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# Assessment of Thermo-Mechanical Behaviour of Barkin-Ladi Fireclay Brick as Refractory Furnace Lining

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**Abstract:** This study, the thermo-mechanical behavior of barkin-ladi was assessed with a view to investigating its appropriateness for refractory furnace lining. The study involved physical, mechanical and thermal properties which were investigated, evaluated and its suitability for refractory brick used for furnace lining was ascertained. At the best sintering temperature of 1200°C, the following results of the fireclay brick showed the apparent porosity of 24.26%, bulk density of 1.82 g/cm$^3$, firing shrinkage of 9%, cold crushing strength of 16.02 MPa, thermal shock resistance of 24 cycles and a refractoriness of 1665°C. Based on these results the fireclay brick has excellent foundry properties that present it as suitable for the production of fireclay bricks for furnace lining.

**Key words:** Assessment, thermo-mechanical, refractory, fireclay brick, sintering temperatures

## INTRODUCTION

Refractories are clay materials that can withstand high temperature of 538°C and above (Vishnevskii *et al*., 1975). Fireclay refractory bricks are used in the construction of furnace lining, reactors and kiln (Djangang *et al*., 2008). Clay is a compound mixture with a varying structure dependent on the geographical site. It is occurring in unlimited abundance as a natural substance and it is formed by rock weathering through incessantly formation on the earth's surface (Amkpa and Badarulzaman, 2016a, b).

Clay as the name applies is both materials possessing particle size of not fewer than 2 micrometers and the group of minerals that contained similar structures and compositional and characteristics (Bam *et al*., 2015). Earth clay is of a major industrial significance for the manufacture of refractory bricks, pottery and tiles (Manukaji, 2013). Clay used for fireclay refractory bricks composed of predominantly Alumina ($Al_2O_3$) and Silica ($SiO_2$) and when hydrated chemically belongs to alumina-silicates clay group (Amkpa and Badarulzaman, 2016a, b). Alumino-silicate refractory bricks of are classified as acid refractories (Wen *et al*., 2012).

Properties of refractories that should be considered during material selection are essentially chemical, physical and thermal (Amkpa and Badarulzaman, 2016a, b). Strength is one of the greatest and extensively used parameters for assessing the suitability of refractories (Schacht, 2004). Refractory strength is essentially dependent on particle sizes, chemical composition and fusion temperature (Sadik *et al*., 2013).

Refractory fireclay when wet they become plastic and can be formed and molded into different sizes and shapes as manufacturing processes (Aye and Oyetunji, 2013). Manufacture and production of the fireclay bricks are usually is concluded with drying and firing of the bricks (Sadik *et al*., 2013).

There is large quantity of clay deposits in Nigeria with potential for manufacture of refractory bricks but remained under-utilized and instead Nigeria imports her refractories from abroad up to the tune of $2.9 billion annually (Omowumi, 2001). The over dependence of the nation on importation has to be discouraged by an attempt to save and conserve for the country the huge foreign exchange deployed annually. Hence, the motivation to investigate the barkin-ladi clay deposit for its suitability for the production of refractory fireclay bricks for furnace lining.

## MATERIALS AND METHODS

The material clay sample for this study was acquired from barkin-ladi clay deposit in barkin-ladi local government area of plateau state, Nigeria. The clay sample was collected according to (ASTM D4220/D4220M-14).

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**Chemical properties:** The chemical property was determined using the X-ray fluorescence spectrometer Bench top XRF analyzer, model X-Supreme 8000 branded Oxford instrument.

**Preparation of test samples:** Clay samples were ball milled to form fine powder particles. Each of the specimen powder was pressed by compaction into pallets using Caver hydraulic pressing machine. A force of 5 KN was applied with a holding time of 60 sec.

**Sintering process:** Mechanical activation at soaking time of 8 hours and 2.5°C/min. as heating rate, the clay test samples for the physical and mechanical properties were sintered at the varied sintering temperatures of 1200, 1100, 1000 and 900°C.

**Physical properties:** The physical properties of the fireclay brick for apparent porosity, bulk density and firing shrinkage test were conducted and determined according to (ASTM C20-00).

**Apparent porosity:** The sintered weight of the clay sample was taken using digital balance and recorded as dried weight D(g). The clay sample immersed in water weighed taken and recorded as weight S(g). The clay sample was placed in the triple stand basket and soaked in water and weighed while suspended in air and recorded as W(g):

$$\text{AP: } \frac{\text{W-D}}{\text{W-S}} \times 100\% \quad (1)$$

**Bulk density:** The bulk density was conducted to determine the volumetric bulk of the clay. The sintered dried sample was weighed and recorded as $W_1$(g). About 1000 g of mercury was measured and poured into a beaker and the sample was saddled on the surface of the mercury immersed into the mercury using densometer and weight taken and recorded as displaced weight $W_2$(g):

$$\text{BD: } \frac{W_1}{W_2} \times \rho \text{g/cm}^3 \quad (2)$$

**Firing shrinkage:** The determination of the firing shrinkage was performed to by measuring the initial length before sintering as length $l_1$ (cm). The sintered clay samples length are measured and recorded as length $l_2$:

$$\text{FS: } \frac{l_1 - l_2}{l_1} \times 100\% \quad (3)$$

**Cold Crushing Strength (CCS):** The determination of Cold Crushing Strength (CCS) was conducted as the brick failure through the compression strength test was performed. Test sample of size 20×20×20 mm were used. Hydraulic strength machine was used through the application of steady load on it. The force at which a crack revealed was noticed. The mechanical property of the fireclay brick was determined according to (ASTM C133-97):

$$\text{CSS: } \frac{\text{Force}}{\text{Sample surface area}} \text{ MPa} \quad (4)$$

**Thermal shock resistance (cycles):** Test sample of size 50×100× 20 mm were produced and placed in the furnace to reach the temperature of 1200°C as required by the test. The clay sample was withdrawn from the furnace at the stated temperature and held for duration of 10 min. The technique was continued till a presence of a crack was noticed. The clay sample thermal shock resistance was noted as the amount of cycles required to effect a crack. The thermal shock resistance was performed according to (ASTM C1100-88).

**Refractoriness (PCE):** The clay sample being formed into a conical shaped with three segar cones of identified fusion temperatures of 29, 30, 31 and placed 82° horizontally on a plaque. The clay sample with the segar cones are transferred into the refractoriness testing equipment and heated from room temperature of 27-1700°C the highest fusion temperature for fireclay refractory bricks (Bam *et al.*, 2015). The segar cone that bends with the clay sample will represent the refractoriness of the brick. The refractoriness test was performed according to ASTM (2013a, b).

## RESULTS AND DISCUSSION

**Chemical composition:** The chemical property of the clay sample showed that it contained 40% of $Al_2O_3$ and 56.4% of $S_iO_3$ with 3.39% of impurities. The XRF analysis in Table 1 indicated that the Barikin-lade fireclay belongs to alumino-silicate group of fireclay (ASTM, 2013; Aye and Oyetunji, 2013). This manifestation of the clay chemically, makes it suitable for the production of refractory fireclay brick (Schacht, 2004).

**Apparent porosity:** The maximum apparent porosity of the clay sample was 47.8% at the lowest sintering temperature of 900°C as compared with least porosity of 24.26% obtained at the maximum sintering temperature of 1200°C. The apparent porosity of the clay sample fell within the standard values of 20-3% for refractory

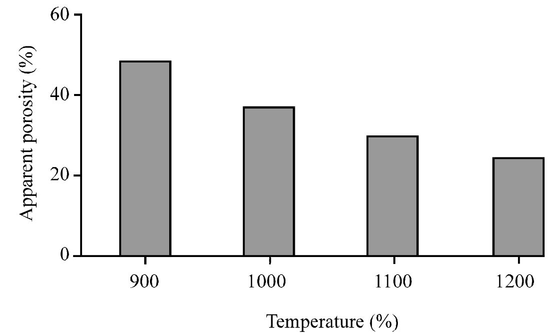


Fig. 1: Apparent porosity against varied sintering temperatures

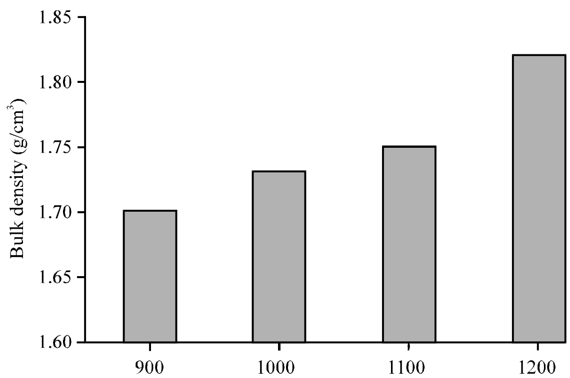


Fig. 2: Bulk density against varied sintering temperatures

Table 1: Chemical composition

| Oxide | Percentage |
|---|---|
| $Al_2O_3$ | 40.0 |
| $SiO_2$ | 56.4 |
| $Fe_2O_3$ | 0.60 |
| $TiO_2$ | 1.64 |
| MgO | 0.30 |
| $K_2O$ | 0.23 |
| $P_2O_3$ | 0.26 |
| $SO_3$ | 0.02 |
| CaO | 0.31 |

fireclay bricks (Bam *et al*., 2015). It was observed in (Fig. 1) that as the sintering temperature was increased, the volume of clay sample open pore (porosity) decreased. This indicated that there was the sintering temperature has effect on the apparent porosity of the clay sample.

**Bulk density:** The bulk density of the clay sample was 1.7 g/cm$^3$ at the lowest sintering temperature of 900°C as compared with the highest bulk density value of 1.82 g/cm$^3$ at the highest sintering temperature of 1200°C. The result of the bulk density as presented in Fig. 2 showed that the clay sample fell within the standard

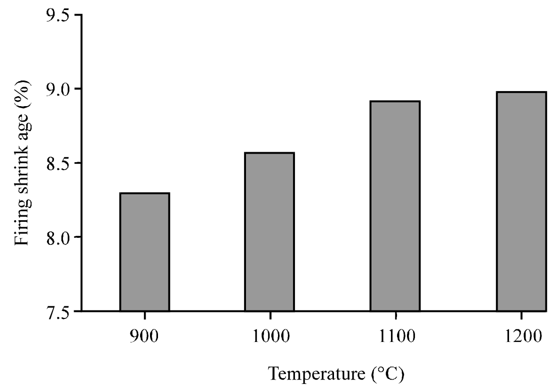


Fig. 3: Firing shrinkage against varied sintering temperatures

values of 1.7-2.3% for refractory fireclay bricks (Yakubu and Abdulrahim, 2014). The result presented the Barikin-ladi clay sample volume increased as the sintering temperature was increased. This means there was influence of sintering temperatures on the material clay volume.

The firing shrinkage of the clay sample at the lowest sintering temperature of 900°C was 8.3% as compared to the highest value of 8.92% attained at the highest sintering temperature of 1200°C. The clay sample firing shrinkage fell within the standard values of 7-10% for refractory fireclay bricks (Aderibigbe, 2014). As noticed in Fig. 3 that the firing shrinkage increased as sintering temperature was increased. The $S_iO_2$ content was responsible for the raise in firing shrinkage because at eutectic temperature, when silica matured will reduce the pore spaces in the brick.

**Cold crushing strength:** The mechanical strength as performed under cold crushing strength revealed the clay sample had the lowest CCS at minimum sintering temperature of 900°C was 10.56 MPa as compared with the highest CCS value of 16.02 MPa at the maximum sintering temperature of 1200°C. The CCS of the clay sample fell within the standard values of 15-59 MPa for refractory fireclay bricks (ASTM, 2015a, b; Bam *et al*., 2015). The CCS result as presented in Fig. 4 indicated that as the sintering temperatures were increased, the cold crushing strength increased as well. The factors responsible for this behaviour are $Al_2O_3$ which contribute to the clay structural strength and the $S_iO_2$ becomes densify at the highest sintering temperature (Amrane *et al*., 2011).

**Thermal shock resistance:** Thermal shock resistance result of the clay sample indicated that the fireclay brick can withstand up to 24 cycles and this fell within the

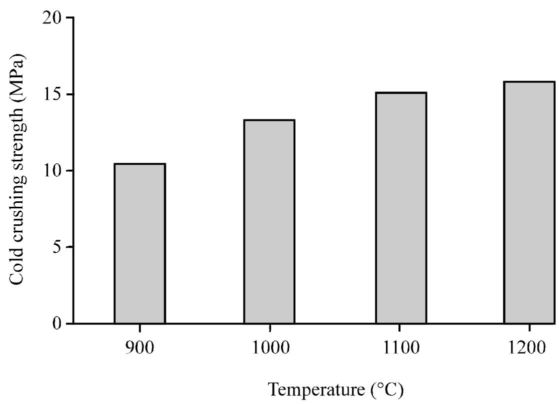


Fig. 4: Cold crushing strength varied sintering temperatures

standard values of 20-30 cycles for refractory fireclay bricks (Bam *et al*., 2015). This means the clay sample has a high degree of resistance to rapid change in temperature.

**Refractoriness:** Refractoriness of barikin-ladi fireclay brick was 1665°C which corresponded to segar cone 30 (PCE) and this signified the fusion temperature of the clay sample. The sample fusion temperature fell within the standard values of 1500-1700°C for refractory fireclay bricks (ASTM, 2013a, b; Yakubu and Abdulrahim, 2014).

## CONCLUSION

In the sintering process for the clay sample, it was revealed that the varied sintering temperatures had effect on the physical, mechanical and thermal properties of the produced fireclay brick. It was observed that 1200°C was the best and optimal among the varied sintering temperatures. $Al_2O_3$ (Alumina) contributed to the mechanical property of CCS, $SiO_2$ (silica) contributed to the densification of the refractory fireclay brick at high temperature and fireclay brick vitrification. The deductions on the chemical, physical, mechanical and thermal properties result proofs that the barikin-ladi fireclay was suitable for the production of refractory fireclay brick for furnace lining.

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