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# Developing Recipe from Local Ceramic Raw Materials for Making Crucibles in Ghana

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## Abstract

The study experimented with using local ceramic raw materials (white clay, kaolin and silica or quartz) found in AssinFosu in the Central Region of Ghana to manufacture crucibles for melting metals and other precious minerals. Various physical tests were conducted on the materials to arrive at the body compositions. The compositions were also investigated for their elemental components by using X-ray fluorescence (XRF). The results revealed that the composition of $Cru_c$ containing 70% of white clay, 20% of kaolin, 8% of quartz and 2% of white grog; sintered at 1500˚C was very successful and therefore used to develop the recipe to manufacture the proposed crucibles. The "throwing" technique was employed to fabricate the crucibles. Test for thermal expansion was conducted for the manufactured crucibles at 1000˚C for thermal shock and microcracking tests. It was found out among others, that the recipe developed had very good physical and chemical properties of alumina silicate refractory materials and was fit for use at any high-temperature application. The study also recommended among others, that the researchers and institutions responsible for clay research such as Ghana Geological Survey Authority (GGSA) and Centre for Scientific and Industrial Research (CSIR) collaborate to improve upon this innovative idea.

## Keywords

White Clay, Crucibles, Compositions, Throwing, Kaolin, Quartz

## 1. Introduction

In Ghana, subsequent governments have, in one way or another, tried to implement policies that would drive the country from a primarily agricultural economy to a mixed agricultural-industrial one [1]. This is because Ghana's economy has since independence been agrarian. To be able to industrialize Ghana's economy, its industrial capacities need to be adequately improved by targeting the expansion of the metal processing industries. According to Ahmed and Awareng [2], the economic and industrial capacity of a nation is highly related to its metal processing capacity. This metal processing becomes incapacitated when basic equipment like crucibles is unavailable [2]. Crucibles are ceramic vessels used in areas of applications where high temperature of heat is required [3]. Crucibles are also reaction vessels in which high-temperature transformation takes place without interacting with the heating materials [4]. The major raw materials for producing crucibles are clay and other graphite materials [5]. In Ghana, the presence of this naturally endowed mineral resource is relatively abundant in the earth's crust [6]. Despite its abundance, there is little or no documented evidence of locally produced clay-graphite bonded crucibles. There are few industries that import crucibles while the small and medium scale operators result in the use of cut-out compressor ports [7]. It is against this backdrop that the study seeks to find out the suitability of selected clays and other raw materials found at Assin Fosu in the Central Region of Ghana to develop a recipe for the local manufacturing of crucibles.

### 1.1. Statement of the Problem

In Ghana, even though there is availability of local ceramic raw materials which could be exploited to manufacture crucibles, most industries import crucibles for melting precious minerals thereby putting pressure on the country's scarce foreign exchange currencies. Preliminary thermos-physical properties of some clays from different parts of Ghana carried out by the researchers for various refractory purposes suggested the possibility of making crucibles from local materials especially, considering the strength and other properties of these clays. It is in light of this that the study deemed it prudent to solve a protracted problem, especially in the Ghanaian manufacturing industry by fabricating local crucibles through the use of local ceramic raw materials mined from Assin Fosu in the Central Region of Ghana.

### 1.2. Objectives of the Study

1) To determine the suitability of the selected materials for local production of crucibles.

2) To develop recipe from the selected materials to manufacture local crucibles.

### 1.3. Scope of the Study

The study is limited to the use of only local ceramic raw materials mined from AssinFosu to develop the recipe and subsequently produce crucibles.

### 1.4. Importance of the Study

The study would be useful to small and medium scale processing industries which smelt gold or metals.

### 1.5. Research Question

How can local ceramic raw materials be used to manufacture crucibles?

## 2. Brief History of Crucibles

According to Aigbodian *et al*. [8], a crucible is a ceramic or metal container in which metals or other substances are melted or subjected to a very high- temperature. Again, it can also be defined as a refractory container used in a furnace for glass, metal and pigment production as well as laboratory processes, which can resist high-temperature to melt or otherwise alter its content. Crucible is also a ceramic or metal container for which metals or other materials are melted or subjected to a very high-temperature [9]. Another definition given by Torres *et al*. [10] is that crucibles are ceramic vessels used for dry, that is, high-temperature reactions. In another development, Adeoti *et al*. [11] define crucibles as refractory open-mouth vessels used for melting steel, glasses, iron and others.

Even though crucibles were historically made from clay, they can also be made from any metal that withstands temperatures high enough to melt or otherwise other its contents [10].

### Uses of Crucibles

Crucible is used in laboratories to contain chemical compounds when heated to extremely high temperatures. Crucibles help to keep metals when being heated in it, keep heat and melt losses to a minimum and also help to avoid overheating of the metal [8].

## 3. Materials and Methods

### 3.1. Materials, Tools and Equipment

In undertaking the study, four material samples namely white clay, kaolin, quartz and white grog were obtained from Assin Fosu in the Central Region of Ghana. The material samples were neatly kept in white polythene bags to guarantee that there was no physical or environmental contamination of the material samples [12]. The sample of materials is shown in **Figures 1-4** respectively.

The scale was used to weigh the processed materials. The scraper and the cutting wire were used to aid in "throwing" the crucibles as shown in **Figure 5** and **Figure 6**.

Equipment used in executing the project were: 1) gaskilnused for sintering the crucibles, 2) electrical kiln for heating the test pieces, 3) electronic weighing machine for measuring the recipe developed, 4) potter's wheel for "throwing" the crucibles, 5) mortar and pestle for grinding the raw materials into powdered forms, and 6) standard sieve for sieving ground materials to obtain finer particle sizes. These equipment have been displayed in **Figures 7-12** respectively.

### 3.2. Materials Processing Method

The raw materials (white clay, kaolin, grog and quartz) were pounded into

Figure 1. White clay from Assin Fosu.

Figure 2. Kaolin from Assin Fosu.

Figure 3. Quartz.

Figure 4. White grog.

Figure 5. Scale.

Figure 6. Scraper and cutting wire.

Figure 7. Gas kiln.

Figure 8. Electrical kiln.

Figure 9. Electronic weighing machine.

**Figure 10.** Potter's wheel.

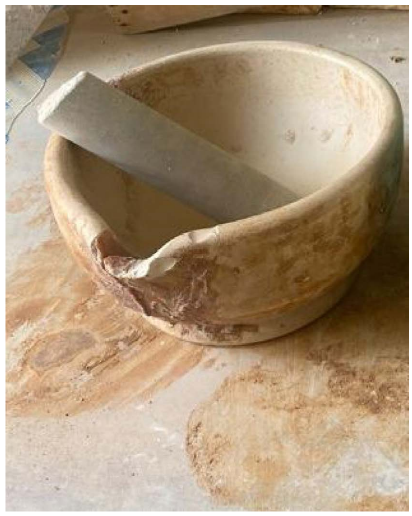

**Figure 11.** Mortar and pestle.

**Figure 12.** Standard sieve.

powdered form by using pestle and mortar. The individual materials were sieved through the 120 meshes to obtain finer particle sizes, weighed on a measuring scale and put into a bigger basin. The materials were then dry-mixed, water added and thoroughly stirred to form a uniform mixture as seen in **Figure 13**.

The mixture was then sieved to obtain finer particle sizes to form a slurry (liquid-like) ceramic body as shown in **Figure 14**.

The slurries formed were later allowed to settle down for four (4) days for proper segregation between the water and the clay body. The floating water was then emptied and the dispersed fine ceramic body in water (slurries) was then poured into Plaster of Paris (POP) moulds as seen in **Figure 15**.

**Figure 13.** Wet mixture of raw materials (Source: Field work, 2023).

**Figure 14.** Series of sieving of mixture to obtain creamy body (Source: Field work, 2023).

**Figure 15.** Pouring of creamy body into moulds (Source: Field work, 2023).

The moulds were left undisturbed for another four (4) days for the complete exhausting of the water. The ceramic body was then taken from the moulds, dried in the sun and later in an electric kiln at 120˚C for 22 hours. The dried ceramic body was compressed into normal test sample sizes for bulk density, linear shrinkage, apparent porosity and water absorption tests. The test pieces were sintered at the temperatures of 1400˚C and 1500˚C and then evaluated for physical, thermal and mechanical properties as defined below:

**Bulk Density (%)**: Bulk density can be defined as the ratio of the weight of a unit volume of loose materials (such as soil or powder) to the same volume of water expressed in kg/cm$^3$. It is the mass of the particles of material divided by the total volume occupied. The total volume includes particle volume and inter-particle volume [11].

The dried weight which is the weight after firing (DW) was then measured, each of the test pieces was suspended in a known volume of water in a measuring cylinder, where the suspended weight was taken as (SSW) and the volume of water displaced in the cylinder was documented. The dried weight divided by the volume of water displaced is known as the bulk Type equation here. Density of the test pieces [11].

$$\text{Bulk Density} = \frac{\text{Mass}}{\text{Volume displaced}\left(\text{g}/\text{cm}^3\right)} = \frac{\text{DW}\left(\text{g}\right)}{\text{Vol. displaced}\left(\text{g}/\text{cm}^3\right)}$$

**Linear Shrinkage (%) Test**: it was obtained by the deference between the initial heights of the test pieces taken and the final heights after sintering expressed in percentage gave the linear shrinkage.

$$\text{Linear Shrinkage}\left(\%\right) = \frac{\text{Intial height} - \text{final height}}{\text{Final height}} \times 100$$

**Porosity (%)**: Porosity measured the amount of water the refractory materials absorbed under a specified condition or the measurement of the percentage of water needed or necessary to be added to a composition to obtain a saturated surface [11]. The test pieces were dried until a constant weight of each sample was obtained to make the normal procedure for porosity and water absorption.

$$\text{Porosity}(\%) = \frac{\text{Suspended weight} - \text{dry weight}}{\text{Suspended weight}} \times 100$$

## 4. Results and Discussions

After various preliminary body tests, three (3) recipes were developed with the following compositions: 1) $Cru_a$ consisting of 65% white clay, 15% kaolin, 5% quartz and 10% white grog, 2) $Cru_b$ comprising 70% white clay, 15% kaolin, 5% quartz and 10% white grog; and lastly 3) $Cru_c$ composing of 70% white clay, 20% kaolin, 8% quartz and 2% white grog. These compositions were experimented with their suitability and potency to serve as potential recipes for making crucibles. For the purposes of analysis, samples of the compositions were rolled into slabs (test pieces) and labeled as $Cru_a$, $Cru_b$ and $Cru_c$. The test pieces were subjected to physical and chemical experiments to understand the various properties of the compositions.

**Density test results**: In determining the bulk density of the compositions, the test pieces were immersed in a graduated cylinder filled with water to regulate the volume of water displaced. The test pieces that were denser displaced a lot of water while the less dense pieces displaced relatively less water. It came to light that $Cru_c$ was denser followed by $Cru_b$ and the least dense was $Cru_a$ as shown in Figure 16. A dense object weighs more than a less object that is the same size [13].

**Plasticity Test**: It was conducted to determine the ability to work with the composed ceramic body. It was done by rolling samples into rope-like forms and then coiling them around the fingers to experience the level of cracks developed. It was realized that sample $Cru_a$ had more cracks (low plastic), followed by sample $Cru_b$ with little cracks (medium plastic), and sample $Cru_c$ had no cracks (high plastic). Finally, the colours of the samples were noted and recorded as

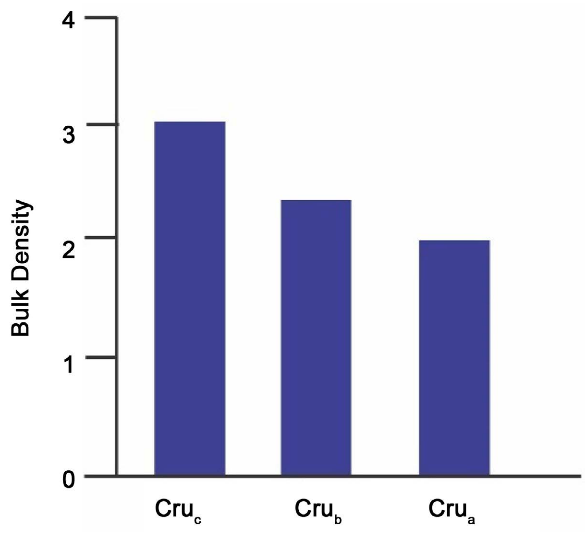


**Figure 16.** Chart showing the bulk density of compositions.

shown in Table 1.

**Shrinkage Test**: In order to find out how the samples would shrink, a shrinkage test was carried out by forming 12 briquettes and 12 MOR bars, 5 cm diagonal lines were created on each of the briquettes with 4 for each composition ($Cru_a$, $Cru_b$ and $Cru_c$) and were allowed to dry under room temperature for days. Afterward, dry shrinkage was conducted on each briquette to determine how each one has shrunk and recorded as highlighted in Table 2.

Dry shrinkage test was given by:

Dry shrinkage = wet measurement (WM) − dry measurement (DM)

Thus, dry shrinkage test = WM − DM

For $Cru_a$, slab No. 1: 5.00 cm − 4.70 cm = 0.30 cm, slab No. 2: 5.00 cm − 4.70 cm = 0.30 cm, slab No 3: 5.00 cm − 4.70 cm = 0.30 cm, slab No 4: 5.00 cm − 4.70 cm = 0.30 cm.

For $Cru_b$, slab No. 1: 5.00 cm − 4.80 cm = 0.20 cm, slab No. 2: 5.00 cm − 4.80 cm = 0.20 cm, slab No. 3: 5.00 cm − 4.80 cm = 0.20 cm, slab No. 4: 5.00 cm − 4.80 cm = 0.20 cm.

**Table 1.** Plasticity tests of clay materials.

| Sample name | Dry weight | Wet weight | Colour | Plasticity | Mls (water) |
|---|---|---|---|---|---|
| $Cru_a$ | 590 g | 600 g | Almond white | (600 g − 590 g = 10 g) = Low | 700 |
| $Cru_b$ | 600 g | 620 g | Almond white | (620 g − 600 g = 20 g) = Medium | 700 |
| $Cru_c$ | 610 g | 650 g | Off white | (650 g − 610 g = 40 g) = High | 700 |

**Table 2.** Dry shrinkage test results.

| Sample name | Slab No. | Wet measurement | Dry measurement | Shrinkage results |
|---|---|---|---|---|
| $Cru_a$ | 1 | 5.00 cm | 4.70 cm | 0.30 cm |
| | 2 | 5.00 cm | 4.70 cm | 0.30 cm |
| | 3 | 5.00 cm | 4.70 cm | 0.30 cm |
| | 4 | 5.00 cm | 4.70 cm | 0.30 cm |
| $Cru_b$ | 1 | 5.00 cm | 4.80 cm | 0.20 cm |
| | 2 | 5.00 cm | 4.80 cm | 0.20 cm |
| | 3 | 5.00 cm | 4.80 cm | 0.20 cm |
| | 4 | 5.00 cm | 4.80 cm | 0.20 cm |
| $Cru_c$ | 1 | 5.00 cm | 4.90 cm | 0.10 cm |
| | 2 | 5.00 cm | 4.90 cm | 0.10 cm |
| | 3 | 5.00 cm | 4.90 cm | 0.10 cm |
| | 4 | 5.00 cm | 4.90 cm | 0.10 cm |

For $Cru_c$, slab No. 1: 5 cm − 4.9 cm = 0.1 cm, slab No. 2: 5 cm − 4.9 cm = 0.1 cm, slab No. 3: 5.00 cm − 4.90 cm = 0.10 cm, slab No. 4: 5.00 cm − 4.90 cm = 0.10 cm.

After drying, the samples were heated by firing to determine the fired shrinkage test at two different firing temperatures 1400˚C and 1500˚C respectively in a gas kiln. This was done to ascertain how further the samples could shrink and to adjust it when working with such materials as exhibited in **Table 3**.

Fired shrinkage test was also given by:

Dry measurement (DM) – fired measurement (FM)

Thus, dry shrinkage test = DM – FM

Calculating fired shrinkage at 1400˚C

For $Cru_a$, slab No. 1: 4.70 cm – 4.60 cm = 0.10 cm, slab No. 2: 4.70 cm – 4.60 cm = 0.10 cm.

For $Cru_b$,: slab No. 1: 4.80 cm – 4.70 cm = 0.10 cm, slab No. 2: 4.80 cm – 4.70 cm = 0.10 cm.

For $Cru_c$, slab No. 1: 4.90 cm – 4.80 cm = 0.10 cm, slab No. 2: 4.90 cm – 4.80 cm = 0.10 cm.

Calculating fired shrinkage at 1500˚C

For $Cru_a$, slab No. 3: 4.70 cm – 4.50 cm = 0.20 cm, slab No. 4: 4.70 cm – 4.50 cm = 0.20 cm.

For $Cru_b$, slab No. 3: 4.80 cm – 4.60 cm = 0.20 cm, slab No. 4: 4.80 cm – 4.60 cm = 0.20 cm.

For $Cru_c$, slab No. 3: 4.90 cm – 4.70 cm = 0.20 cm, slab No. 4: 4.90 cm – 4.70 cm = 0.20 cm.

From **Table 3**, it came to light that all the three (3) samples $Cru_a$, $Cru_b$ and $Cru_c$ had the same fired shrinkage results (0.10 cm) at 1400˚C and another same fired shrinkage results (0.20 cm) at 1500˚C. These results implied that the composed ceramic bodies had perfect shrinkage tests and could be used to make ceramic products including crucibles.

**Table 3.** Fired shrinkage test at 1400˚C and 1500˚C respectively.

| Sample name | Slab No. | Fired shrinkage test at 1400˚C | | Sample name | Slab No. | Fired shrinkage test at 1500˚C | |
|---|---|---|---|---|---|---|---|
| | | DM-FM | Fired shrinkage | | | DM-FM | Fired shrinkage |
| $Cru_a$ | 1 | 4.70 cm - 4.60 cm | 0.10 cm | $Cru_a$ | 3 | 4.70 cm - 4.50 cm | 0.20 cm |
| | 2 | 4.70 cm - 4.60 cm | 0.10 cm | | 4 | 4.70 cm - 4.50 cm | 0.20 cm |
| $Cru_b$ | 1 | 4.80 cm - 4.70 cm | 0.10 cm | $Cru_b$ | 3 | 4.80 cm - 4.60 cm | 0.20 cm |
| | 2 | 4.80 cm - 4.70 cm | 0.10 cm | | 4 | 4.80 cm - 4.60 cm | 0.20 cm |
| $Cru_c$ | 1 | 4.90 cm - 4.80 cm | 0.10 cm | $Cru_c$ | 3 | 4.90 cm - 4.70 cm | 0.20 cm |
| | 2 | 4.90 cm - 4.80 cm | 0.10 cm | | 4 | 4.90 cm - 4.70 cm | 0.20 cm |

Furthermore, the study continued with the physical test on porosity. Porosity refers to the pore space within a fired clay body. Here, the sintered briquettes were weighed according to the sintered temperatures at 1400˚C and1500˚C; and soaked in water overnight.

The porosity was given by:

Porosity = soaked weight − fired weight

Thus, Porosity = soaked weight (SW) − fired weight (FW)

Calculating porosity at 1400˚C

For $Cru_a$, slab No. 1: 68.70 − 65.50 = 3.20, slab No. 2: 64.50 − 61.30 = 3.20.

For $Cru_b$, slab No. 1: 75.60 − 74.30 = 1.30, slab No. 2: 67.50 − 66.20 = 1.30.

For $Cru_c$, slab No. 1: 72.10 − 71.40 = 0.70, slab No. 2: 66.30 − 65.60 = 0.70.

Calculating porosity at 1500˚C

For $Cru_a$, slab No. 3: 70.40 − 68.30 = 2.10, slab No. 4: 63.5 − 61.4 = 2.10.

For $Cru_b$, slab No. 3: 80.10 − 79.00 = 1.10, slab No. 4: 73.20 − 72.10 = 1.10.

For $Cru_c$, slab No. 3: 78.30 − 77.80 = 0.50, slab No. 4: 69.00 − 68.50 = 0.50.

Calculating for percentage (%) porosity is given by:

$$\%\ \text{Porosity} = \frac{\text{soaked wight}(\text{SW}) - \text{fired weight}(\text{FW})}{\text{soaked weight}(\text{SW})} \times 100$$

Therefore, calculating percentage (%) porosity for the samples at 1400˚C;

For $Cru_a$, slab No. 1:

$$\%\ \text{porosity} = \frac{68.70 - 65.50}{68.70} \times 100 = \frac{3.20 \times 100}{68.70} = \frac{320}{68.70} = 4.70\%$$

$$\text{Slab No. 2:}\quad \%\ \text{porosity} = \frac{64.50 - 61.30}{64.50} \times 100 = \frac{3.20 \times 100}{64.50} = \frac{320}{64.50} = 4.96\%$$

For $Cru_b$, slab No. 1:

$$\%\ \text{porosity} = \frac{75.60 - 74.30}{75.60} \times 100 = \frac{1.30 \times 100}{75.60} = \frac{130}{75.60} = 1.72\%$$

$$\text{Slab No. 2:}\quad \%\ \text{porosity} = \frac{67.50 - 66.20}{67.50} \times 100 = \frac{1.30 \times 100}{67.50} = \frac{130}{67.50} = 1.93\%$$

For $Cru_c$, slab No. 1:

$$\%\ \text{porosity} = \frac{72.10 - 71.40}{72.10} \times 100 = \frac{0.70 \times 100}{72.10} = \frac{70}{72.10} = 0.97\%$$

$$\text{Slab No. 2:}\quad \%\ \text{porosity} = \frac{66.30 - 65.60}{66.30} \times 100 = \frac{0.7 \times 100}{66.30} = \frac{70}{66.30} = 1.05\%$$

Again, calculating percentage (%) porosity for the samples at 1500˚C;

For $Cru_a$, slab No. 3:

$$\%\ \text{porosity} = \frac{70.40 - 68.30}{70.40} \times 100 = \frac{2.10 \times 100}{70.40} = \frac{210}{70.40} = 2.98\%$$

$$\text{Slab No. 4:}\quad \%\ \text{porosity} = \frac{63.50 - 61.40}{63.50} \times 100 = \frac{2.10 \times 100}{63.50} = \frac{210}{63.50} = 3.31\%$$

For $Cru_b$, slab No. 3:

$$\% \text{ porosity} = \frac{80.10 - 79.00}{80.10} \times 100 = \frac{1.10 \times 100}{80.10} = \frac{110}{80.10} = 1.37\%$$

Slab No. 4: $\% \text{ porosity} = \frac{73.20 - 72.10}{73.20} \times 100 = \frac{1.10 \times 100}{73.20} = \frac{110}{73.20} = 1.50\%$

For $Cru_c$, slab No. 3:

$$\% \text{ porosity} = \frac{78.30 - 77.80}{78.30} \times 100 = \frac{0.50 \times 100}{73.20} = \frac{50}{73.20} = 0.68\%$$

Slab No. 4: $\% \text{ porosity} = \frac{69.00 - 68.50}{69.00} \times 100 = \frac{0.5 \times 100}{69.00} = \frac{50}{69.00} = 0.72\%$

The values obtained for the porosity had been recorded in Table 4. From Table 4, it was realized that sample $Cru_a$ had high porosity (3.20 at 1400˚C and 2.10 at 1500˚C), followed by $Cru_b$ (1.30 at 1400˚C and 1.10 at 1500˚C) and $Cru_c$ had the least porosity (0.70 at 1400˚C and 0.5 at 1500˚C). Therefore, the sample $Cru_c$ fired at 1500˚C was suitable for the manufacturing of the proposed crucible because of its low porosity and percentage (%) porosity values of 0.68% and 0.72% which were all less than 1% and therefore appropriate percentage values of porosity for a good refractory material [14] [15].

Addressing the chemical properties, major oxides in the clay samples were analyzed at the Geological Survey Laboratory Department in Accra. The oxides of the samples were determined by using X-Ray fluorescence (XRF) with an ARL 9800XP spectrometer and yielded the following results as detailed in Table 5.

From Table 6, the individual oxides showing their percentages in the sampled clays had been outlined. It indicated that the composition $Cru_a$ contained 55.82% of Silica ($SiO_2$) and 37.61% with other minerals constituting 6.57% as shown in Figure 17.

For composition $Cru_b$, it consisted of 57.81% of Silica ($SiO_2$) and 36.82% of alumina ($Al_2O_3$) with other minerals covering 5.37% as seen in Figure 18.

For composition $Cru_c$, it had 60.57% of quartz ($SiO_2$) and 30.72% of alumina (($Al_2O_3$) as well as other minerals containing 8.71% as highlighted in Figure 19).

From Table 5, the silica ($SiO_2$) content of $Cru_c$ indicated 60.57% which was a

**Table 4.** Weight of fired pieces at 1400˚C and 1500˚C respectively.

| Sample name | Slab No. | Fired weight (1400˚C) | | | | Sample name | Slab No. | Fired weight (1500˚C) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SW | FW | Porosity | % | | | SW | FW | Porosity | % |
| $Cru_a$ | 1 | 68.70 | 65.50 | 3.20 | 4.70 | $Cru_a$ | 3 | 70.40 | 68.30 | 2.10 | 2.98 |
| | 2 | 64.50 | 61.30 | 3.20 | 4.96 | | 4 | 63.50 | 61.40 | 2.10 | 3.30 |
| $Cru_b$ | 1 | 75.60 | 74.30 | 1.30 | 1.72 | $Cru_b$ | 3 | 80.10 | 79.00 | 1.10 | 1.37 |
| | 2 | 67.50 | 66.20 | 1.30 | 1.93 | | 4 | 73.20 | 72.10 | 1.10 | 1.50 |
| $Cru_c$ | 1 | 72.10 | 71.40 | 0.70 | 0.97 | $Cru_c$ | 3 | 78.30 | 77.80 | 0.50 | 0.68 |
| | 2 | 66.30 | 65.60 | 0.70 | 1.05 | | 4 | 69..00 | 68.50 | 0.50 | 0.72 |

**Table 5.** Mineralogical composition (major oxides) of Assin Fosu Clays (XRF).

| Major oxides | Sample name | | |
|---|---|---|---|
| | $Cru_a$ | $Cru_b$ | $Cru_c$ |
| %MgO | 0.03 | 0.02 | 0.04 |
| $\%Al_2O_3$ | 37.61 | 36.82 | 30.72 |
| $\%SiO_2$ | 55.82 | 57.81 | 60.57 |
| $\%K_2O$ | 0.35 | 0.40 | 0.89 |
| %CaO | 0.09 | 0.08 | 1.20 |
| $\%TiO_2$ | 1.70 | 1.96 | 1.06 |
| %MnO | 0.95 | 0.10 | 0.85 |
| $\%Fe_2O_3$ | 0.08 | 0.06 | 0.05 |
| Loss of ignition | 3.35 | 2.74 | 4.56 |

**Table 6.** Potential recipes developed for making crucibles at 1400˚C and 1500˚C.

| Materials | A $Cru_a$ (wt. %) | B $Cru_b$ (wt. %) | C $Cru_c$ (wt. %) |
|---|---|---|---|
| White clay | 65 | 70 | 70 |
| Kaolin | 15 | 15 | 20 |
| Quartz ($SiO_2$) | 5 | 5 | 8 |
| White grog | 15 | 10 | 2 |

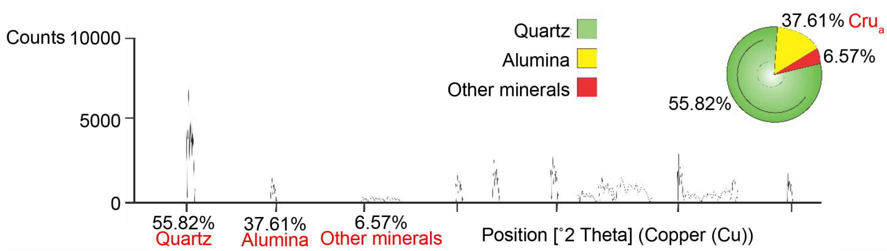


**Figure 17.** Results of XRF pattern for composition $Cru_a$ (Source: Field work: GSA: 2023).

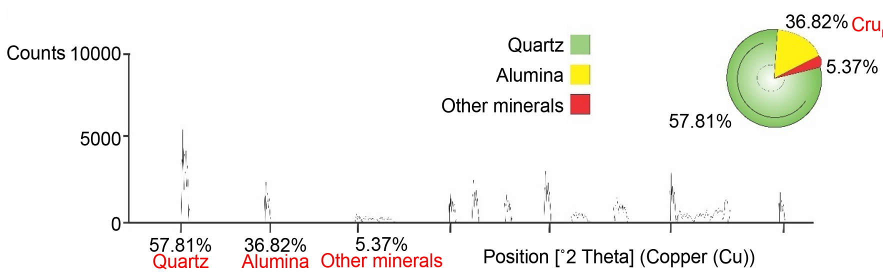


**Figure 18.** Results of XRF pattern for composition $Cru_b$ (Source: Field work: GSA: 2023).

signal of required standard for a good refractory ceramic body and also more appropriate as a recipe for making crucibles and other refractory products. Therefore, the preliminary tests (physical and chemical) conducted guided the study to formulate the ceramic bodies for making the proposed crucibles as shown in Table 7.

From Table 6, the recipe $Cru_a$ consisted of 65% white clay, 15% kaolin, 5% quartz and 15% white grog. $Cru_b$ comprised 70% white clay, 15% kaolin, 5% quartz and 10% white grog. Last but not least, $Cru_c$ is composed of 70% white clay, 20% kaolin, 8% quartz and 2% white grog. The individual recipes were mixed with equal volumes of water to determine their water plasticity (the amount of water needed to make a clay body workable or mouldable). It came out that sample $Cru_c$ was the most plastic followed by $Cru_b$ and then $Cru_a$. Therefore, the study adopted sample $Cru_c$ as the recipe to produce the crucibles. The "throwing" technique was employed to fabricate various shapes, forms and sizes of crucibles on the potter's wheel. This was because special refractories components depend on the forming method, since it has an important influence on properties especially in relation to porosity distribution and final grain size [16]. However, crucibles were also made from the recipes $Cru_a$ and $Cru_b$ for comparative discussions on the compositions. In the "throwing" process, the recipes were kneaded to remove any air bubbles and made into lumps as seen in Figure 20.

The balls of various recipes were then "thrown" on the potter's wheel by adopting "centering" method as seen in Figure 21, followed by the "pulling" method which made the crucibles into the required shapes and forms as seen in Figure 22. These processes were repeated until enough crucibles were made as shown in Figure 23.

The manufactured crucibles were dried under room temperature and further dried in an electric oven at 100˚C for 24 hours. The crucibles were grouped into two and sintered in the gas test kiln at 1400˚C and 1500˚C respectively. Preheating was done for three (3) hours so as to prevent the crucibles from breaking in the cause of thermal transformation. The sintering was then gradually increased

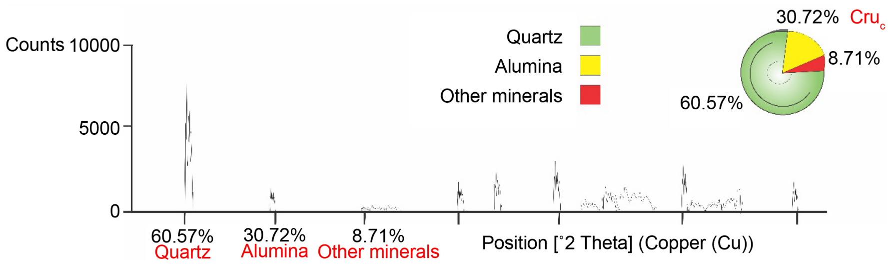


Figure 19. Results of XRF pattern for composition $Cru_c$. (Source: Field work: GSA: 2023).

Table 7. Physical appearance of the manufactured crucibles.

| Crucible name | Physical appearance in colour at 1400˚C | Physical appearance in colour at 1500˚C |
|---|---|---|
| $Cru_a$ | Almond white | Almond white |
| $Cru_b$ | Almond white | almond white |
| $Cru_c$ | Almond white | Off white |

Figure 20. Kneaded balls of ceramic body.

Figure 21. Centering of ceramic body (Source: Field work, 2023).

Figure 22. Pulling of centred ceramic body (Source: Field work, 2023).

Figure 23. Different forms and shapes of "thrown" crucibles.

at intermittent intervals, and later increased to the full sintering stage of 1400˚C and 1500˚C which both took six (6) and eight (8) hours respectively. Figure 24 and Figure 25 show different crucibles sintered at 1400˚C and 1500˚C respectively having different colours.

Table 7 indicates the physical appearance of the sintered crucibles at temperatures of 1400˚C and 1500˚C. It was revealed that $Cru_a$ and $Cru_b$ had almond white colours for both temperatures while $Cru_c$ at 1400˚C also had almond white colour. However, $Cru_c$ sintered at 1500˚C had off-white colour indicating the high content of kaolin in the developed recipe.

## Test for Thermal Expansion (Shock) in the Manufactured Crucibles

Testing for thermal shock in crucible production is very important and key to determining its functionality. This is because the thermal shock if the thermal shock successfully done, the crucible would be suitable for use. To ascertain this test, the manufactured crucibles were sintered in an electric test kiln to 1000˚C. With the aid of a mechanized metal tool, each crucible was brought out and back into the hot kiln as seen in Figure 26.

The purpose was to allow penetration of cold air into the pores of the hot crucible while hot air in the hot pores would also try to come out, resulting in contraction and expansion of the body which normally could result in cracks leading to thermal shock [17]. After the conducted test, none of the crucibles developed cracks as the sample is shown in Figure 27.

Again, the manufactured crucibles were subjected to scanning electronic microscope (SEM) analysis. The SEM revealed a white block-like level and indicated the chemical intermetallic composition of the recipe developed. The result confirmed what other studies had revealed that a good refractory body is rich in quartz ($SiO_2$) and alumina ($Al_2O_3$) as exhibited in block-like morphology [18]. The crucibles were also microscopically examined for microcracking and it came to light that the manufactured crucibles had no cracks. This also signified that the crucibles were of high quality. Figure 28 shows a sample of the manufactured crucibles that have passed the thermally induced microcracking test.

**Figure 24.** Crucibles sintered at 1400˚C.

**Figure 25.** Crucibles sintered at 1500˚C.

**Figure 26.** Testing for thermal shock in the crucible.

**Figure 27.** Hot crucible after passing the thermal shock test.

**Figure 28.** Sample of tested manufactured crucible (Source: Field work, 2023).

## 5. Conclusion

From **Table 6**, the refractoriness of the manufactured crucibles indicated that sample $Cru_c$ sintered at 1500˚C had the highest form of refractoriness followed by sample $Cru_b$ and then $Cru_a$. This result supports the claims made by Titiladunayo & Fapetu [19] and Aye & Oyetunji [20] that a good refractory body should have refractoriness in the range of 1500˚C - 1700˚C. Therefore, the sample $Cru_c$ sintered at 1500˚C was within this range. Hence, the study was very successful. This also implied that kaolin was highly responsible for refractoriness of the crucibles. The physical, mechanical and thermal properties of the manufactured crucibles showed that the crucibles were of good value and fit for use at any high-temperature application. It was realized that these ceramic raw materials (white plastic clay, kaolin, silica and grog) in different percentages by weight, if well treated technically could be employed to make different refractory items in the ceramic industry in Ghana.

## Recommendations

The study recommends further collaboration between the researchers and institutions responsible for clay research such as Ghana Geological Survey Authority (GGSA) and Centre for Scientific and Industrial Research (CSIR) to improve upon this innovative idea. This would go a long way to bring back some of the collapsing ceramic industries in Ghana into operation and help the country to save costs for importing crucibles and other high-fired products. Again, it could also help create jobs for upcoming ceramic technologists and artists in Ghana so as to reduce the rate of unemployment in the country.

There could be further research to ascertain if the recipe developed could be used to produce other highly refractory products especially, high ceramic technology products.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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