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# Probing Optimal Blends of Pozzolans to Develop Supplementary Cementing Material Within Busia County, Kenya.

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**Abstract:** *Utilization of pozzolanic materials in cement manufacturing offers an alternative method of preparing cement with increased durability of concrete and better mechanical properties. It also reduces the high energy requirement associated with production of Ordinary Portland Cement (OPC). This study investigated the use of natural pozzolans within Busia County, that is; rice husks ash (RHA), bagasse ash (BA), clay and broken bricks (BB) to make Pozzolana Cement (PC). Three types of pozzolana ashes were made and characterized using electrical conductivity tests, X-Ray Fluorescence and X-Ray diffraction analysis. The Pozzolans comprised of: RBC- mixture of RHA, ground BB and clays, BBC- had BA, ground BB and clay and RBBC -RHA, BA, ground BB and clays. The binder was prepared by mixing each Pozzolana ash with lime at different intervals. Mortar was tested for physical cement tests. Chemical composition tests showed that the Pozzolans studied were good pozzolanic material for use in supplementary cement production, with a combined percentage of Silica ($SiO_2$), Iron Oxide ($Fe_2O_3$), and Alumina ($Al_2O_3$) of more than 70%. $SiO_2$ had the highest percentage. The levels of MgO were less than 2.8%. The electrical conductivity test done showed that BA had the highest rate of decrease in the electrical conductivity followed by RHA, BB and least was clay. In addition, optimal Pozzolana: Lime ratio was 2:1, and the best blend of the pozzolana ashes was RBC, which gave a 28 days compressive strength of $2.88 N/mm^2$ cured in air. The optimal Pozzolana: Lime binder had an initial setting time of 130 minutes with a final setting time of 677 minutes indicating that the binder took a longer time to attain the peak hydration as compared to PPC cement. The study provides an alternative method for making cement which is ecofriendly, cheap 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.*

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## I. Introduction

The world population has increased steadily leading to urbanization and high demand to expand infrastructure which has necessitated the increase in demand for use of cement for construction. Manufacture of Ordinary Portland Cement (OPC) process involves use of a lot of energy and also emits a lot of carbon dioxide to the atmosphere implicated in global warming and climate change (van Deventer *et al.*, 2010). The process is also expensive and consumes huge quantities of natural resources which can remain for next generations. In addition, concrete structures lack durability which may waste natural resources. Therefore, it is crucial to acquire and develop sustainable binding materials suitable for construction which redress the decrease of the world's most vital fossils energy and decrease the undesirable impacts involved in cement production on the environment.

Alternative cementitious materials are tiny materials used together with Portland cement or used as Portland cement. The use of cementitious materials is cheap and enhances the properties of the concrete. These materials include; silica fume, limestone, dust and natural or manufactured pozzolans. Their use 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 them durable (Gartner, 2004).

Pozzolan is defined as a siliceous or alumino-siliceous material that contains small quantities or lucks cementitious value but when ground to fine form and reacted with alkaline or alkaline earth hydroxides at room temperature and in presence of moisture will lead to formation of or will assist in formation of compounds with cementitious properties according to the American Society for Testing and Materials (Habeeb and Fayyadh, 2009).

Pozzolans are prepared by reacting silicate-based materials and calcium hydroxide which is formed by hydration of cement to make additional cementitious materials. The pozzolans are mixed with lime to form additional calcium silicate hydrate, which is responsible for binding concrete. When more lime is consumed, there is increase in the strength of the concrete, decrease in its density, decrease in pozzolans efflorescence, decrease or elimination of the propensity for alkali-silica reaction (Girard, 2011).

Time is a major factor to consider during hydration because the rate of hydration decreases steadily with time (Lothenbach *et al.*, 2011). In addition, the size of anhydrated cement particles decrease with time. For example, a study done by Otieno (2014) showed that, after 28 days in contact with water, grains of cement were found to have hydrated to a depth of only 4µm, and 8µm after a year.

Pozzolanic materials have two basic properties; their tendency to react with lime and ability to form products able to bind when combine with lime (Juenger *et al.*, 2011). Properties of pozzolans depend mostly on the major components which are silica and alumina. Silica and alumina combine with calcium hydroxide and form cementitious compounds, specifically the calcium silicate hydrates (C-S-H) and calcium aluminum hydrates. Materials with a high percentage of silica that is amorphous tend to be more pozzolanic because amorphous silica is more soluble than crystalline silica (Scrivener and Nonat, 2011).

Finely ground bricks and other ceramic materials have been used in mortar mixes since ancient times. Not all bricks, however, have pozzolanic potential. The Smeaton project and other studies have been instrumental in establishing the parameters for pozzolanicity of brick regarding firing temperature and particle size (Teutonico *et al.*, 2000). The Smeaton project proved that brick dust with a particle size below 75 microns had a greater impact on accelerating setting time and creating a higher strength hydraulic mortar. Also, the Smeaton project determined that bricks fired below 950ºC had the most positive effect on strength and durability, but was not conclusive in whether this was related to firing temperature alone or associated with the mineralogical composition of the brick (Vieira and Monteiro, 2009).

The quality, characteristics of the clay and its ability to act as pozzolan are determined by the mineralogy composition of the brick clay. As a general rule, clays containing 20-30% alumina and 50-60 % silica and the remainder consisting of magnesia carbonate, calcium carbonate and iron oxide are considered ideal for brickmaking. Clay composition is highly variable among different sources, and composition can vary significantly even among the same beds (Rogers, 2011).

Bagasse is a fibrous residue as a result of the extraction of juice (sugar) from sugarcane. Sometimes it is used in industries as fuel in boilers. Previously, it was burnt as a means of solid waste disposal but now, since it has been found to be very useful, it is burnt under controlled temperatures for further use. The BA contains amounts of unburnt matters, Silicon, Aluminium and Calcium Oxides. Bagasse Ash can be identified as a probable pozzalanic 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 (Sua-Iam and Makul, 2013).

BA depicts good pozzolanic properties when heated between 800 and $1000^0$C for 20 mininutes (Morales *et al.*, 2009) or treated by air calcination at $600^0$C for 3 hours. The good pozzolanic properties are atributed to the presence of amorphous silica, low Carbon content and high specific surface area (Cordeiro *et al.*, 2009).

Corderio, and others 2009 proved that pozzolanic activity of BA may be significantly increased by mechanical grinding in a vibratory mill. Ground BA with a loss on ignition of less than 10% provided an excellent pozzolanic material and could be used to partially replace Portland cement in concrete (Chusilp *et al.*, 2009).

Rice husk is an agricultural by-product generated from rice production. When incinerated into ash, the rice husk ash has been accepted as a pozzolana because it contains about 67-70% silica, about 4.9 Aluminium and 0.956% Iron Oxide (Oyetola and Abdullahi, 2006). The rice husk ash contains Silica in amorphous form which is able to react with calcium hydroxide ($Ca(OH)_2$) during hardening. Using RHA specifically with coarser average particle size reduces the amount of water consumed more than fly ash mixtures (Givi *et al.*, 2010a). The workability observed from 50% to 100% for proportionate replacement of RHA from 5% to 20%. This is attributed to the fact that, the cement particles are evenly distributed hence could trap large amounts of water resulting to decrease of water requirements to the system in order to achieve desirable consistency.

The particle packing effect is also associated with the Partial replacement of cement with RHA improved workability of fresh concrete for both 95µm and 5µm particle sizes. However, the RHA with average particle size of 95µm gave rise to higher stump values for comparable cases. Ultimately it was found that 10% ultra-fine RHA – blended concrete could be considered as an optimum formulation because of its value of comprehensive strength, less water permeability and acceptable workability. From the literature, it has been observed that partial substitution of cement with RHA enhances the comprehensive strength and workability of concrete and reduces its water permeability. On top of that, reducing RHA average particle size results to a desirable effect on the comprehensive strength and water permeability of hardened concrete but indicates adverse effect on the workability of fresh concrete.

Studies on the cementitious properties of lime: RHA mixes depict that there is still contradiction concerning the magnitude of compressive strength obtained with a given blend of lime: RHA mortar mixes and as regards the optimum lime: RHA mix ratio for maximum strength gain. Mehta & Pitt; (2006) examined the compressive strength properties of rice husks ash: lime cements using an 20:80 lime: ash blend and found out that at 3 days, a mortar strength greater than 10 $N/mm^2$ was achieved and at 28 days strength greater than 35 $N/mm^2$ was achieved.

In Kenya several experiments on pozzolanic activity of RHA have been done. Mitullah and Wachira, (2003) examined the pozzolanic activity of RHA with commercially hydrated lime (CHL) and was able to prove the best results were obtained when a ratio of 2:1 lime:RHA was used.

Waswa-Sabuni B. and others; (2002) tested the pozzolanic activity of RHA obtained from rice husks from Mwea rice mills (Kenya) using a controlled burn RHA (500-700°C) to make lime:RHA mortar and concrete cubes. The cement proportions were 100:0, 80:20, 70:30, 60:40 and 50:50 lime:RHA. Chemical analysis of the ash showed high silica content (greater than 70%) indicating high pozzolanic property. They established that RHA improved the compressive strength of lime greatly with the strength increasing with increased amount of RHA. Of all the lime:RHA ratios used, the 50:50 lime: RHA mix gave the best results with a mortar strength of 2.8 $N/mm^2$ and concrete cube strength of 12.7 $N/mm^2$, workability and setting times were found to decrease with increased amounts of RHA.

In Busia County, Kenya, there are potential pozzolanic clays which have been used for pottery and brick making. Rice husks and bagasse are agricultural wastes also found within the region and a blend of these may lead to production of pozzolana cement which is produced at lower energy than Portland cement and may therefore avail an affordable binder.

The information gap addressed in this respect is to determine the optimum pozzolana: lime ratio for making cementitious materials using a blend of rice husks ash, bagasse ash, broken bricks and clays as pozzolana within Busia County, Kenya.

BA and 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.

## II. Materials And Methods

### 2.1 Sampling

Waste bricks were collected from construction and demolition sites within Busia County. Bagasse was collected from the local sugar industries around Nambale Sub County. Rice husks were collected from paddy fields in Bunyala Sub County. Limestone was collected from Tororo Uganda. The clay samples were collected from pottery sites in Butula sub County.

### 2.2 Sample Pre-Treatment

Bagasse and limestone were heated in a kiln at controlled temperatures between 700ºC -900ºC. The kiln measured about 1m x 1m and 1.5m high. The walls of the kiln were made of bricks and a metallic chimney at the top. The temperature within the kiln was controlled by opening and closing of the holes on the kiln walls.

The BA obtained was sieved through a mesh, and the lime produced was slaked. The same process was repeated with rice husks but the temperatures were between $500^oC$ -$700^oC$. Broken bricks and clay samples were ground using a laboratory ball mill and pulverized at a temperature of $500^oC$. Each sample was passed through 100 micron 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.

### 2.3 Electrical Conductivity Test

This was carried out according to a method described by Vu and others, (2001). Double distilled water (200 ml) was put in a 500 ml glass beaker then placed on a hot magnet plate and then heated at a temperature of 40 ± 1°. Calcium hydroxide was added to the distilled water till saturation point. Magnetic stirrer was used to mix the solution after addition of calcium hydroxide for two minutes. Electrical conductivity of this solution was determined using a conductivity meter. 5.0g of the pozzolana sample was added to the saturated solution maintained at 40 ± 1 °C. The contents of the beaker were continuously stirred for two minutes. The electrical conductivity of the resulting solution was then measured. The difference between the conductivity of the saturated solution of calcium hydroxide and the pozzolana solution was calculated as a measure of the pozzolanic activity of the sample. This procedure was done in triplicate for each of the pozzolana samples and the average recorded.

### 2.4 XRF Analysis

Solid samples of pozzolana ashes were irradiated with high energy X-rays from a controlled X-ray tube. The results of the elemental composition of the pozzolans were then tabulated in a table.

### 2.5 Loss on Ignition (LoI)

Representative samples of known weight were ignited in a muffle furnace and heated gradually to 900$^{o}$C and the temperature maintained for 30 minutes. The crucible was cooled and weighed. LoI was expressed as a percentage of original sample weight. The results were represented on a table

### 2.6 Development of Pozzolanic Cement

The binder was made by replacing Pozzolana Lime ratios of 1:2, 1:1 and 2:1. Specimen used in lime pozzolan strength development and set time were mixed according to ASTM C305 using a Hobart C-100 mixer.

### 2.7 Standard Consistency

The Vicat method as specified by the European Standards EN 196-3:2000 was used. The plusnger, made of brass, is of at least 45 mm effective length and 10 mm diameter. The Vicat mould, also made of brass, is in the form of a truncated cone with a depth of 40 mm and an internal diameter of 75 mm. 450g of the binder was gauged with water to form a cement paste of standard consistency. The paste was transferred immediately to the mould of the Vicat Apparatus resting on a non-porous plate, which had previously been placed on a lightly greased plane glass base-plate, and filled to excess without compacting or vibrating. The excess material was removed by a gentle sawing motion with a straight edge. The Vicat apparatus was calibrated with the plunger by lowering the plunger to rest on the base plate to be used and adjusting the pointer to read zero on the scale. The plunger was raised to the stand-by position. Immediately after leveling the paste, the mould and the base-plate was transferred to the Vicat apparatus and positioned centrally under the plunger. The plunger was lowered gently until it was in contact with the paste. The plunger was allowed to pause in this position for two seconds in order to avoid initial velocity. The moving parts were then quickly released and the plunger allowed penetrating vertically into the center of the paste. The scale was read when penetration ceased.

The recorded scale reading indicates the distance between the bottom face of the plunger and the base-plate. The water content for this paste was calculated as a percentage of the mass of the dry Pozzolana. Lime cement and recorded as water required for standard consistence.

### 2.8 Setting time test

### 2.8.1 Initial setting time

The Vicat method was also used for the determination of the initial setting time. The pozzolana cement paste, using the percentage of water recorded for the standard consistency, was gauged into the Vicat mould. The paste, confined in the mould and resting on the base plate, was placed under the Vicat apparatus with the needle provided for the initial setting time determination in place. The needle was then lowered gently into contact with the surface of the test block and quickly released and allowed to sink in. This process was repeated until the needle, when brought into contact with the test block and released as described above, did not penetrate beyond a point approximately 4mm from the bottom of the mould. The period elapsing between the time when the water was added to the cement and the time at which the needle ceased to pierce beyond 4mm from the bottom of the test block was noted as the initial setting time.

### 2.8.2 Final Setting Time

For the determination of the final setting time, the needle used for the initial setting time was replaced by the needle with an annular attachment. The cement block was also turned upside-down for the determination. The cement paste was considered as finally set when, upon applying the needle gently to the surface of the test block, only the needle made an impression, while the attachment failed to do so. The time from gauging, at which the needle ceased to pierce the test block, as described above, was noted as the final setting time.

### 2.8.3 Strength of Lime: Pozzolana Binder

Mortar compressive strength test was conducted on each Pozzolana; Lime mix in order to give an indication of strength of the resulting binder. This was performed in accordance to BS EN 196-1 (2005), using standard mortar prism test. The prismatic test specimens were 40 mm x 40 mm x 160mm in size and were cast from a batch of plastic mortar containing one part by mass of cement and three parts by mass of standard sand with a water: binder ratio of 0.9.The standard water: binder ratio for mortar compressive test is usually 0.5, however a higher water-cement ratio of 0.9 established from the standard consistency was used for the mix of Lime: pozzolan binder due to its high water demand.

The materials for each mortar cube were mixed separately. 450 g of each binder were blended with 1350 g of standard sand in a motorized mixer. Afterwards, the required quantity of water was added and mixed for about 4 min. The mortar cubes were moulded in average room temperature of 25$^{o}$C. The moulding involved tamping the mortar 60 times in the moulds and then vibrating them on a vibrating machine for 2 minutes. After gauging, the moulds were covered with a metal plate and placed under damp jute sacks to be cured for 24 hours. The pozzolana cement cubes were removed from their moulds after 24 hours and left to cure in air at a temperature of 23 $\pm 2^0$ C and relative humidity of 65±5 for 28 days. This is because lime cement does not harden in water and it takes a long time to cure therefore the 3 and 7 days strength was not able to be determined. The cubes after curing were tested for compressive strength by loading the sides of the cubes uniformly with a compressive strength testing machine until fracture appeared. The maximum load in $N/mm^2$ was recorded.

### 2.9 Data Analysis.

The data obtained was graphically represented, then further subjected to student's t-test to show significant difference or otherwise between samples.

## III. Results And Discussion

### 3.1 Elemental composition

The analysis done using XRF spectroscopy showed high content of $SiO_2$ followed by $Al_2O_3$, $Fe_2O_3$, CaO and least was MgO in all the samples analyzed (Table 1). 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 $SiO_2$, a major component of cement. The materials used met the standard required for pozzalana materials (Claus, 2008)

**Table 1: XRF Analysis For Elemental Composition**

| **Property in %** | **RBC** | **BBC** | **RBBC** | **CLAY** | **BB** | **BA** | **RHA** |
|---|---|---|---|---|---|---|---|
| **$SiO_2$** | 77.95± 2.34 | 66.929±1.88 | 80.199±1.65 | 58.597±1.43 | 70.795±2.01 | 65.791±1.87 | 94.873±3.22 |
| **$Al_2O_3$** | 13.06±0.998 | 22.737±1.32 | 11.643±0.96 | 27.017±1.29 | 21.305±1.17 | 13.523±1.658 | 0.511±0.002 |
| **$Fe_2O_3$** | 3.719±0.763 | 5.730±1.112 | 3.490±0.856 | 8.708±0.897 | 2.916±4.324 | 5.719±1.113 | 0.708±0.012 |
| **CaO** | 1.53±1.002 | 1.604±0.811 | 1.096±0.054 | 2.884±0.682 | 0.934±0.016 | 9.951±1.215 | 0.902±0.002 |
| **MgO** | 1.469±0.872 | 0.753±0.025 | 0.972±0.104 | 0.691±0.008 | 0.905±0.102 | 0.000 | 0.000 |

The percentage composition of the Clay, BA, BB and RHA was determined and tabulate in pictogram in figure 1. In all the samples used, Silcon (iv) oxide had the highest percentage. $SiO_2$ was highest in RHA with a94.9% and lowest in clay with 58.6%. The percentage of $Al_2O_3$ was highest in the clay, followed by BB, BA and least in RHA. Levels of MgO in all the samples were below 1.5 %.

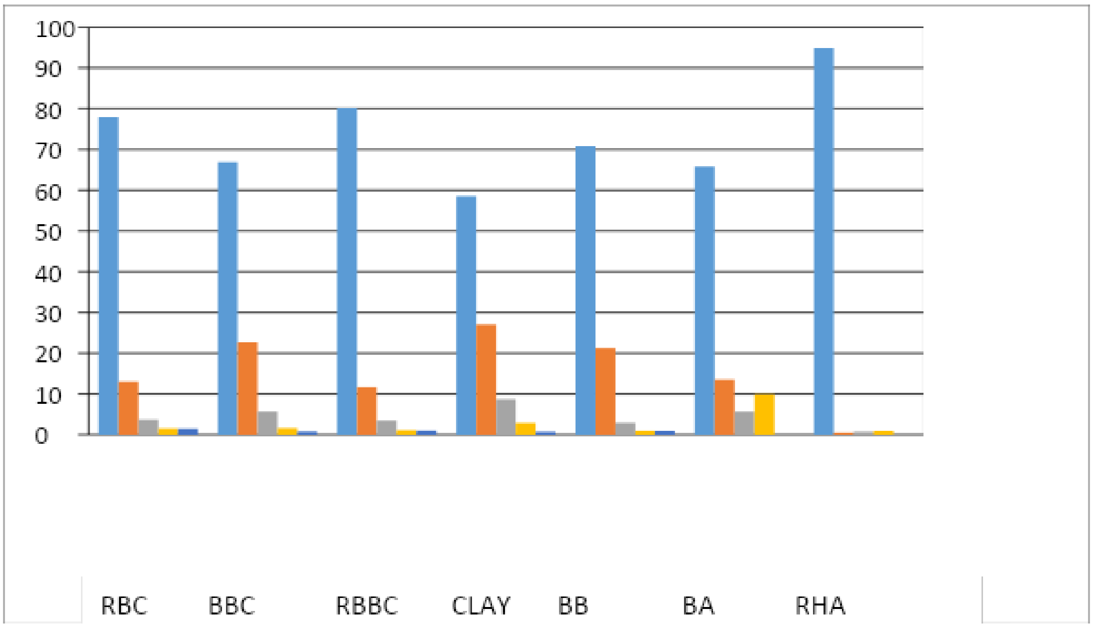

**Fig. 1: The percentage elemental composition**

Chemical analysis of the clays used was done and tabulate on table 2. Silcon (iv) oxide had the highest percentage in all the clays used i.e, Clay 1, 2 and 3. Clay 1 had high percentage of $SiO_2$ only. Clay 3 had high percentage of aluminum oxide, iron (iii) oxide and calcium oxide. Magnesium oxide was only present in clay 2. The composition of this clay met the ASTM and the Brazilian standards of specification for pozzolans that, pozzolans should have more than 70% by weight of silica ($SiO_2$), aluminum oxide ($Al_2O_3$), and iron oxide

($Fe_2O_3$) (Dodson, 2013). This avails the required glassy content to react with lime in the presence of water at room temperature to produce the cementing materials (Protus, 2014).

**Table 2: Chemical properties of Clays used**

| **Property in %** | **Results obtained Clay 1** | **Results obtained Clay 2** | **Results obtained Clay 3** | **Mean Results** |
|---|---|---|---|---|
| **$SiO_2$** | 67.593±1.624 | 59.482±1.678 | 48.716±1.043 | **58.597** |
| **$Al_2O_3$** | 23.260±0.886 | 23.672±0.989 | 34.119±0.994 | **27.017** |
| **$Fe_2O_3$** | 5.414±0.642 | 5.730±0.736 | 14.979±0.945 | **8.708** |
| **CaO** | 1.147±0.004 | 7.261±0.034 | 0.244±0.002 | **2.884** |
| **MgO** | 0.000 | 2.072±0.004 | 0.000 | **0.691** |

Chemical composition of BB1, BB2 and BB3 also showed the most prevalent was $SiO_2$. BB3 had the lowest amount of $SiO_2$ though it had the highest amount of $Al_2O_3$. The results are depicted in table 3.

**Table 3**: Chemical properties of Broken Bricks used

| **Property in %** | **Results obtained BB 1** | **Results obtained BB 2** | **Results obtained BB 3** | **Mean Results** |
|---|---|---|---|---|
| **$SiO_2$** | 75.735±1.348 | 76.610±1.868 | 60.040±1.250 | **70.795** |
| **$Al_2O_3$** | 16.15±0.942 | 17.030±0.587 | 30.734±0.969 | **21.305** |
| **$Fe_2O_3$** | 0.046±0.001 | 2.640±0.103 | 6.062±0.081 | **2.916** |
| **CaO** | 1.456±0.446 | 0.785±0.016 | 0.560±0.002 | **0.934** |
| **MgO** | 1.612±0.003 | 1.104±0.036 | 0.000 | **0.905** |

Magnesium oxide had highest percentage of 1.61%. These indicated the amount of magnesium in all the samples was lower than the highest limit of 5% as per ASTM standard (ASTM C, 1991). Normally, the level of MgO in commercial cement should be less than 2.8%. High amount of MgO is not recommended because it will cause destructive expansion of the concrete. MgO has the ability to react with water in concrete to form expansive $Mg(OH)_2$. $Mg(OH)_2$.reacts with silica in the pozzolana to form non cementitious magnesium silicate hydrates (El-Didamony *et al.*, 2014).

Comparative analysis was done between the properties of the lime used and the commercial lime and the results were indicated on table 4.

**Table 4**: Chemical properties of Lime used

| **Property in %** | **Results obtained for Lime used** | **Properties of Commercial Lime** |
|---|---|---|
| **$SiO_2$** | 0.000 | 0.000 |
| **$Al_2O_3$** | 1.092±0.47 | 1.948 |
| **$Fe_2O_3$** | 2.599±0.000006 | 0.345 |
| **CaO** | 93.353±0.432 | 96.342 |
| **MgO** | 0.000 | 0.000 |

**$Al_2O_3$ $T_{cal}$ =1.621**
**$T_{tab}$ = 4.303**
**$T_{cal} < T_{tab}$**
**Hence no significant difference**
**$Fe_2O_3$ $T_{cal}$ = 650,673**
**$T_{tab}$ = 4.303**
**$T_{cal} > T_{tab}$**
**Hence there is significant difference**
**CaO $T_{cal}$ =1.9004**
**$T_{tab}$ = 4.303**
**$T_{cal} < T_{tab}$**
**Hence no significant difference**

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

### 3.2. Loss of ignition

Analysis of loss of ignition was done and the results obtained are shown in table .5

**Table 5: Loss on Ignition Results**

| RBC | BBC | RBBC | CLAY | BB | BA | RHA |
|---|---|---|---|---|---|---|
| 8.50% | 6.34% | 8.28% | 9.58% | 3.43% | 15.62% | 13.73% |

The BS EN 450 required a loss of ignition (LoI) of less than 7% for fly ash to be used in concrete (Jones *et al.*, 2006), while the ASTM C 618-93 allows up to 12% LoI (Adnan *et al.*, 2009) . From the above results, BB met both the standards, clay met the ASTM standards. The LoI of 15.62% and13.73% for BA and RHA was however relatively high compared to the requirement of other pozzolanas used as cement replacement materials. This could be attributed to some small quantities of un-burnt material in the ash. Although the ash was burnt at about $700^o$ C, it is possible that some pockets of material came out either un-burnt or partially burnt. 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 (Parhizkar *et al.*, 2010).

### 3.3 Decrease in Electrical Conductivity

The results obtained for the reaction between the pozzolans and $Ca(OH)_2$ displayed a gradual decrease in the electrical conductivity of the system. This property is associated with the pozzolanic reaction between amorphous silica (Si) and CH to give the formation of gels (C-Si-H), with a corresponding decrease in the CH concentration in the solution (Villar-Cociña *et al.*, 2011). Decrease in electrical conductivity up to 8 days is shown on figure 2 below.

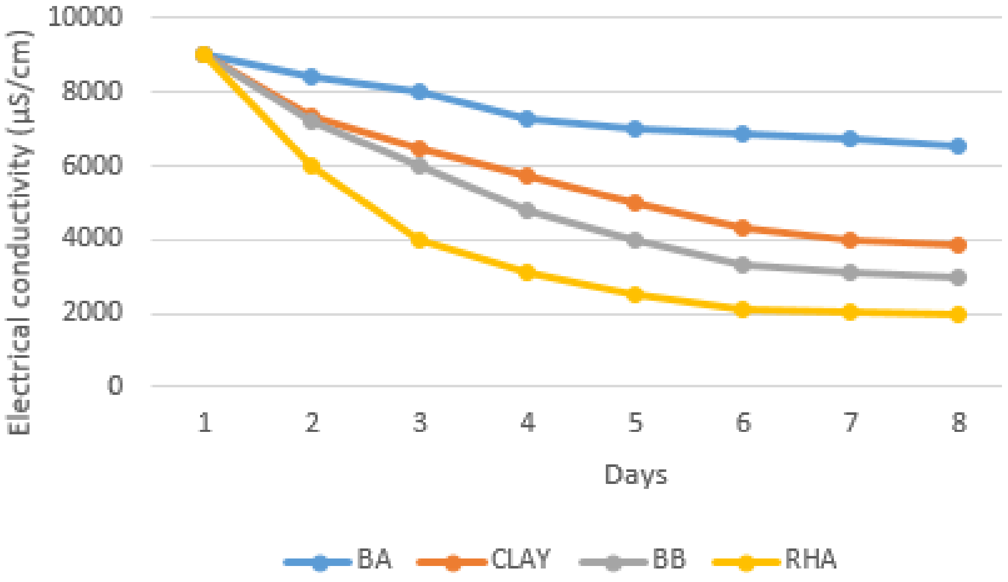

**Fig. 2: Electrical conductivity values taken for 8 days**

RHA had the highest rate of decrease in the electrical conductivity followed by BB, Clay and least was BA. Decrease in the electrical conductivity is caused by reduction of the $Ca(OH)_2$ 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).

### 3.4 Standard Consistency

The standard consistency for these binders was 0.9. The increase in water demand is due to the smaller particle size of the Pozzolana: Lime binder which increased the surface area of the whole mix translating into higher water volume to form a workable paste (Memon *et al.*, 2012).

### 3.6 Setting Time

The initial and final setting time of the samples are shown in a pictogram on figure 3 and also on table 6 below.

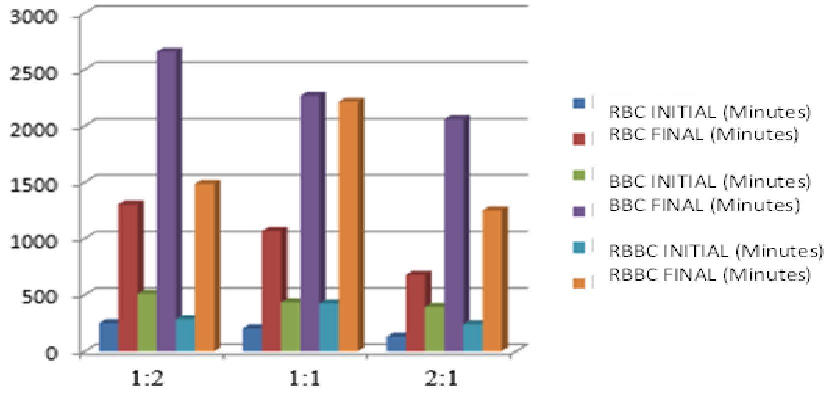

**Fig. 3: setting time test**

**Table 6**: Setting Time Data

| POZ:LIME RATIO | | RBC | BBC | RBBC |
|---|---|---|---|---|
| 1:2 | **Initial** | $250 \pm 0.000^{d}$ | $509.667 \pm 1.527^{i}$ | $285.333 \pm 1.527^{e}$ |
| | **Final** | $1302.667 \pm 1.527^{l}$ | $2657 \pm 0.000^{o}$ | $1485 \pm 0.000^{k}$ |
| 1:1 | **Initial** | $204.667 \pm 1.527^{b}$ | $435.333 \pm 0.577^{h}$ | $425.333 \pm 1.527^{g}$ |
| | **Final** | $1068.333 \pm 2.517^{k}$ | $2226.667 \pm 2.517^{n}$ | $2213.667 \pm 2.517^{n}$ |
| 2:1 | **Initial** | $129 \pm 0.0^{a}$ | $394 \pm 0.0^{f}$ | $239.667 \pm 0.577^{c}$ |
| | **Final** | $676.667 \pm 2.5171^{j}$ | $2057.667 \pm 1.527^{m}$ | $1250.667 \pm 4.041^{l}$ |

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

**Table 7: Kenyan Standards (KS EAS 18) for Portland Pozzolanic Cement**

| Initial Setting time (minutes) | Final Setting Time (minutes) |
|---|---|
| Minimum 75 | Maximum 600 |

Setting Times and Mortar Compressive Strength of Optimal POZ: Lime mix

Mortar compressive strength of optimal POZ: Lime Binder with age In accordance to KS EAS 18-1 2001: composition specification and conformity criteria of common cements, PPC is required to conform to the following: minimum initial setting time of 75 minutes, maximum final setting time of 600 minutes, a 2 day minimum mortar compressive strength of 7Mpa, and 28 day minimum mortar compressive strength of 32.5Mpa. Initial set corresponds to a rapid rise in temperature while final set corresponds to the peak temperature (Gambhir, 2013).

The results of the setting times in Table 6 indicate that the optimal Lime:RHA binder meets the minimum requirement of initial setting time but does not conform to the maximum requirement for final setting time of portland pozzolanic cement in accordance to KS EAS 18-1. The results show that the binder takes a longer time to reach the peak hydration temperature; the final setting time is approximately 11 hours as compared to the required maximum of 10 hours. This means that the 11 hours hydration of the binder is very slow compared to that of PPC cements. Since setting of cement paste is controlled by reaction of $C_3A$ with water, the high setting times found could also be due to the low quantity of alumina in the RHA. Table 2 shows that the amount of alumina in the RHA is only 4.76% which means that in the optimal binder the total amount of alumina is approximately 3.33% whereas in the production of portland cements, alumina constitutes approximately 7% of the raw material (Tsakiridis *et al.*, 2004). Thus there is need to introduce an accelerating admixure to increase rate of hydration and lower the setting time of the binder to the required range and to also achieve high early strengths. The mortar compressive strength of optimal POZ:Lime binder was determined at various ages of 2 days, 3 days, 7 days, 14 days and at 28 days. KS EAS 18-1 specifies only a 2 day minimum mortar compressive strength of 7Mpa, and 28 day minimum mortar compressive strength of 32.5Mpa.

### 3.5 Mortar comprehensive strength

Mortar comprehensive strength was determined for 28 days and the results are tabulated in Table 8.

**Table 8: Mortar compressive strengths for 28 days results**

| POZ : LIME RATIO | RBC ($N/mm^2$) | BBC ($N/mm^2$) | RBBC ($N/mm^2$) |
|---|---|---|---|
| **1:2** | $1.53 \pm 0.016^d$ | $0.75 \pm 0.008^e$ | $0.90 \pm 0.008^g$ |
| **1:1** | $1.88 \pm 0.031^b$ | $0.88 \pm 0.016^g$ | $1.35 \pm 0.008^e$ |
| **2:1** | $2.88 \pm 0.008^a$ | $0.97 \pm 0.004^f$ | $1.61 \pm 0.0^c$ |

i. Means in the above table followed by same superscripted letter are not significantly different at 95% confidence level.

ii. Means in the above table followed by different superscripted letter are significantly different (Tukey's test $P < 0.05$) p values.

All the values where significantly different from the standard value ($2N/mm^2$) of LP 20 Indian standard. 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.

Compressive strength of Pozzolana: Lime cement mixes was found to generally increase with increased amount of Pozzolan, this is because there is adequate Silica, Alumina and Iron Oxide to react with $Ca(OH)_2$ to form more cementitious compounds that is Calcium Silicates and Calcium Aluminates. Reduction of Pozzolana in the mix resulted in the reduction of available Silica, Alumina, and Iron Oxide to react with $Ca(OH)_2$ to form the C-S-H hence a reduction in the compressive strength of the binder.

The need for air curing arose from the fact that lime cement does not harden in water but hardens when exposed to the air by absorbing carbon dioxide from the air to form calcium carbonate hence its strength. Thus in the case of air curing, it is expected that both hardening and hydration reaction contribute to the compressive strength of the mix. The hydration reaction between $Ca(OH)_2$ and $SiO_2$ from the Pozzolana is controlled by equation below;

$$3Ca(OH)_2 + 2SiO_2 \rightarrow 3CaO.2SiO_2.3H_2O$$

From molecular mass theory calculations based on equation above, and reducing for the percentages of CaO in the lime and $SiO_2$ in the Pozzolana, it was found that the optimum mix, based purely upon the hydration equation, should be 52% Lime with 48% Pozzolana. The results of air cured samples are approximately confirmed using this calculation. This is however dependent on the available $H_2O$ which reacts with CaO to form $Ca(OH)_2$.The reaction between lime and silica from Pozzolana shown in equation is exothermic. The resulting heat of hydration further elevates the temperature of the mix hence increasing the rate of chemical reaction of hydration and of gain of strength in case of air curing at early ages.

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

The pictorial presentation of the mortar comprehensive strength results is shown in figure 4

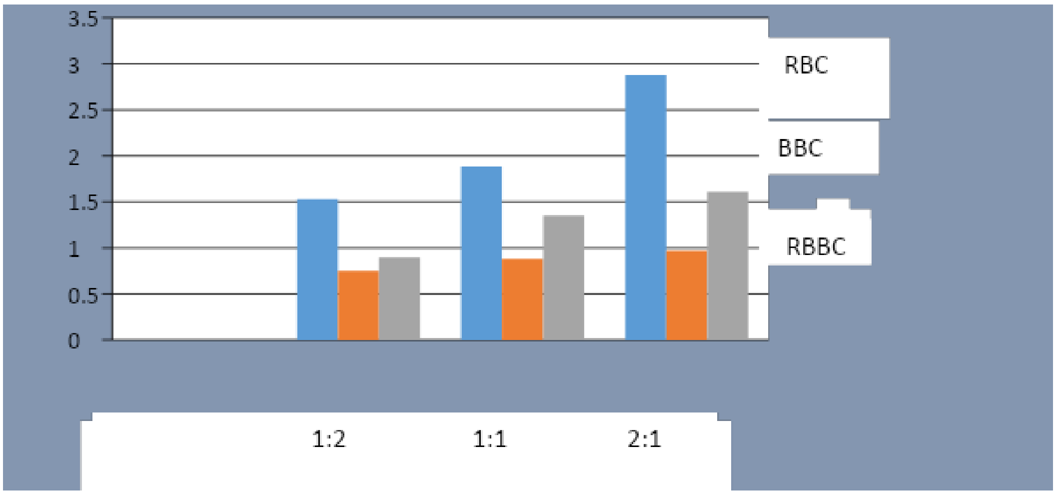

**Fig. 4: Mortar compressive strengths for 28 days results**

## IV. Conclusions

From the results of chemical composition tests, it can be concluded that the RHA BA, BB and Clay studied are good pozzolanic material for use in supplementary cement production, with a combined percentage of Silica ($SiO_2$), Iron Oxide ($Fe_2O_3$) and Alumina ($Al_2O_3$) of more than 70%, which was above the ASTM C 618 minimum standards.

In addition, data obtained shows decrease in the electrical conductivity of all the pozzolans used. RHA had the highest rate of decrease in the electrical conductivity followed by BB, Clay and least was BA.

The study also shows that, a blend of RHA, BB and Clay with air curing is recommended and a Pozzolana: Lime ratio of 2:1. The optimal Pozzolana : Lime binder had an initial setting time of 130 minutes with a final setting time of 677 minutes indicating that the binder takes a longer time to reach the peak hydration temperature as compared to PPC cement. This means that the hydration of the binder is very low compared to that of PPC cements.

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

The strengths achieved were quite significant for certain structural applications. The 28 day mortar compressive of 2.88 $N/mm^2$ is good enough for structural applications such as masonry mortar, floor screed, plaster and rendering for use in low cost housing as classified by BS EN 998-1.

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