Effect of cassava peel on the insulating properties of Ogugu clay deposit

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Abstract

The most commonly used agricultural waste materials in enhancing the insulating properties of clay are sawdust and rice husk. However, there is scarcity of information on the use of cassava peel despite its abundance and easy accessibility. This study therefore considers the insulating tendency of cassava peel when added to clay. Easy accessible ogugu clay deposit was utilized and the chemical analysis was determined, cassava peel was then added in a percentage by weight of 5-30%. Ogugu clay had low refractoriness of 1100^0C but the addition of cassava peel at certain percentage compositions increased the refractoriness to 1200^0C. The addition of cassava peel to the clay was found to have great effect on the insulating properties such as linear shrinkage, total shrinkage, bulk density, modulus of rupture, apparent porosity and water absorption at firing temperatures of 900 to 1200^0C. Chemical analysis revealed SiO_2 (57.44%) and Al_2O_3 (13.27%) as major constituent and also a reasonable high concentration of Fe_2O_3 (7.92%) and alkali oxide fluxes. The result of this study showed that cassava peel was suitable in enhancing the insulating properties of ogugu clay and can thus be utilized in inducing insulation in clay minerals when desired.

Keywords: *Refractory, Insulating properties, Ogugu clay, Cassava peel, Apparent porosity*

1.0 Introduction

Insulators simply refer to materials that offer high resistance to the flow of heat or electric current. They are utilized in situations where high temperature applications are required in most industrial processes as they tend to minimize the heat flow. Consequently, when such materials are able to withstand high temperatures they are said to be refractory. Nigeria as a developing country has a lot of industries which utilize refractory materials in abundance [1]. One of such is metallurgical industries which require materials that can withstand high temperatures. The refractory or insulating materials are also utilized excessively in kiln design and construction industries. The most important raw material in the production of refractory materials is clay [2]. Clays are naturally occurring alumino-silicates minerals produced by chemical weathering or disintegration of rocks [3]. Surprisingly, despite the high deposit of various clay minerals in Nigeria, local manufacture of refractory materials has been very low. Presently, most of the refractory present in Nigeria is largely sourced by importation, about 38,000 to 120,000 tonnes annually, which have a great and negative financial implication to the country [4]. Present economic realities suggest the need for internal sourcing of raw materials such as clay for production of needed refractory or insulating materials. As a result some Nigerian researchers have investigated the use of local clay minerals in refractory and insulating applications in order to help reduce the negative financial implications of importation [1, 2, 5, 6]. However, there is still an abundance of clay mineral deposits in Nigeria which have not been considered or investigated. In this regard, ogugu clay deposit present in abundance in Awgu local government area of Enugu state, Nigeria was utilized and investigated in this study. It is also important to note that apart from the naturally occurring fire clays which can be used in refractory, other clays can have their refractory properties enhanced by inducing insulation. This is usually achieved by the addition of some materials such as sawdust, rice husk or other agricultural waste [7]. Insulation however, rarely adds to refractory life and indeed may even reduce it. It however, does save energy by reducing the heat loss through many refractory structures [5]. These insulating bodies are highly porous refractory having low thermal conductivity and high thermal insulating properties suitable for minimizing heat losses and maximizing heat conservation in furnaces [5]. The insulating effect is principally the result of achieving series of air spaces between the sintered or vitrified clay bodies. They derive their low thermal conductivities from their pores, while their heat capacity is determined by the entire solid body [8]. Also important to note is that for the refractory body to have good insulating properties it must be highly porous, have low thermal conductivity, possess low solid density and have reasonably low shrinkage [1, 5]. Furthermore, the waste agricultural material to be utilized in inducing insulation in the clay body should also be readily available, locally soured and of low cost in order to keep the cost of production low. Sawdust and rice husk are the most widely used materials to induce insulation in clay or refractory bodies by many researchers [9]. In Nigeria, there is abundance of cassava peel waste which is readily available and of low-cost. However despite its abundance, a serious literature search showed a dart of information on the use of cassava peel in enhancing the insulating properties of clay minerals. This study therefore investigated the use of cassava peel as a low-cost agricultural material in enhancing the insulating properties of ogugu clay deposit. The physicochemical properties of the clay was determined to verify its industrial applicability after which it was mixed with cassava peel to determine the effect on the insulating properties of the clay.

2.0 Materials and Methods

2.1 Sample preparation

Ogugu clay was obtained from Ogugu, in Awgu local government area of Enugu State, Nigeria by random sampling at different points. The clay was taken at a depth of 1.55 m and mixed properly to obtain a uniform and homogenous sample. The cone and quartered method was used to obtain a representative sample as described by Abubakar *et al* [10]. Thereafter, the collected clay was dispersed in excess water in a pre-treated plastic container and stirred vigorously to ensure proper dissolution. The dissolved clay was then filtered through a 0.425 mm mesh sieve to get rid of unwanted particles and plant materials. The filtrate was allowed to settle, after which excess water was decanted off. The clay was then sundried and oven dried at 100 ^{0}C for 3 hr, pulverized and passes through a mesh sieve of size 0.18 mm to obtain the raw clay (100C), which does not contain cassava peel additive. The cassava was supplied from Ogbete market, Enugu State, Nigeria and was washed with excess water in order to get rid of impurities from the surface. It was then sliced to remove the peel by the use of a kitchen knife and the cassava peels were further washed with water. The washed cassava peels were sundried for several weeks to get rid of moisture, then oven dried further at 60^{0}C for 4 hrs. The dried cassava peel was then pulverized using a grinder then passed through a mesh sieve of size 0.18 mm in order to obtained uniform particles as the sieved clay.

The effect of cassava peel on the insulating properties of Ogugu clay was studied by mixing the clay and cassava peel in the following percentage proportions by weight of clay to cassava peel respectively; 95% to 5% (95C5CP), 90% to10% (90C10CP), 85% to15% (85C15CP), 80% to 20% (80C20CP), 75% to 25% (75C25CP) and 70% to 30% (70C30CP). 1.6 kg of each sample was weighed and mixed with appropriate amount of water to make it plastic for the molding process [11].

2.2 Molding process

The samples were molded as described previously [11]. This was done by molding the samples into three types of shapes using metallic moulds and the application of lubricants to the surface of the moulds to prevent the test pieces from sticking to the surface. The first shape was cylindrical with a width of 3.5 cm and height 3 cm, the second was a rectangular piece with length 8 cm, width 4 cm and height 1.5 cm, while the third had a long rectangular shape with length 9.5 cm, width 2 cm and height 1.5 cm. This was performed for each sample.

2.3 Making moisture determination

This was determined by weighing the cylindrical test pieces immediately after molding and recorded as the wet weight, *Wo*. The test pieces were air-dried for 24 hr and then dried in an oven at 105^{0}C until a constant weight was recorded. After drying the test pieces were weighed and the dried weight recorded as *Wi*. The making moisture was then calculated [11]:

$$Making\ Moisture\ (\%) = 100[Wo\text{-}Wi]/Wo$$

2.4 Modulus of plasticity determination

The relative plasticity was determined using the cylindrical test pieces. The original height, *Ho* of the test pieces were obtained by the use of the venier caliper by taking the average of three sides. Afterwards, a manual plastometer machine was used to deform the test pieces. The deformation height, *Hi* was recorded taking the average of three sides. The relative plasticity was then calculated [11]:

Relative Plasticity = Ho/Hi

2.5 Modulus of rupture determination

Five long rectangular test pieces were made and air dried for 7 days after which they were oven dried at 105^0C until a constant weight was obtained. Four of the pieces were fired to their respective temperatures of 900, 1000, 1100 and 1200^0C in a laboratory kiln (Fulham Pottery). The electrical transversal strength machine was used to determine the breaking load, P (Kg). A vernier caliper was used to determine the distance between support L (cm) of the transversal machine. The height, H (cm) and the width, B (cm) of the broken pieces were determined and the average value obtained from the two broken parts was recorded. The modulus of rupture was then calculated [12]:

Modulus of Rupture $(KgF/cm^2) = 3PL/2BH^2$

2.6 Determination of shrinkage

Immediately after molding of the rectangular test pieces, a vernier caliper was used to insert a 5m mark on each of them; this was recorded as the original length *Lo* (cm). The test pieces were then air dried for 7days and then dried in an oven at 105^0C until a constant weight was obtained. The shrinkage from the 5cm mark was then determined and recorded as the dried length, *Ld* (cm). Afterwards, four of the dried samples were fired to their respective temperatures of 900, 1000, 1100 and 1200^0C each temperature corresponding to a particular test piece. The shrinkage of the test pieces from the 5cm mark were then determined and recorded as the fired length, *Lf* (cm). The shrinkage was then calculated [13]:

Linear Shrinkage (%) = 100[Ld - Lf]/ Ld

Total Shrinkage (%) = 100[Lo – Lf]/ Lo

2.7 Determination of water absorption

The fired test pieces obtained after firing were then weighed and the weight recorded as dry weight, *M1* (g). Thereafter, the test pieces were soaked in water for one hour, then removed, cleaned and weighed immediately and recorded as soaked weight, *M2* (g). The water of adsorption was then calculated [11]:

Water Absorption (%) = 100 [M2 – M1]/ M1

2.8 Determination of porosity and density

After the procedure described above was completed. The suspended weight of the test pieces were then determined by the use of a lever balance and recorded as *M3* (g). The apparent porosity and bulk density were then calculated [11]:

Apparent Porosity (%) = 100 [M2- M1]/ [M2 – M3]

Bulk Density (g/cm^3) *= M1/[M2 – M3]*

2.9 Chemical characterization

0.2 g of the clay was weighed into a beaker and 10 mL of aqua regia (HCl + HNO_3 in the ratio 3:1 respectively) was added and digested in a hot plate in a fume cupboard. 10 mL of Hydrofluoric acid was also added to aid the digestion process. After digestion 30 mL of de-ionized water was added and the mixture filtered through a filter paper into a 250 mL volumetric flask and made up to the meniscus mark with de-ionized water. The sample was then analyzed for the elemental composition by the use of the Atomic Absorption spectrophotometer (AAS) (Buck scientific model 210 VGP). The concentration of metal oxide in the clay was expressed in mg/L. The percentage composition of the elements in the clay was calculated from the equation [11]:

% Composition = 100CV/M

Where C (mg/L) is the elemental composition obtained from the AAS, V (L) is the volume of the volumetric flask in which the digested solution was diluted and M (mg) is the mass of sample diluted.

2.10 Determination of loss on ignition

The weight of an empty porcelain crucible was determined and recorded as W1 (g), 2.0 g of the dried pulverized clay was added and the weight of the crucible + clay was determined, W2 (g). The sample was then ignited in the laboratory kiln at 1200^0C. After, the cooling of the sample the weight of the crucible + sample after ignition was determined, W3 (g). The loss on Ignition was then calculated [11]:

Loss on Ignition (LOI) = 100[W2 – W3]/ [W2 – W1]

3.0 Results and Discussion

Table 1 shows the result for the characterization of ogugu clay deposit. The major constituent of ogugu clay was found to be silica and alumina while other metal oxides are present in smaller concentrations as impurities. Such kind of chemical composition is expected for any clay, since clay is mainly an aluminosilicate mineral. The alumina content (13.27%) of ogugu clay was lower than the standard required for the manufacture of ceramics (> 26.5%) and refractory bricks (25-44%) [14]. The amount of alumina in a clay is very important in describing the refractoriness of the clay, as the higher the alumina content the more refractory the clay [10]. The low concentration of alumina in ogugu clay may indicate a low or moderate refractoriness of the clay [11]. However, the concentration of silica (57.44%) was found to be very high which satisfies the standard for the manufacture of refractory bricks (>51.7%) and high melting clays (53-73%) [14]. The Fe_2O_3 concentration (7.92%) of ogugu clay was high and within the standard for the manufacture of high melting clays (1-9%) but above the requirement for the manufacture of ceramics (0.5-1.2%) and refractory bricks (0.5-2.4%) [10]. This high Fe_2O_3 concentration usually impacts a reddish coloration to the clay body after firing, as seen in Table 1 where ogugu clay showed a transformation from brown to reddish coloration after firing. Such reddish coloration is usually desired in the manufacture of some flower vase, pots and bricks, but will not be desired in the manufacture of refractory white ware products. In this study were we desire to obtain a good refractory or insulating properties of ogugu clay, the high iron content is not desirable as it may act as fluxes affecting the high temperature characteristics of the clay [15]. Also, iron is a conductor and will hinder the insulating properties of the clay, hence the addition of agricultural materials such as cassava peel is necessary to induce insulation. Importantly, the presence of high concentrations of alkali oxides (K_2O, CaO and Na_2O) as shown in Table 1 indicates the tendency of ogugu clay to have low or moderate refractoriness. This is because these alkali oxides act as mild fluxes which reduce the vitrification temperature and refractoriness of the clay during firing [16]. In fact, the low alumina, high Fe_2O_3 and alkali oxides concentrations suggest a low refractory property of ogugu clay, hence the need to improve the insulating or refractory properties of the clay. The loss on ignition (LOI) (10.27%) of ogugu clay was within the standard for the manufacture of ceramics (> 8.18%), refractory bricks (8-18%) and high melting clays (5-14%) [17]. As reported previously [11], the slightly high LOI is desirable when a porous body is required due to the removal of the ignitable components during firing which would favour insulation. It is observed from Table 1 that ogugu clay has low refractoriness and did not show any sign of failure at 1100^0C, however at higher temperatures signs of failure were observed. This implies that ogugu clay did not meet the accepted standard of 1580 – 1750^0C for refractory materials [13]. However, the presence of additives might help improve the refractory properties. Ogugu clay was found to have low refractoriness when compared to other clays reported by some researchers, such as Adiabo clay (1200^0C) [13], Mangada clay (1300^0C) [2] and Ezzodo clay (1200^0C) [11]. This low refractoriness may be due to the low alumina and high alkali oxide and iron oxide content in ogugu clay mineral as stated earlier.

Table 1: Characterization of Ogugu clay without cassava peel additive

Parameters	Value
Al_2O_3 (%)	13.27
SiO_2 (%)	57.44
Fe_2O_3 (%)	7.92
CaO (%)	3.43
K_2O (%)	3.87
Na_2O (%)	2.93
MgO (%)	0.53
MnO (%)	0.09
LOI (%)	10.27
Colour before firing	Brown
Colour after firing	Reddish
Refractoriness (^{O}C)	1100
Modulus of Plasticity	1.21
Making moisture (%)	19.74

The effect of cassava peel additive on the physical properties of ogugu clay at firing temperatures of 900-1200^0C are shown in Figs.1-6. The linear shrinkage of ogugu clay with and without the addition of cassava peel is shown in Fig.1. As stated earlier, for a clay to have good insulating characteristics, it must have a reasonably low linear shrinkage [1]. It was observed that an increase in linear shrinkage with increase in firing temperature was obtained for all the samples. The increase is due to the removal of combustible component from the clay with temperature increase and the burning off of the cassava peel component in the mixed samples which resulted in the compression or coming together of the clay particles during sintering and vitrification as temperature increases. It was also observed that the clay without cassava peel (100C) had the lowest linear shrinkage of 0.83 to 2.03% at 900 to 1200^{0}C while the highest was recorded for the 70% clay mixed with 30% cassava peel (70C30CP) with values of 6.79 to 9.92%. In general an increase in linear shrinkage with increase in cassava peel concentration in the sample was obtained. This is due to the fact that as more cassava peel was contained in the sample, more of its components were removed during firing which resulted in more space and a greater compression of the body during sintering and vitrificaton. It is also very important to note that despite the addition of cassava peel in all the compositions, the linear shrinkage was reasonably low and was within the standard (<10%) required for insulating materials [5]. Similarly, the total shrinkage of the samples is shown in Fig.2 and followed the same trend as the linear shrinkage, also having reasonably low shrinkage values. However, the total shrinkage is of little significance since the value is affected by the making moisture applied during molding. It is therefore expected that the more the amount of water added to the clay to make is plastic for molding, the greater the total shrinkage and the higher the plasticity of the clay.

The modulus of rupture (MOR) of ogugu clay with and without cassava peel additive at different firing temperatures of 900 to 1200^{0}C is shown in Fig.3. It is observed that an increase in MOR with increase in firing temperature for all the samples was obtained. The increase may be attributed to the tendency of the clay body to become more compact and rigid due to increase in shrinkage with temperature [11]. It can also be due to bond formation in the glassy phase of the fired material [15]. It was also observed that the highest MOR was achieved with 95% clay mixed with 5% cassava peel (95C5CP) followed by the 90% clay and 10% cassava peel (90C10CP) indicating that the addition of cassava peel to ogugu clay increased the strength of the fired body which is desirable in the manufacture of any product. Further increase in the concentration of cassava peel in the clay (> 10% cassava peel) led to a corresponding decrease in the MOR with strength values even lower than that of ogugu clay without cassava peel (100C). The decrease in MOR as the concentration of cassava peel increased may be due to the burning off of the cassava peel component during firing which induces porosity, thus reducing the strength and weight of the body. The higher strength obtained for 95C5CP and 90C10CP than 100C indicates that such concentration of cassava peel in the mixture was appropriate to enable suitable blending of the components in order to achieve better strength and refractoriness after sintering and vitrification. This is supported by the fact that although ogugu clay has low refractoriness of 1100^{0}C, however after the addition of cassava peel the samples exhibited refractoriness of up to 1250^{0}C, except for 75C25CP and 70C30P which still had a refractoriness of 1100^{0}C. This indicated that insulation has the ability to increase the refractoriness of a clay body due to the air spaces or pores induced to trap and reduce the effect of heat flow. This result is contrary to that reported by Hassan *et al* [2] in which the addition of sawdust and rice husk reduced the refractoriness of mangada clay which was attributed to the very high silica content of the clay. Cassava peel was found to be a suitable additive both in increasing the strength and refractoriness of ogugu clay which is desirable.

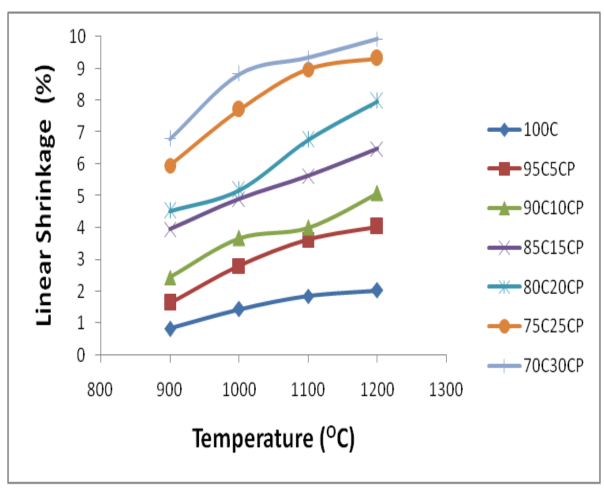

Fig.1: Effect of firing temperature on the linear shrinkage of the clay samples

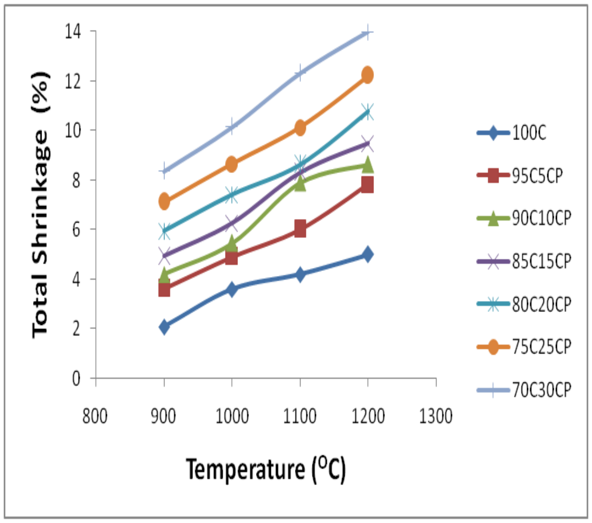

Fig.2: Effect of firing temperature on the total shrinkage of the clay samples

The results of the bulk density of ogugu clay with and without the addition of cassava peel when fired at different temperatures of 900-1200°C is shown in Fig.4. An increase in the bulk density of all the samples with increase in firing temperatures was obtained. This increase indicated that the samples became more compact and dense with increase in firing temperature [11]. As the firing temperature increases the samples experience more shrinkage and increase in strength resulting in a corresponding increase in bulk density. Furthermore, as observed in Fig.4, a decrease in the bulk density of ogugu clay with increase in concentration of cassava peel was obtained. The highest bulk density of 1.79-1.84 g/cm^3 was achieved for the clay without cassava peel (100C) at firing temperatures of 900 to 1200°C, while the lowest value was obtained for 70C30CP with bulk density of 1.55-1.57 g/cm^3 at the given temperature range. This implies that the addition of cassava peel tend to make the fired body lighter which is desirable, as a good insulating refractory must have a low solid density [1, 5]. As expected for any good insulating refractory, the bulk density should range between 1.6 to 2.0 g/cm^3 [9, 14]. The range of values was exhibited by all the samples except the mixture of 70% ogugu clay and 30% cassava peel (70C30CP). The decrease in bulk density with increase in concentration of cassava peel in the sample is attributed to void formation resulting from the burning off of cassava peel, an organic matter from the body during firing making the sample lighter. Similar result was obtained in the use of sawdust in enhancing the insulating properties of fire bricks at different firing temperatures [9].

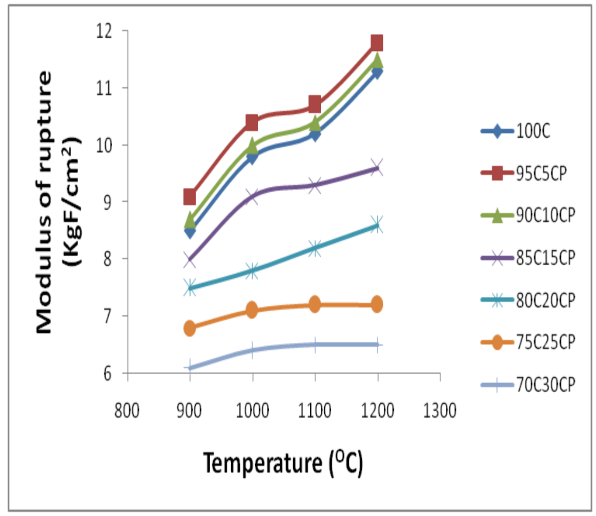

Fig.3: Effect of firing temperature on the modulus of rupture of the clay samples

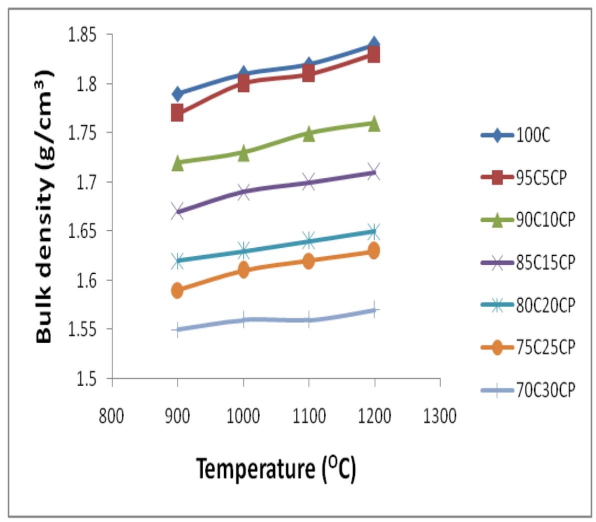

Fig.4: Effect of firing temperature on the bulk density of the clay samples

The result of the apparent porosity of ogugu clay with and without the addition of cassava peel is shown in Fig.5. A decrease in the apparent porosity of all the samples with increase in firing temperature was recorded. This decrease is attributed to the increase in shrinkage of the body with increase in firing temperature which resulted in the closure or reduction in size of some of the pores. This is expected because as the samples shrinks with firing temperature the number of pores gets reduced. It was also observed from Fig. 5 that the apparent porosity increased with increase in the concentration of cassava peel in the body. The highest apparent porosity of 45.11-52.13% was obtained for 70C30CP while the lowest of 24.26 – 29.26% was obtained for 100C at firing temperatures of 900 to 1200^{0}C. This is desirable, as one of the major requirements for a good insulating refractory is that it must be highly porous [5]. The presence of pores helps the insulating characteristics of the fired body by serving as air spaces to trap heat and prevent flow or conduction. The apparent porosity showed an increase as the percentage of cassava peel increased because the cassava peel burnt off at elevated temperatures inducing porosity. Therefore the more the cassava peel was added the more the pores created [9]. The 75C25CP and 70C30CP met the standard requirement of apparent porosity (> 45%) for the production of insulating firebricks [18]. The samples containing lower concentrations of cassava peel although possess apparent porosity below the standard for insulating firebricks also displayed reasonably high porosity and showed much greater strength. Hence will be more useful or applied in insulating material production were products with high strength are desired.

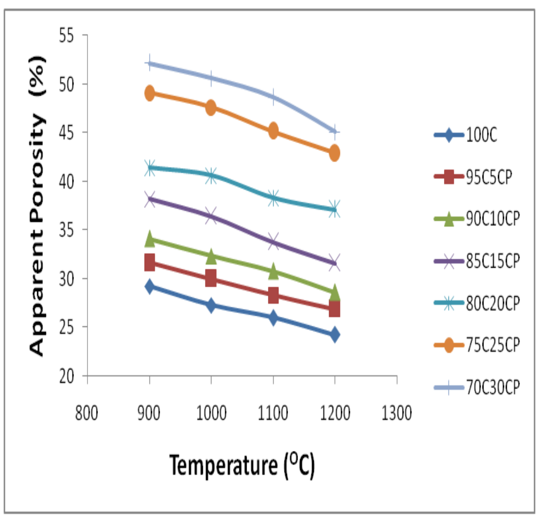

Fig.5: Effect of firing temperature on the apparent porosity of the clay samples

Fig.6 showed the effect of firing temperature on the water absorption of ogugu clay with and without the addition of cassava peel. As observed, similar trend as the apparent porosity was obtained in which a decrease in water absorption of all the samples with increase in firing temperature was obtained. This is because the water absorption is dependent on the pores and is directly proportional to the apparent porosity of the fired body. Since the pores are responsible for water uptake, the decrease in water absorption is attributed to a decrease in porosity of the clay body with increase in firing temperature. Similar to the case of apparent porosity, the water absorption showed an increase with increase in the percentage of cassava peel in the fired body, also attributed to increase in porosity due to the burning of more of the cassava peel. The water absorption potential can be reduced by the addition of glaze on the surface of the product, but this method should only be performed in products that require the addition of glaze materials.

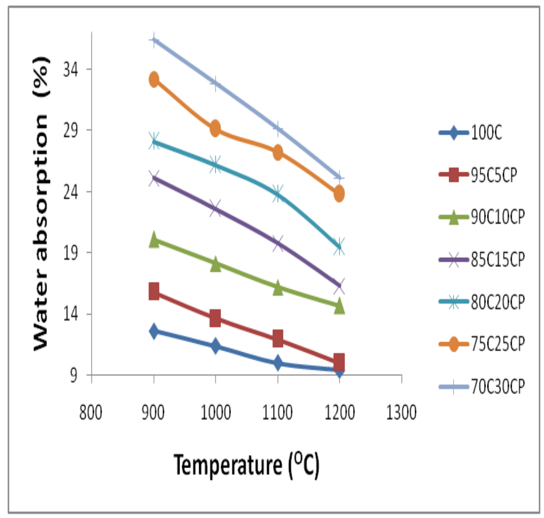

Fig.6: Effect of firing temperature on the water absorption of the clay samples

4.0 Conclusion

The result of this investigation showed that cassava peel was effective in enhancing the insulating properties of ogugu clay deposit. The linear shrinkage obtained after cassava peel addition for all the samples was within the standard required for insulating materials. Ogugu clay sample became lighter with cassava peel addition after firing with a decrease in bulk density with increase in percentage addition of cassava peel. The bulk density of the sample was also within the standard requirement for good insulating refractory, except the 70% clay and 30% cassava peel mixture. Some of the compositions of clay blended with cassava peel also showed a higher strength or modulus of rupture than ogugu clay alone. Importantly, the addition of cassava peel enhanced greatly the apparent porosity of ogugu clay which is required for a god insulating body. Although, ogugu clay had low refractoriness, the addition of cassava peel at certain concentrations was found to improve slightly the refractoriness, but not suitable enough to be used in high temperature refractory. A complete evaluation of the physical properties indicated that the addition of 5 to 20% cassava peel was most suitable in enhancing the insulating properties of ogugu clay. Therefore cassava peel was found to be a suitable agricultural waste material that can be used to induce insulating properties when desired in a clay body.

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