

Suitability of Tanzanian kaolin, quartz and feldspar as raw materials for the production of porcelain tiles

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Abstract: Kaolin and quartz from Pugu; and feldspar from Morogoro were investigated to determine their suitability as raw materials for the production of porcelain tiles. From the mineralogical analysis, kaolin sample was found to contain kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$) and quartz (SiO_2); quartz sample was found to contain only quartz mineral silica (SiO_2); and feldspar sample was found to contain albite ($\text{NaAlSi}_3\text{O}_8$) and microcline (KAlSi_3O_8). The major chemical compounds found in kaolin and feldspar were SiO_2 and Al_2O_3 , and quartz sample was found to contain SiO_2 and SO_3 . The tiles made from the raw materials and fired between 900 °C and 1200 °C were found to have the water absorption of 12.4 - 13.7%, bulk density of 1.89-1.95 g/cm³, apparent porosity of 24.1-26.0%, linear shrinkage of 0.0-1.7%, compressive strength of 107.4-380.4 kg/cm² and loss on ignition of 3.6-6.0%. Among the studied compositions and firing temperatures, tiles made from a blend containing 40% kaolin, 45% feldspar and 15% quartz; and fired at 1100 °C were found to have the best properties for the production of porcelain tiles. This is an indication that the Tanzanian kaolin, quartz and feldspar are suitable raw materials for the production of porcelain tiles.

Keywords: Tanzanian Kaolin, Quartz and Feldspar, Porcelain Tiles

1. Introduction

Demand for ceramic tiles is increasing day to day and the researchers are becoming interested in developing lucrative tiles with mechanical strength for household uses as well as for decoration purposes [1]. Although tiles are extensively used in building structures, they are faced with problems including cracking and spalling [2]. Among different types of ceramic tiles, porcelain tiles present high mechanical strength, high wear and stain resistance, high brightness when polished after firing and low water absorption [3-5]. Water absorption of less than 0.5%, make porcelain tiles high-performance materials with zero or almost zero apparent porosity, high fracture strength, as well as good chemical, stain and frost resistance [5], enabling them to be used in environments with erratic conditions of humidity, pH and temperature [6]. It is imperative to be aware that a porcelain tile formation is based on three major raw materials, which are kaolinite clay, quartz and feldspar [3,5,7].

Tanzania is endowed with numerous kaolinite clay deposits in various places, of which some are believed to hold the largest reservoir in Africa [8-10], and perhaps the

Pugu kaolin deposit is one of the largest in the world [11]. In addition, quartz and feldspar, the most abundant and widespread mineral in the Earth's crust [12,13], are also plenty in Tanzania [14,15].

On one hand, the underutilization of Tanzanian kaolin, quartz and feldspar natural deposits for industrial ceramic production is typified by scanty scientific literature. On the other hand, very few, if any, scientific data are available on which to base plans and prediction for large scale, long term ceramics commercial development in Tanzania [2]. It was therefore intended in this work to contribute towards shedding light on the suitability of using Tanzanian kaolin, quartz and feldspar as raw materials for the production of useful ceramic materials.

2. Experimental

2.1. Sampling

Kaolin and quartz samples were collected from the Pugu hills, 35 km west of Dar es Salaam, and feldspar sample was obtained at Jumbadimwe village in Rubeho ward in Gairo district in Morogoro region.

2.2. Preparation of Samples

The samples were separately dried at 150 °C in the oven for 24 h and then ground by using mortar and pestle. The powdered samples were sifted through a sieve of 300 µm pore size. Grinding and sieving were repeated until almost all the materials passed through the sieve.

2.3. Chemical and Mineralogical Analyses

The mineralogy and chemical composition of kaolin, quartz and feldspar were done by using X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF), respectively. The XRD analysis was carried out at the Geology Department of the University of Dar es Salaam, and XRF analysis was carried out at the Southern and Eastern African Mineral Centre (SEAMIC).

2.4. Preparation of Porcelain Tiles

Nine different compositions of kaolin (35-55%), feldspar (35-50%) and quartz (5-20%) were prepared as shown in Table 1.

Table 1. Sample Compositions in Percentage Weight

Code	Kaolin (% wt.)	Feldspar (% wt.)	Quartz (% wt.)
C1	35	50	15
C2	40	45	15
C3	45	40	15
C4	45	45	10
C5	50	45	5
C6	50	40	10
C7	50	35	15
C8	55	35	10
C9	45	35	20

Water was added in small portions to each of the mixtures and mixed thoroughly until the required paste was formed. For each composition, nine tiles were made and allowed to dry for 7 days at room temperature and subsequently oven-dried at 110 °C for 24 h followed by cooling them in the desiccators. The length and weight of each of the oven dried tiles were recorded, thereafter fired in kiln at temperatures between 900 and 1200 °C. The firing temperature was maintained for 8 h. Then the fired tiles were allowed to cool slowly to room temperature by natural convection after turning the kiln off and leaving them inside the kiln for 24 h. After cooling, the length, width and height of each tile were recorded.

2.5. Determination of Physico-Mechanical Properties of the Porcelain Tiles

The water absorption, bulk density and apparent porosity were measured according to ASTM C373-8817, which involved drying tiles in an oven at 150 °C for 24 h and cooling in desiccators. The dry mass of the tiles (D) was then measured, followed by water impregnation, which involved boiling tiles in distilled water for 5 h and then left soaked in water for an additional 24 h at room temperature. After impregnation, the suspended mass (S) of each tile was recorded. The saturated mass (M) was measured after

removing all excess water from the surface by using moistened cotton cloth.

The water absorption, A , expressed as a percent, was calculated as the ration of the mass of water absorbed to the mass of the dry specimen [16], given by the expression:

$$A = [(M - D)/D] \times 100\% \quad (1)$$

The bulk density, B (g/cm^3), of the specimen, which is the quotient of its dry mass divided by the exterior volume, including pores, [16], is given by:

$$B = D/V \quad (2)$$

where D is the mass of dry specimen and V is the exterior volume, given by $V = M - S$.

The apparent porosity, P , expressed as a percent, which is the ratio of the volume of open pores to the exterior volume of the specimen [16], is given by:

$$P = [(M - D)/V] \times 100\% \quad (3)$$

The linear shrinkage (LS) of fired tile expressed as a percent is given by:

$$LS = [(L_g - L_f)/L_g] \times 100\% \quad (4)$$

where L_g and L_f are the length (mm) of green and fired tiles, respectively [17].

Compressive strength (CS) is given by:

$$CS = \frac{\text{Maximum Load}}{\text{Cross Section Area}} \quad (5)$$

To determine this parameter, the area of the tiles was calculated, and then the tiles were placed on a compressive strength tester. The load was applied axially until failure occurred. The load that caused cracks was used to calculate the CS .

The Loss On Ignition (LOI) expressed as a percent of the relationship of the weight reduction to the total weight of the sample and is given by:

$$LOI = [(m_1 - m_2)/m_1] \times 100\% \quad (6)$$

where m_1 and m_2 are weights of samples before and after firing, respectively [18].

3. Results and Discussion

3.1. Mineralogical Composition of Kaolin, Quartz and Feldspar

The X-ray diffractograms for kaolin sample is presented in Fig. 1. As can be seen from this figure, the kaolin sample was found to contain major peaks of clay mineral kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$) and a non clay mineral quartz (SiO_2) as an impurity. Identical to observations reported in the literature [5, 19-22], kaolinite was identified by the reflections at $d =$

7.1616 Å around 14° 2θ and d = 3.5545 Å around 29° 2θ; and quartz registered reflections at d = 4.2499 Å around 24° 2θ and d = 3.3314 Å around 31° 2θ [20-22].

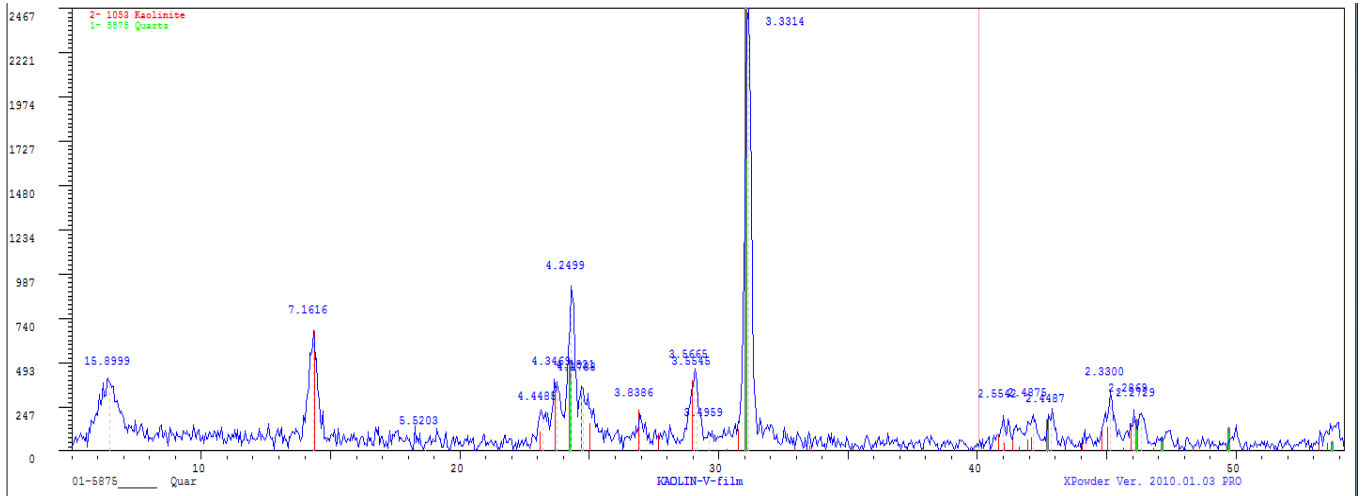


Figure 1. X-Ray Diffractogram of Kaolin.

Apart from kaolinite and quartz peaks, kaolin sample also contained other minor peaks. Other peaks can be due to the presence of microcline ($KAlSi_3O_8$) in the sample. The microcline can be identified by the presence of peaks around 24° and 32° 2θ. The reflections at d = 3.3314 Å around 31° 2θ

may be due to the presence of illite.

The X-ray diffractogram of quartz sample is shown in Fig. 2. It is observed that the quartz sample contains mainly silica (SiO_2). Quartz was identified by the reflections at d = 4.2499 Å around 24° 2θ and d = 3.3366 Å around 31° 2θ [20-22].

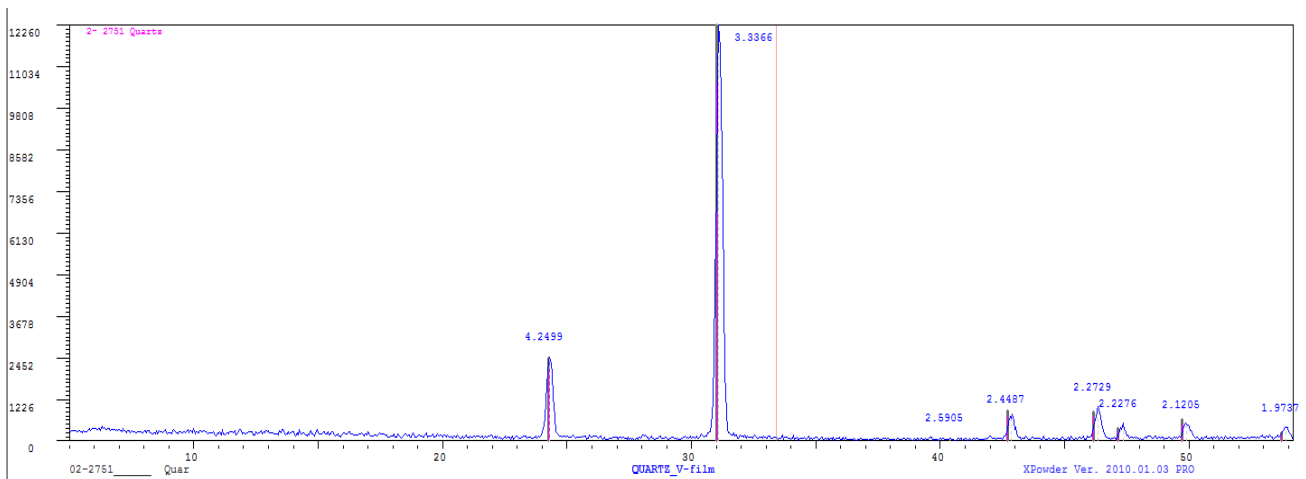


Figure 2. X-Ray Diffractogram of Quartz.

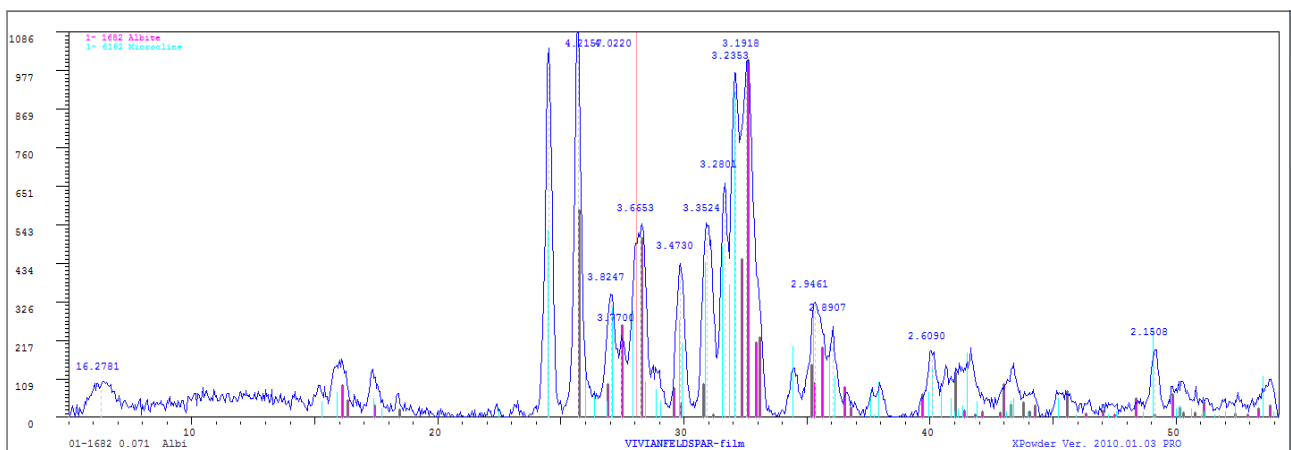


Figure 3. X-Ray Diffractogram of Feldspar.

Fig. 3 shows the X-ray diffractogram of feldspar sample. One of the minerals observed are sodium feldspar (albite) ($\text{NaAlSi}_3\text{O}_8$) identified by the reflections at $d = 4.0220 \text{ \AA}$ around $26^\circ 2\theta$ and $d = 3.1918 \text{ \AA}$ around $33^\circ 2\theta$ [5, 22, 23]. Another mineral was potassium feldspar (microcline) (KAlSi_3O_8), which was identified by the reflections at $d = 4.2159 \text{ \AA}$ around $24^\circ 2\theta$ and $d = 3.2353 \text{ \AA}$ around $32^\circ 2\theta$ [20].

Apart from albite and microcline peaks, the X-Ray Diffractogram (Fig. 3) also contained other minor peaks. These can be attributed to the presence of sanidine ($\text{K}(\text{Si}_3\text{Al})\text{O}_8$), identified by peaks around 21° , 27° , 35° , and $52^\circ 2\theta$ as well as the presence of oligoclase ($(\text{Na,Ca})\text{Al}(\text{Al,Si})\text{Si}_2\text{O}_8$), identified by peaks around 22° , 38° , 39° , 43° , 45° , 48° and $50^\circ 2\theta$ [23].

3.2. Chemical Composition of Kaolin, Quartz and Feldspar

Table 2 shows the chemical compositions of kaolin, feldspar and quartz. As can be observed from this table, silica was a dominant oxide in kaolin sample (63.71%) followed by alumina (31.34%). The percentage of K_2O and Na_2O were 1.34% and 0.41%, respectively. The oxides CaO (0.04%) and MgO (0.53%) along with coloured oxides Fe_2O_3 (1.02%), TiO_2 (0.60%), were also present.

Table 2. Chemical Compositions of Kaolin, Feldspar and Quartz.

Oxides, Cl and LOI	Kaolin (%)	Quartz (%)	Feldspar (%)
SiO_2	63.71	94.95	62.7
Al_2O_3	31.34	0.37	13.8
Na_2O	0.41	-	0.78
MgO	0.53	0.05	0.06
SO_3	0.23	1.02	1.00
K_2O	1.34	0.12	11.99
CaO	0.04	0.95	7.63
TiO_2	0.60	0.13	0.03
Cr_2O_3	0.02	0.18	0.11
MnO	0.01	0.04	0.06
Fe_2O_3	1.02	1.92	0.82
BaO	-	-	0.41
Cl	0.72	0.23	-
LOI	0.03	0.04	0.40

The results were found to be within the range of kaolin to be used in the production of porcelain tiles [4]. The coloured and fluxing oxides are required to be in small amount in all components so as to avoid excessive fluxing as well as undesired variation on the product colour [4]. The LOI (0.03%) was lower than the amount required for the kaolin used in porcelain tiles (5.0-12.8%) [4]. This can be attributed to low content of volatilizes soil components *i.e.*, organic matter, water and carbonates [5].

The amount of silica and alumina in the quartz sample were 94.95% and 0.37%, respectively (Table 2), which, according to literature [4], were lower than the amount required in order for quartz to be considered suitable for the production of porcelain body (98.0-99.1% and 0.65-0.8%, respectively). Generally, the amount of silica is higher in quartz because quartz is the mineral which consists of silica in crystal form [24]. The low amount of alumina can cause formation of the

product with high linear shrinkage and hence unstable product [4, 25]. The total amount of K_2O and Na_2O is (0.12%) which is within the range of requirement for quartz used in porcelain tiles body (0.1-0.2%) [4]. Besides, the oxides Fe_2O_3 (1.92%), TiO_2 (0.13%), CaO (1.92%) and MgO (0.13%), were also present in significant levels. These amounts were higher than the amount required for quartz to be used as the raw material in porcelain tiles. If coloured and fluxing oxides are present in higher amount may cause excessive fluxing as well as undesired variation on the product colour [4]. The LOI in quartz sample (0.04%) was lower than the amount required for quartz as the raw materials used in porcelain tiles body [4].

It is clearly seen from Table 2 that the amount of silica in feldspar sample (62.70%) is lower than the amount required in order for feldspar to be considered suitable for the production of porcelain body (66.3-79.5%) [4]. Alumina was present in high amount (13.80%) followed by the total percentage of Na_2O and K_2O (12.77%) and then LOI (0.40%). All of them were within the range for feldspar to be used in the porcelain tiles [4]. The coloured oxides Fe_2O_3 and TiO_2 were present in small percentages (0.82% and 0.03%, respectively) which were within the range for feldspar to be used in the porcelain tiles. The other oxides CaO (7.63%) and MgO (0.06%) were present in higher amount than required [4].

3.3. Physico-Mechanical Properties of the Porcelain Tiles

The comparison on the variation of water absorption at 900, 1100 and 1200 °C is shown in Fig. 4.

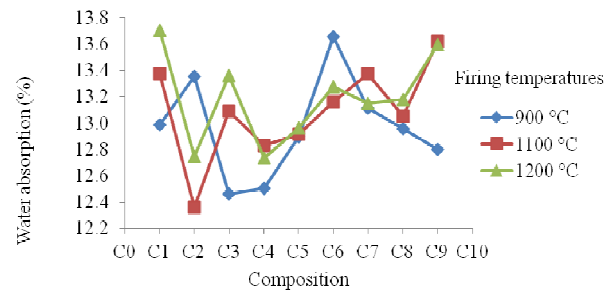


Figure 4. Water absorption for the porcelain tiles with different composition fired at 900, 1100 and 1200 °C.

Generally the water absorption decreases with increase in firing temperature due to the formation of the liquid phase and densification at high firing temperatures [26,27]. The liquid phase formed is the one which fills the pores and decreases the porosity. Water absorption is directly related to open porosity [17,26] and porosity decreases with increase in firing temperature [8]. This was observed from the tiles made from composition C2 and C6 where the water absorption of the tiles decreased with increase in firing temperature.

For the tiles made from composition C1, C3, C4, C5, C7, C8 and C9, the water absorptions were found to increase with increase in firing temperature. The increase in water absorption at higher firing temperature is thought to be caused by bloating which takes place as a result of the expansion of gasses enclosed in the pores and cause the increase in porosity

[9]. In addition, the high firing temperature can cause mullite crystals to become coarse and decrease densification and hence increase water absorption [26].

It was expected for water absorption to decrease with increase in feldspar content. This is because feldspar contains alkaline oxides *i.e.*, K_2O and Na_2O , which melt at relatively low temperature, and acts as fluxing agent and assist in liquid phase formation [1,4,5,27]. Based on this facts, the tiles made with compositions with high percentage of feldspar *i.e.*, composition C2, C3, C4 and C5 had the lowest water absorption. For the same reason it was expected that, the tiles made from composition C1 will have lowest water absorption than the rest of the tiles but this was not the case. This may be attributed to low percentage of kaolin which was responsible for the formation of unstable aluminosilicate spinel phase. It is the unstable aluminosilicate spinel phase which forms mullite phase and mullite forms the liquid phase [27-30]. The liquid phase is responsible for blocking the open porosity, increase the density and decrease water absorption. Thus, the water absorption decreases with the increase in amount of kaolin in the composition. For the same reason, it was expected for the tiles made from composition C8 to have the lowest water absorption but that was not the case. This may be related to the low percentage of feldspar in the tiles. In addition, water absorptions from tiles of the tested compositions and fired different temperatures were higher than the standard water absorption required for porcelain tiles (less than 0.5% [6]). Water absorption of the clay product is affected by the properties of clay, method of manufacturing and the firing temperature. The high water absorption indicated that, the tiles produced in this work were porous.

Although the standard requires water absorption of the porcelain tiles to be less than 0.5%, this is only necessary for floor tiles [27]. According to technical standards the tiles with water absorption higher than 10% can be used as wall tiles [17]. The majority of standard wall tiles have glazed porous bodies with water absorption between 10% and 20%. Thus the tiles produced in this work (with water absorption in the range 12.4-13.7%) are suitable wall tiles. The Chinese National Standards (CNS) requires the water absorption of tile to be less than 16% [17]. The tiles in this study are in agreement with CNS. Although all the tiles made from all compositions (35-55% kaolin, 35-50% feldspar and 5-20% quartz) and firing temperatures (900, 1100 and 1200 °C) had water absorption that met the CNS, the tiles made from composition C2 (40% wt. kaolin, 45% wt. feldspar, 15% wt. quartz), fired at 1100 °C are the best tiles because they have the lowest water absorption (12.4%). The tiles with low water absorption have high fracture strength, and good chemical, stain and frost resistance, enabling them to be used in any environment [5,6].

The combined effect of firing temperature (900, 1100 and 1200 °C) on the bulk density is given in Fig. 5. The bulk densities of the tiles increased with firing temperature because of the increase in densification and then decreased as the firing temperature was increased further. The decrease in bulk density at higher firing temperature was attributed to bloating which takes place as gasses are expelled from the matrixes and

cause the increase in porosity [9].

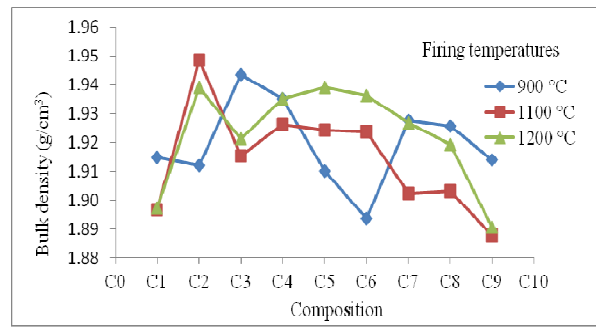


Figure 5. Bulk density of the porcelain tiles with different composition fired at 900, 1100 and 1200 °C.

The tiles made from composition C9 had the lowest bulk densities when compared with the rest of the tiles. This is because the bulk density of the porcelain body decreases with the decrease in feldspar content and vice versa. The fluxing oxides help in the formation of liquid phases which fill the pores and increase the bulk density of the porcelain body [27]. The bulk density of the porcelain body reaches its maximum when there are enough liquid phases to block the open porosity. The temperature at which the porcelain body reaches its maximum bulk density decreases with increase in feldspar content [9]. Thus, the porcelain tile with high feldspar content was expected to reach its maximum bulk density at low temperature than the porcelain tile with low feldspar content. However, the actual temperature will depend on the composition of the raw materials in question [9]. That is why composition C1, C3, C4, C7, C8 and C9 had their maximum density at low firing temperature (900 °C), composition C2 had maximum density at 1100 °C and composition C5 and C6 had their maximum density at 1200 °C. For the same reason it was also expected for the tiles made from composition C1 to have the higher bulk density than the rest of the tiles but that was not the case. This observation was due to small percentage of kaolin.

The tiles containing higher water absorption were found to contain lower value of bulk density. This is because the tile density and moisture absorption have an indirect relationship to each other. It is important for the tile to have the large density and weight because as the weight or the density of the tile increases, the tiles become stronger [26]. All the bulk density results obtained in this study were within established refractory standards for fireclay (1.71-2.1 g/cm³) [19]. Although all the tiles made from all compositions (35-55% kaolin, 35-50% feldspar and 5-20% quartz) and firing temperatures (900, 1100 and 1200 °C) had bulk density that met the established refractory standards for fireclay, tiles made from composition C2 (40% wt. kaolin, 45% wt. feldspar, 15% wt. quartz) and fired at 1100 °C were the best since they had the highest bulk density (1.95 g/cm³). The tiles with high bulk density seem to be correlated with high compressive strength, heat conductance, and low water absorption [26].

The variation of apparent porosity with firing temperature (900, 1100 and 1200 °C) is given in Fig. 6. The apparent

porosity is expected to decrease with increase in firing temperature. This is because high temperature results into formation of enough liquid phases to block the open porosity [9]. This observation was also supported by other authors [17] who noted that the amount of liquid phase formed increases with firing temperature. However, this was not the case for some of the compositions. The apparent porosity for the tiles made from composition C2 and C6 were found to decrease with the increase in firing temperature and then increased as the firing temperature was increased further.

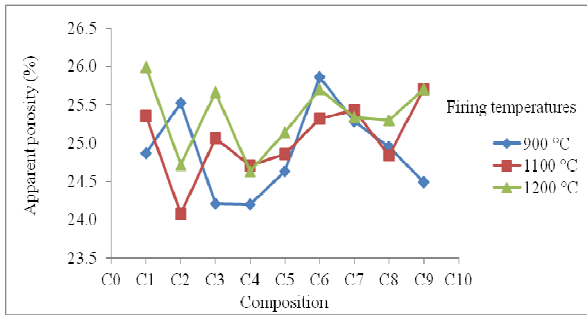


Figure 6. Apparent porosity for the porcelain tiles with different composition fired at 900, 1100 and 1200 °C.

The apparent porosity for the tiles made from composition C1, C3, C5, C8 and C9 was found to increase with firing temperature. The increase in apparent porosity at higher firing temperature is thought to be caused by bloating which takes place as gasses are expelled from the matrixes and cause the increase in porosity [9]. It was also expected for the apparent porosity to decrease with the increase in fluxing oxides, Na_2O and K_2O and feldspar content in the tiles [27]. The high porosity value for the tiles made from composition C9 fired at 1100 and 1200 °C could be a result of low feldspar content. The tiles with high content of quartz were expected to have high porosity because as the quartz content increased, the porosity also increased because of the low dry bulk density [3]. That is why tiles made from composition C1, C3 and C9 had high porosity (26.0%, 25.7% and 25.7%, respectively).

Porosity of the tiles is expected to decrease with increase of kaolinite content in the composition [3]. This is because when kaolinite is heated produces liquid phase which fills the pores and decreases the porosity. Larger kaolinite content in the mixture enhances the number of interfaces between particles (or its products after dehydration). This helps to increase the amount of nuclei [3]. Tiles made from composition C1 had low kaolinite content which made them to have high apparent porosity than the tiles made from other compositions. The tiles with higher water absorption were found to contain higher apparent porosity. This is because as stated previously, the porosity and water absorption have direct relationship to each other. All the apparent porosity values obtained in this study were found to be within 20-30%. However, the tiles made from composition C2 (40% wt. kaolin, 45% wt. feldspar, 15% wt. quartz) and fired at 1100 °C were the best tiles since they had the lowest apparent porosity (24.1%). The tiles with the lowest apparent porosity have the lowest water of absorption, high density and high compressive strength [26]. It is

important for the porcelain tile to be fired at the temperature which gives the minimum value of the apparent porosity. This is because the optimum vitrification is achieved when the apparent porosity reaches a minimum value which is normally zero or just close to it [9]. The actual temperature at which the porcelain tile gives the minimum value of the apparent porosity depends on the composition of the raw materials used [9].

The comparison on the variation of linear shrinkage at 900, 1100 and 1200 °C is shown in Fig. 7. The linear shrinkage of the porcelain tiles is expected to increase with firing temperature due to formation of liquid phase which is responsible for blocking the open porosity leading to decrease in shrinkage [6,27].

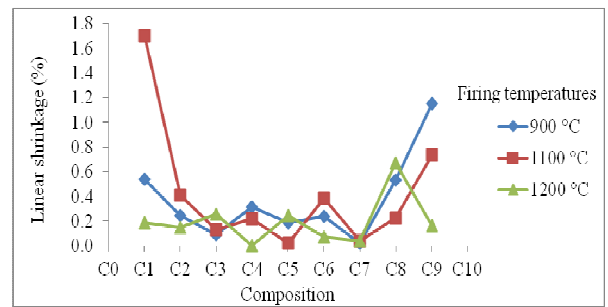


Figure 7. Linear shrinkage for the porcelain tiles with different composition fired at 900, 1100 and 1200 °C.

This was observed in the tiles made from composition C1, C2, C3 and C6. Anomalous trend was observed for the tiles from composition C1, C2 and C6 in which the linear shrinkage were found to increase with increase in firing temperature up to the maximum and then decreased as the firing temperature was increased further. The maximum linear shrinkage indicated that the sintering mechanism was complete [27]. For the tiles made from the other compositions, the linear shrinkage of the porcelain tiles was found to decrease with firing temperature and increased in fluxing oxides, Na_2O and K_2O and feldspar content in the tiles. The reason behind these phenomena is the formation of liquid phase as the temperature and fluxing oxides increased which eventually filled the pores leading to decrease in shrinkage [27].

For the same reason it was expected for the tiles made from composition C1 to have the lowest linear shrinkage than the rest of the tiles but that was not the case. This observation was due to low percentage of kaolin in the composition [27-30]. The liquid phase formed by kaolin is responsible for blocking the open porosity leading to decrease in shrinkage [27]. Although all the tiles tested in this study have the linear shrinkage lower than the established refractory standards for fireclay [31] the tiles made from composition C7 (50% wt. kaolin, 35% wt. feldspar, 15% wt. quartz) were found to have the lowest linear shrinkage (0.0%). The low linear shrinkage indicates the good stability of the tiles and the best refractory clays are the ones with greater amount of stability. The high shrinkage causes destruction of the product during firing and drying stages of production [28].

The combined effect of compressive strength with increase

in firing temperature is shown in Fig. 8. It was expected that the compressive strength would increase with firing temperature. The increase in compressive strength with the increase in firing temperature was caused by the decrease in porosity and increase in bulk density with increasing temperature [26]. This was observed only in compositions C6 and C7. Whereas for composition C2, C4, C8 and C9 the compressive strength of the tiles increased with firing temperature to the maximum (1100 °C) and then decreased as the firing temperature was increased further. Compressive strength of the tiles made from composition C1 and C5 were found to decrease with the increase in firing temperature. The decrease in compressive strength at higher firing temperature might be due to bloating which caused the increase in porosity, and the decrease in both bulk density and compressive strength [9].

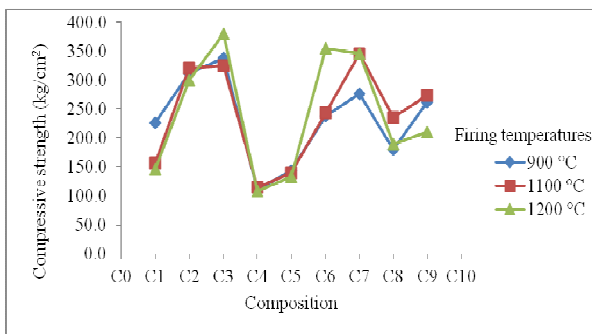


Figure 8. Compressive strength of the porcelain tiles with different composition fired at 900, 1100 and 1200 °C.

The compressive strengths of the tiles also increased with feldspar content. The reason behind this is that, feldspar melts at relatively low temperature, and acts as the flux. The molten phases which are formed tend to fill the pores, and decrease the porosity which causes the increase in bulk density of the porcelain body [27] and hence caused the increase in compressive strength [26]. For the same reason the tiles made from composition C1 which consisted of maximum percentage of feldspar were expected to have the highest compressive strength than the rest of the tiles. But that was not the case. This was attributed to low percentage of kaolin present in composition C1 which formed mullite phase and ultimately the liquid phase [27-29]. The liquid phase blocked the open porosity which resulted into increased both density and compressive strength. Thus, the compressive strength decreased with decreased amount of kaolin in the composition. The lower compressive strength indicated that the tiles produced were highly porous and were less dense. Generally, the compressive strength of the clay product was highly affected by one of the following factors; the firing temperature, method of production, physical, chemical and mineralogical properties of the raw material [28]. Although all the tiles made from all compositions (35-55% kaolin, 35-50% feldspar and 5-20% quartz) and firing temperatures (900 °C, 1100 °C and 1200 °C) had the compressive strength lower than the established refractory standards for fireclay, the tiles made from composition C3 (45% wt. kaolin, 40% wt. feldspar, 15%

wt. quartz), fired at 1200 °C were the best tiles because they have the higher compressive strength (380.4 kg/cm²) than the rest of the tiles.

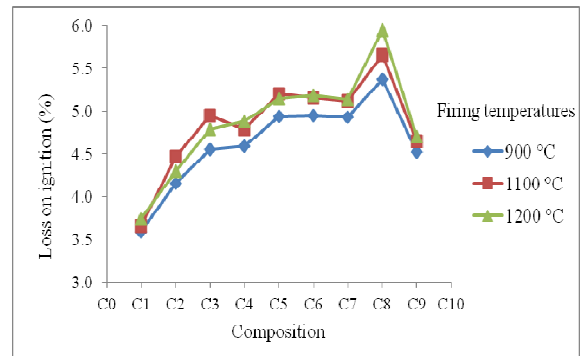


Figure 9. Loss on Ignition for the porcelain tiles with different composition fired at 900, 1100 and 1200 °C.

The comparison on the variation of loss on ignition at 900, 1100 and 1200 °C is shown in Fig. 9. The loss on ignition for the tiles was expected to increase with firing temperature. This was because as the temperature increased the amount of chemically and mechanically bonded water and organic matters loss increased, hence increased loss on ignition [4, 26].

The tiles made from composition C8 had the highest loss on ignition than the rest of the tiles. This was due to higher percentage of kaolin in these tiles compared to the rest of the tiles because the loss on ignition was expected to increase with the increase in kaolin content. The increase in loss on ignition with the increase in kaolin content occurred because kaolin consisted mainly of the mineral kaolinite which was a hydrated aluminium silicate. On firing, kaolin tended to lose its water of hydration. The loss of hydrated water caused the decrease in weight of the tiles after firing and hence increased the loss on ignition. On the other hand the tiles made from composition C1 had the lowest loss on ignition due to its low kaolin content. All the LOI values obtained from all the compositions and all firing temperatures were found to be between 3.5-6.0%. This means that the tiles produced were of good quality. The LOI values are required to be low because of its effect on the porosity and linear shrinkage of refractory fireclay. Decreased porosity gives porcelain materials of high bulk density and hence high compressive strength. Although all the tiles made from all compositions and firing temperatures had low LOI, the tiles made from composition C1 (35% wt. kaolin, 50% wt. feldspar, 15% wt. quartz) were found to have the lowest LOI (3.6%, Fig. 9).

4. Conclusion

Dependence of the composition of the raw materials to the suitable firing temperature for the preparation of porcelain tiles was clearly observed. From the compositions and firing temperatures (900 °C, 1100 °C, 1200 °C) studied, the tiles made from these raw materials were found to have the water absorption of 12.4-13.7%, bulk density of 1.89-1.95 g/cm³,

apparent porosity of 24.1-26.0%, linear shrinkage of 0.0-1.7%, compressive strength of 107.4-380.4 kg/cm² and loss on ignition of 3.6-6.0%. Moreover, the tiles made from composition C2 and fired at 1100 °C were found to have better properties than tiles made from other compositions and/or fired at other temperatures. Thus, the suitable composition of the raw materials was found to be 40% wt kaolin, 45% wt feldspar and 15% wt quartz. The best firing temperature was found to be 1100 °C.

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