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# Pozzolanicity and Compressive Strength Performance of Kibwezi Bricks Based Cement

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***Abstract:*** *This study investigated the pozzolanicity and compressive strength of mortar made from a mixture of ground calcined clay bricks (GB)vis-a-vis OPC and PPC from Kibwezi region-Kenya. The GB was subjected topozzolanicity tests and blended with OPC at replacement levels of 25, 35, 45 and 50 percent to make OPCGB. Similar blends were also made with PPC but at lower replacement levels of 15, 20 and 25 to make PPCGB.Water to cement ratios of 0.4, 0.5 and 0.6 were used to make mortar prisms.Three mortar prisms were prepared for each category of cement. The mortar prisms were subjected tocompressive strength analysis. The results showed a decrease in compressive strength with increase in replacement of OPC and PPC on 3$^{rd}$, 7$^{th}$and 28$^{th}$ day of curing. 15 percent replacement showed a better compressive strength development compared to 20 and 25 percent replacement for PPC. PPC, OPCGB-35 and PPCGB-15 exhibited similar performance in terms of strength development. The test cements, PPCGB-15 and OPCGB-35 can thus be used in building similar structures as commercial PPC.*

***Key Words:*** *GB, OPCGB, PPCGB, OPC, PPC*

## I . Introduction.

The poor climatic conditions in Kibwezi region, Makueni County in Kenya has led to less agricultural produce and also lack of other income generating activities. Clay brick making has therefore become one of the major economic activities of many residents. This provides a cheap source of building material as well as source of income. Wet clay is used as brick binder since it has no added cost. This has led to construction of weak structures which can collapse under adverse weather conditions. Kibwezi which is located at the base of volcanic Chyulu hills has soil which is suitable for clay brick making. This is because they are mainly Ferralsols, Cambisols and Luvisols[1]. Also just like other soils in drylands, the soils contain low organic matter with a carbon content of between 0.1-0.5 percent [1]. Portland cement, a major ingredient of holding together pieces of aggregates to form a solid mass is unaffordable to many in developing countries [2]. This is due to high energy cost for its production[3]. In Kibwezi region -Kenya, building materials are unaffordable to a majority of its low earning population. This has led to poor housing and structures.

Calcined clay has been shown to be potential pozzolanic material[4, 5,6]. Calcined clay in the form of ground fired ceramic items like tiles, bricks et cetra has been used in improving the properties of lime mortars [7]. Muthengia blended Ordinary Portland Cement (OPC) with broken bricks and other materials and found that the resulting Portland Pozzolanic cement met the Kenya standard up to 45 percent replacement [5]. Most Kenyan-clays are pozzolanic when calcined [8,9,6]. GB can thus be put to an economic use by blending it with Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC). The pozzolana reduces the quantity of clinker used hence making the cements affordable. This may lower the cost of construction hence improving the living standards of the low income earners. There is need therefore, to investigate the pozzolanicity and the compressive strength of the resultant test cement in for its durability.

## II. Experimental Procedure

Broken brown bricks were sampled randomly from Kinyambu, Mbui Nzau and Kathyaka in Makueni County- Kenya and crushed separately usinga HFM 100 grinder model 62 B/140, HG Herzog (1980). The resultant clay samples were dried at 110 $^oC$ in an oven to constant weight. They were then cooled and finely ground using laboratory ball mill 62 B/140, HG Herzog (1980) to 90 μm mesh size. The powdered GB was blended with commercial OPC to replacement levels of 25, 35, 45 and 50 percent replacement. The GB was similarly blended with commercial PPC at 15, 20, and 25 percent replacement. The blended samples were then milled using laboratory ball mill for ten minutes to ensure uniformity and complete mixing. They were labeled appropriately as OPCGB-25, 35, 45 and 50 percent replacement levels as well as PPCGB-15, 20 and 25 percent replacement levels. The ground clays were subjected to chemical analysis using XRF technique.

The pozzolanic activity test was done in accordance to a literature method [10]. $200cm^3$ of distilled water was placed in a glass beaker on a hot magnetic plate and heated to $40 \pm 1$ °C. 0.8 g calcium hydroxide powder was added to the distilled water to make a saturated solution. Electrical conductivity of the resulting solution was determined using conductivity meter. 5.0 g of ground pozzolana sample was added to the above saturated solution maintained at $40 \pm 1$ °C. The contents were continuously stirred using a magnetic stirrer for two minutes. Electrical conductivity of the resulting solutions was measured after 30 minutes for a period of four hours. The difference between the conductivity of saturated solution of calcium hydroxide and pozzolana solution was calculated as a measure of pozzolanicity.

Mortar prisms were prepared in accordance to KS EAS 18:1-2001 [12] and compressive strength determined at 3rd, 7th and 28 days of curing.

## III. Results and Discussions

### 3.1 Chemical Composition of the Pozzolana

Table 4.1 shows the chemical composition in terms of oxides of sampled ground broken clay bricks (GB).

| OXIDE % | a | ±S.E | b | ±S.E | c | ±S.E |
|---|---|---|---|---|---|---|
| $SiO_2$ | 51.50 | ±0.21 | 60.51 | ±0.09 | 51.84 | ±0.05 |
| $Al_2O_3$ | 15.50 | ±0.10 | 15.09 | ±0.06 | 18.45 | ±0.33 |
| CaO | 1.40 | ±0.03 | 2.16 | ±0.02 | 1.72 | ±0.03 |
| $Fe_2O_3$ | 6.39 | ±0.05 | 8.78 | ±0.08 | 8.57 | ±0.08 |
| $SiO_2 + Al_2O_3 + Fe_2O_3$ | 73.39 | ±0.25 | 84.38 | ±0.12 | 78.86 | ±0.27 |

The results show that all the GB samples had the sum of $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ above the Kenya Standard. The standards require a minimum of 70 percent by weight. These oxides are considered to be the main components of pozzolanas. This is because they react with $Ca(OH)_2$ from OPC during hydration of blended cement and or lime to form cementitious materials [14]. $Fe_2O_3$ is important as it is involved in formation of ($Al_2O_3$-$Fe_2O_3$-tri) mineral group that is structurally similar to ettringite [15]. The presence of iron oxides also allows stabilization of CH to occur efficiently with little cement, as a result of pozzolanic reactions or hardening effects [15].

The alkali levels of all GB samples are within the acceptable values by several standards like Kenya Standard KS 02 1263 (1993) and German standard DIN 1045-2 (2000). The levels should not be in excess of 1.5 percent which would otherwise cause cracking of the concrete. The alkali level maintains the pH of the pore water in cured cement paste above 12. This is important in passivating the rebar if embedded [16]. However, higher levels of the alkalis cause expansion of the cured mortar or concrete through alkali aggregate reactions [3].

The MgO levels of the GB as a pozzolana studied were below the maximum limits of 5 percent [12]. Several commercial cements which have passed Kenya Standard KS 02 1260 (1994) contain below 5 percent for Portland cement according to ASTM C150 (1902). The MgO is limited because of its destructive expansion in concrete that may occur if free MgO hydrates. In cured mortar and concrete, magnesium may form non cementitious magnesium hydrate silicates and expansive $Mg(OH)_2$[13].

In addition to the participation of $Al_2O_3$ in the pozzolanic reaction, the one availed by the pozzolana can also be used to partly bind the chlorides in cement structures via the formation of Friedel‘s salts [18] as shown in equations 4.3 and 4.4;

$$CaCl_2 + 3CaO.Al_2O_3.6H_2O + 4H_2O \longrightarrow 3CaO.Al_2O_3.CaCl_2.10H_2O \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \ 1$$

$$2NaCl + 3CaO.Al_2O_3.6H_2O + Ca(OH)_2 + 4H_2O \rightarrow 3CaO.Al_2O_3.CaCl_2.10H_2O + 2NaOH \quad \ldots\ldots.. \ 2$$

The Friedel‘s salt formation consequently lowers the levels of free chloride and hence reduces the chloride ingress in concrete thus improving on durability of reinforced concrete [18].

### 3.2 Pozzolanicity Test Results.

Fig. 1 shows pozzolanicity test results. The results are presented as percentage loss of conductivity against time.

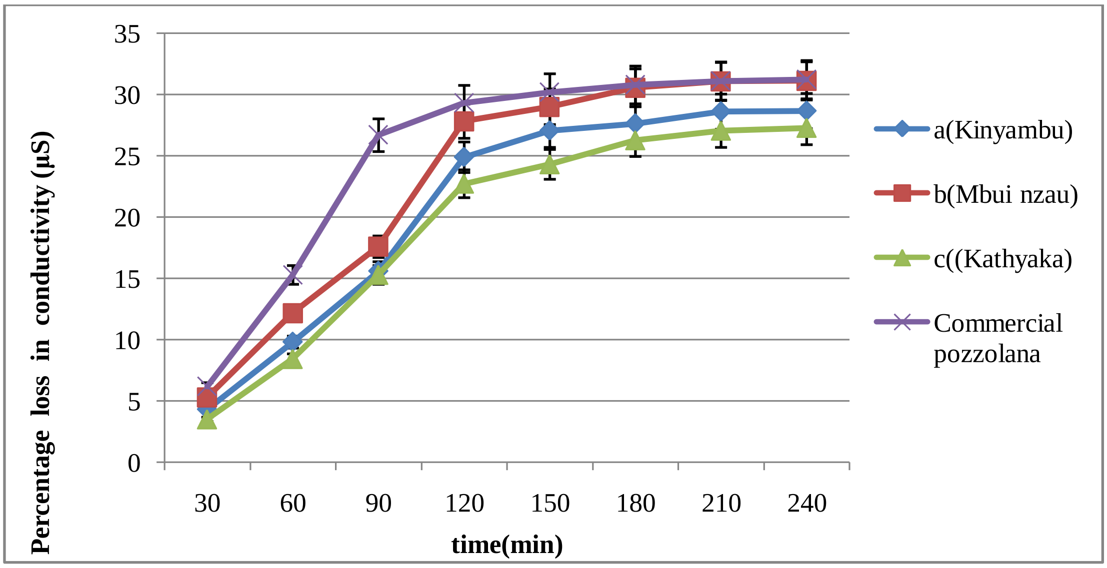


**Figure 1*:* Pozzolanic Activity of the GB Clay Samples**

It was observed that the pozzolanas resulted in decreased conductivity of the water – lime mixture. The loss in electrical conductivity is due to lime fixation as a result of pozzolanic reactivity [19, 14]. [20] while studying the pozzolanic activity of rice husk ash made similar observation and attributed this to decrease in the amount of $Ca^{2+}$ and $OH^{-}$ ions in the water-lime suspension. The silica and aluminate phases, in pozzolana consume $Ca(OH)_2$ as given by equations 1 and 2.

At longer times (approx 120 - 240 min), the percentage loss in conductivity in all the samples was observed to enter a lag phase. This can be attributed to the decline in chemical activity as a result of the consumption of active siliceous and aluminous materials in rejected calcined Kibwezi brick clay and commercial pozzolana samples. Similar observations were made by [6], although he was working with Ugweri Clay as the pozzolana, Calcined at different temperatures and time. Rice husk ash in a solution of lime shows loss in electrical conductivity due to lime fixation as a result of pozzolanic activity [21].

Sample 'b' showed the higher pozzolanic activity compared to 'a' and 'c'. This could be attributed to its higher $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ content than others (Table 1 and 2). This could be the case with the commercial pozzolana which is a volcanic material rich in $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ content. [22] observed that pozzolanic activity increases with silicate content. The workers made a comparative pozzolanic study with silica fume, fly ash and a non-zeolitic natural pozzolana on their influence on electrical conductivity of water –lime mixture. They found that different pozzolanic materials exhibited different pozzolanic activity.

Sample c registered the lowest percentage loss in conductivity despite having a $SiO_2$/.$Al_2O_3$ and $Fe_2O_3$ comparable to that of 'a' (Table 4.1 and 4.2). Perhaps this could be attributed to poor calcinations of clay during brick making. Clays are usually thermally activated at 500-700 $^{o}$C to make them pozzolanic [23]. These are about the same temperature range bricks are fired [24]. Perhaps during the making of bricks in 'c', the pyro-processing conditions were not effective. Thermal analysis of clays show dehydroxylation peaks at about 500 – 700 $^{o}$C [23]. Dehydroxylation of clays leads to formation of amorphous silica [25, 26] responsible for pozzolanic behavior. Beyond 900 $^{o}$C, crystallization of the clay is observed [27; 28]

### 3.3 Compressive Strength Test Results

Figs. 2, 3 and 4 shows the compressive strength performance of the test cements at 3$^{rd}$, 7$^{th}$, and 28 day of curing respectively.

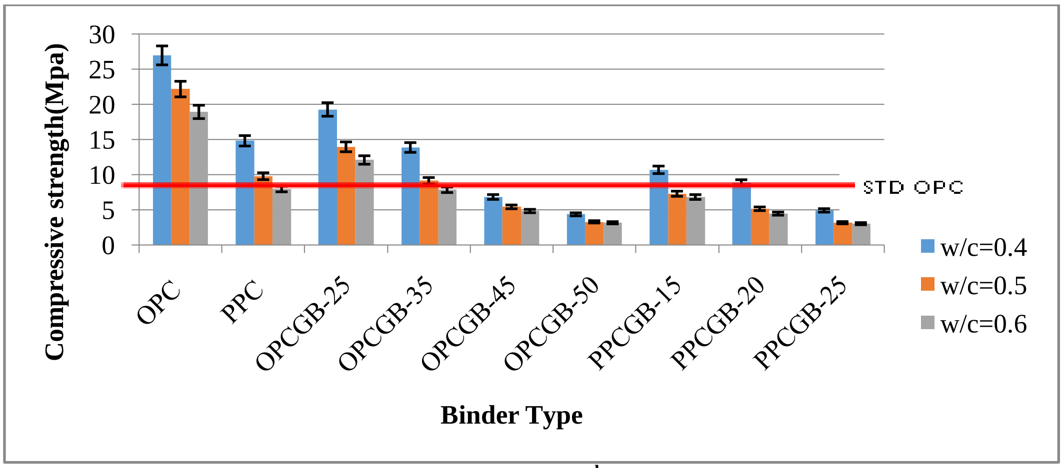


**Fig. 2: Compressive Strength at 3rd Day of Curing**

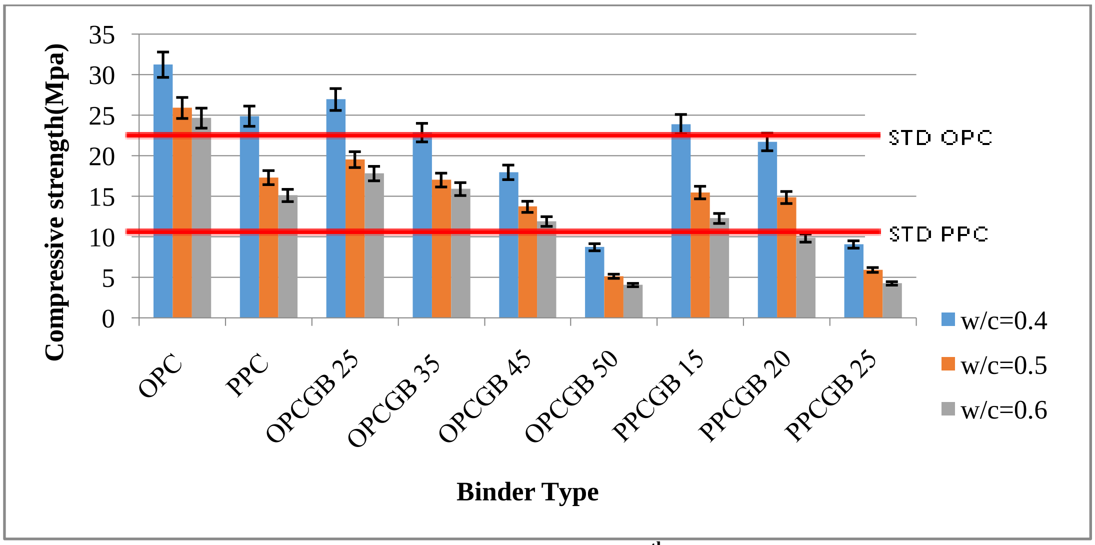


**Fig. 3: Compressive Strength at 7thDay of Curing**

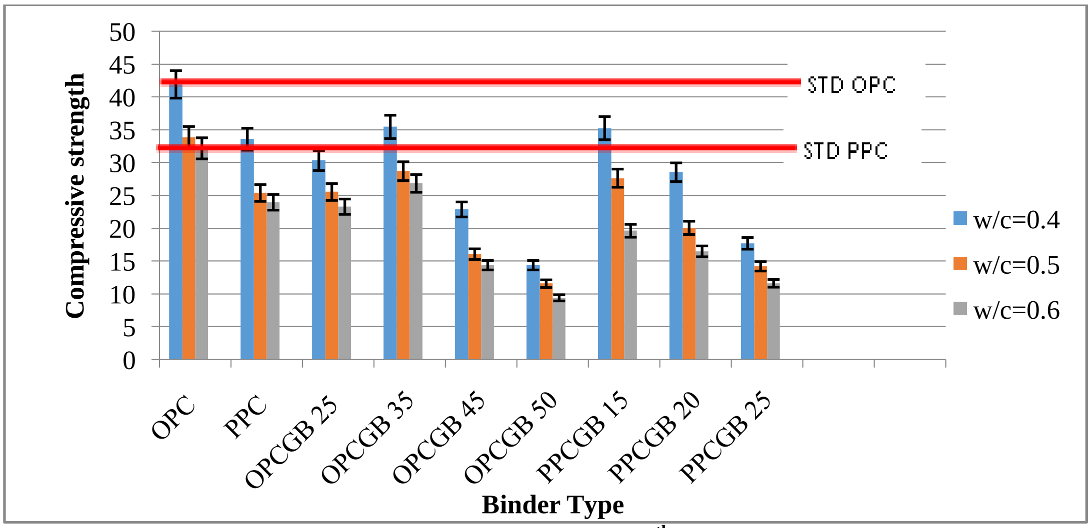


**Fig. 4: Compressive Strength at 28thDay of Curing**

There was no significant difference in terms of compressive strength gain between OPCGB-35 and commercial PPC for 3th, 7th and 28th days at w/c = 0.40, w/c = 0.50, w/c = 0.60. The T-calculated values were 0.1020, 0.5423 and 0.9196, 0.2203, 0.5352, and 0.4419, and 0.0924, 0.1000 and 0.0769 for 3th, 7th and 28th days respectively. This could be linked to the fact that commercial PPC is about 35 percent of the pozzolana blend

[29]. The results also showed no significance difference between PPCGB-15 and commercial PPC for 3$^{th}$, 7$^{th}$ and 28$^{th}$ days at w/c = 0.40, w/c = 0.50, w/c = 0.60. The T-calculated values were 0.0138, 0.0059 and 0.3384, 0.4857, 0.1439, and 0.2183, and 0.0856, 0.1103 and 0.0039 for 3$^{th}$, 7$^{th}$ and 28$^{th}$ days respectively. The T-calculated values were also way below the T-critical value of 6.314. Both OPCGB-35 and PPCGB-15 cement met this specification on 28$^{th}$ day regardless of the w/c used. The rest of the test pozzolana cement did not meet the standards though can be used for light masonry construction purposes like brick binders (ASTM C 91).

## IV. Conclusion

The findings of this work showed that cement made from Kibwezi ground bricks met the KS EAS 18:1-[12] requirements in terms of pozzolanicity and compressive strength and thus pilot project should be established to investigate the probability of production of cementitious material at a larger scale than the laboratory set up using either GB– OPC or GB-PPC mixes.

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