:**  
**23rd February,2019**




*G.P. Kaletwa*  
.....  
**Director General**  
**National Commission for Science,**  
**Technology & Innovation**


*Assumptor*  
.....  
**Applicant's**  
**Signature**

**CONDITIONS**

1. The License is valid for the proposed research, research site specified period.
2. Both the Licence and any rights thereunder are non-transferable.
3. Upon request of the Commission, the Licensee shall submit a progress report.
4. The Licensee shall report to the County Director of Education and County Governor in the area of research before commencement of the research.
5. Excavation, filming and collection of specimens are subject to further permissions from relevant Government agencies.
6. This Licence does not give authority to transfer research materials.
7. The Licensee shall submit two (2) hard copies and upload a soft copy of their final report.
8. The Commission reserves the right to modify the conditions of this Licence including its cancellation without prior notice.



**REPUBLIC OF KENYA**



**National Commission for Science,**  
**Technology and Innovation**

**RESEARCH CLEARANCE**  
**PERMIT**

**Serial No.A 17640**  
**CONDITIONS: see back page**