



## ASSESSMENT OF EFFECT OF ALUMINA ADDITION ON THE REFRACTORARY UNDER LOAD (RUL) PROPERTY OF SOME KAOLIN CLAY DEPOSITS IN NIGERIA

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### ABSTRACT

The impact of alumina addition on the Refractory Under Load (RUL) of kaolin clay deposits in Nigeria have been investigated. The samples deposit were collected from different sites of Ikpeshi Akoko Edo (IKAE) of Edo State, Kasadi Village in Kebbi State (KVK), Alasan in Osun State (AOS) and Badeggi in Niger State and were used as the principal raw material in the sample preparation while ball clay was used as the binder. The kaolin and ball clay were mixed in suitable proportion of 70:30 ratio in the production of the fire clay bricks. Particle size distributions and Refractory under load (RUL) of the samples were determined. Through RUL tests, samples without alumina exhibited varying subsidence behaviours at different temperatures. Samples from Kasadi (KVK) and Alasaan (AOS) showed the greatest improvement at 10% and 15% alumina levels, with lower subsidence and higher peak temperatures. With 10% and 15% alumina additions, respectively, the Kasadi sample reached maximal thermal stability with subsidence temperatures of 1475°C and 1516°C. Excellent refractory properties were likewise demonstrated by the Alasaan sample, but with less early expansion. On the other hand, the Ikpeshi (IKAE) sample underwent more overall deformation, suggesting a lower level of long-term thermal resistance, even if it was initially able to endure high temperatures. Results suggest alumina content influences the thermal stability and performance of kaolin clay, important for firebrick production and industrial applications. Practical tests confirmed the suitability of produced refractory bricks for industrial use, demonstrating comparable performance to standard refractory fire clay.

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### 1.0 Introduction

The pressing needs in Nigeria and the availability of abundant natural resources demand that the direction of utilization of locally available resources be up-graded through scientific and technological insight and new or improved technology to meet the needs of iron and steel industries. Technological development in Nigeria has created awareness and has increased the standard of living of both urban and rural dwellers, leading to increasing use of modern industrial appliances (Olusola, 2014). If Nigeria is to sustain increased industrial growth, the iron and steel industries must be sustained and new one established. Abdullahi *et al.*, 2020 carried out comparative characterization of Malaysian (M-kaolin) and Nigerian (N-kaolin) crude kaolinite resources and reported that concluded that N-kaolin is highly promising for refractory applications. Lawal *et al.*, 2022 studied mineralogical and elemental composition, morphology, thermal stability, alumina and silica content of Argungu Kaolinite and reported that the Kaolinite are characterized by low or free toxic ions that offer the clay as a vital raw material for wide range of industrial applications. These industries make use of furnaces and these furnaces are lined with refractory bricks produced using kaolin or other clays which are presently imported. Refractories belong to the class of ceramic materials which are employed for high temperature applications, usually above 1100°C (Mokwa and Salihi, 2011). Refractory materials are used in linings for furnaces, kiln, incinerators, and reactors. They are also used to make crucibles and moulds for casting glass and metals and for surfacing flame detector systems for rocket launch structures (Hassan, 1990).

Most refractory materials are made from naturally occurring high melting point Oxides, particularly Silica (SiO<sub>2</sub>), Alumina (Al<sub>2</sub>O<sub>3</sub>), Magnesia Oxide (MgO), Chromium Oxide (Cr<sub>2</sub>O<sub>3</sub>), Zirconium Oxide (ZrO) and Iron Oxide (Fe<sub>2</sub>O<sub>3</sub>) (Olusola, 2006). It is pertinent to state that without furnace, a device for heating and or melting metals or alloys, and heat treatment, there would have been no existence of iron and steel industry (Chester,

1975). Considering the importance of furnace to a steel industry, the need for refractory materials cannot be over emphasized since high working temperature is the norm in steel and foundry industries. There are several large deposits of clay across Nigeria. Many industries in Nigeria require clay or its product for operations, like the Nigeria Iron and Steel industry, Ajaokuta, Osogbo Steel Rolling, Delta Steel Company and Nigerian Iron Ore Mining Industries in Itakpe, Kogi State. These industries require huge quantity of refractory materials (clay) for their productions, and these are mostly imported to the country (Shuaib *et al.*, 2018). Manukaji, 2013 revealed that Ajaokuta Steel Industries will require about 36,000 tonnes of refractory bricks that cost N5034 billion annually when operational. Other Nigerian steel companies like Delta Steel Company also consume fire clay worth over N1.4 billion annually in which more than 80% of such clay will be required by Ajaokuta Steel Industry. Kaolin is used for fire bricks because of its unique properties such as natural whiteness, fine particle size, non-abrasiveness and chemical stability, in addition to the general properties mentioned above, it is soft and has low viscosity at high solid contents (Kirabira *et al.*, 2003). Kaolin fire clay refractories, also known as chamotte bricks, belong to the alumino silicate group with alumina content between 25-45 wt%. The others in this group are the semi-acid ( $\leq 25$  wt%  $Al_2O_3$ ) and high Alumina ( $> 45$  wt%  $Al_2O_3$ ) (John *et al.*, 2004). Kaolin is the main source of alumina in the manufacture of fireclay refractories among other industrial minerals. The higher the alumina contents of kaolin, the higher their refractoriness. Raw materials are thus classified to be of high refractory value as the amount of alumina in them increases (Manukaji, 2013). Ball clays are generally used in varying proportions as a binder with kaolin in fire bricks production.

The clay being highly plastic facilitates the forming process and contributes to the dry-strength, or green strength, of the product. In addition, it enhances the sintering process by providing a glassy-phase which bonds the aggregates together. Fireclay refractories, like other ceramic products are processed through three main stages: raw materials preparation, consolidation to compacts and densification by sintering. The main constituents of fireclay refractories are alumina ( $Al_2O_3$ ) and silica ( $SiO_2$ ). These systems are normally based on kaolinitic clays which generally present substantial shrinkage when fired (Alexander *et al.*, 2013). In consideration of shrinkage and cracking of the product, raw materials are fired, crushed and size graded into stable grog (calcined fireclay) and mixed with ground clay slip. The grog promotes drying and limits dry and firing shrinkage whereas the clay promotes sintering and bonding during firing. The materials used for making grog are generally more refractory than the bonding material (Fayyad *et al.*, 2012). However the greatest use of refractories is in the steel and manufacturing industries where it is used as lining materials in blast furnace, converters and open-hearth furnaces. Other important uses of refractories are for cement kiln, glass tanks, ceramics kilns, steam boilers and paper plants Amina *et al.*, 2014). Some research works which border on exploring ceramic refractory raw minerals reported by the Federal Ministry of Mines and Solid Minerals (Olusola, 2006), showed that the following ceramic refractory minerals exist in abundance in all the regions of the country: silica raw materials, kaolin, ball clay, alumina raw materials (kyanite, sillimanite, and corundum), magnesia raw materials (magnesite), and forsterite raw materials (talca, pyrophyllite, serpentine, asbestos). Other typical refractory minerals may be available but of poor grade, or in small, uneconomic deposits. Most of these raw materials have not been exploited for their industrial applications (Shuaib *et al.*, 2018). The need for detailed investigation on the characteristics, properties and use of Nigeria kaolin clay materials cannot be over emphasized. As a developing nation, it is very important to look inward and develop our locally available clay to meet the present demand in our steel and metallurgical industries and for the future development of other industries. Moreover, the nation depends very much on importation of kaolin clay materials from foreign countries (Shuaib *et al.*, 2018). As long as this trend continues, the nation cannot develop technologically. The quality and quantity of iron and steel products we are to produce will go a long way in helping the nation to conserve funds. This particular research intends to utilize kaolin and ball clay as an available raw material to produce a strong refractory fire bricks material that will withstand high temperature before failing under load.

## 2. Materials and Method

### 2.1 Materials

About 25Kg of the Kaolin clay samples were collected from four states in Nigeria, these include Ikpeshi Akoko Edo (IKAE) Local Government Area of Edo State, located on latitude  $7.2629^\circ$  North and longitude  $6.1271^\circ$  East of Nigeria; Kasadi Village in Kebbi State (KVK), Alasan in Osun State (AOS) and Badeggi in Niger State. The samples deposit sites were dugged and collected using an iron digger and hoe respectively. Kaolin was used as the principal raw material in the sample preparation while ball clay was used as the binder. The kaolin and ball clay were mixed in suitable proportion of 70:30 ratio in the production of the fire clay bricks (Mokwa *et al.*, 2019). Particle size distributions and Refractory under load (RUL) were determined for IKAE, KVK, and AOS respectively according to the standard procedures.

## 2.2 Method

Refractory under load (RUL) is a measure of the deformation behavior of refractory ceramic products subjected to a constant load, at an increasing temperature (Mokwa *et al.*, 2019). It is a vital property of refractories, since the time of service of a refractory is determined by its deformation under load at high temperature, finally leading to failure. Test samples were prepared according to ASTM standard by varying Al<sub>2</sub>O<sub>3</sub> content in 0, 5, 10 and 15% respectively. Prepared cylindrical samples of 50 mm diameter by 50 mm height, was placed on an alumina block in an electric tubular furnace and a load (L = 0.2N/mm<sup>2</sup>) was applied, through a system of levers, to an alumina thrust rod. The sample was then heated at a gradually rising temperature of a fixed rate (10°C per min) until the temperature reaches 1000°C and (3-5 °c/min) between 1000°C and 1450°C, as the samples began to deform and sag the changes in length was measured on a recording instrument (Fayad *et al.*, 2012). Table I presents the chemical analysis of the kaolin clay samples used in this study (Mokwa *et al.*, 2019).

**Table I:** Chemical Analysis of the Kaolin Clay Samples

Samples/ Composition (%)	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	MnO	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	ZrO <sub>2</sub>	LOI
IKAE	53.18	30.67	0.934	0.23	0.16	0.020	0.013	0.011	2.01	<0.001	ND	11.95
KVK	57.41	26.88	2.432	0.09	0.01	ND	<0.001	0.04	2.81	<0.001	0.217	8.00
AOS	49.30	33.10	0.435	0.10	0.04	0.025	-	ND	0.02	<0.001	ND	15.64

## 3. Results and Discussion

### 3.1 Elemental Composition Analysis of the Kaolin Clay Samples with Varying Alumina Content

The results of the elemental composition analysis with addition of varying percentage of alumina to the beneficiated kaolin samples are shown in Table 2-4. The higher the alumina in clay sample the higher the refractory temperature and the higher the mechanical strength of such fire clay (Galdina, 1983). It can be seen that with the addition of 5% alumina (Table 2) to the kaolin samples the alumina contents of Edo, Kebbi and Osun clay was able to increase by 35.54, 31.85 and 38.02% compared to the beneficiated sample of 30.67, 26.88 and 33.10%, while the silica contents of the clay samples reduced to 48.13, 52.35 and 44.23% compared to the beneficiated samples of 53.18, 57.41 and 49.30% for Edo, Kebbi and Osun respectively. The alumina content for Edo, Kebbi and Osun kaolin with the addition of 10% (Table 3) were found to increase by 40.59, 36.69 and 43.05%, while that of 15% alumina (Table 4) addition were 45.58, 41.71 and 48.00% respectively, from the tables Osun clay as the highest optimum values of 48.00%. From the results it was observed that as the alumina contents in the clay samples increases the silica contents reduces, which means the higher the alumina in clay samples the lower the silica in such samples (Fayad *et al.*, 2012; Joseph *et al.*, 2023).

**Table 2:** Elemental composition analysis of the 5% addition of alumina to the kaolin clay samples

Location	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	MnO	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	ZrO <sub>2</sub>	L.O.I
EDO	48.13	35.54	0.84	0.21	0.31	0.017	0.011	0.010	2.00	<0.001	Nd	12.10
KEBBI	52.35	31.85	2.12	0.07	0.006	Nd	<0.001	0.030	2.40	<0.001	0.201	8.48
OSUN	44.23	38.02	0.412	0.080	0.071	0.022	0.048	0.120	0.008	<0.001	Nd	15.68

**Table 3:** Elemental composition analysis of the 10% addition of alumina to the kaolin clay samples

Location	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	MnO	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	ZrO <sub>2</sub>	L.o.i
EDO	43.14	40.59	0.80	0.18	0.10	0.015	0.010	0.008	1.97	<0.001	Nd	12.20
KEBBI	47.20	36.69	2.10	0.05	0.006	Nd	<0.001	0.015	2.20	<0.001	0.20	8.50
OSUN	39.08	43.05	0.40	0.062	0.069	0.020	0.044	0.100	0.006	<0.001	Nd	15.69

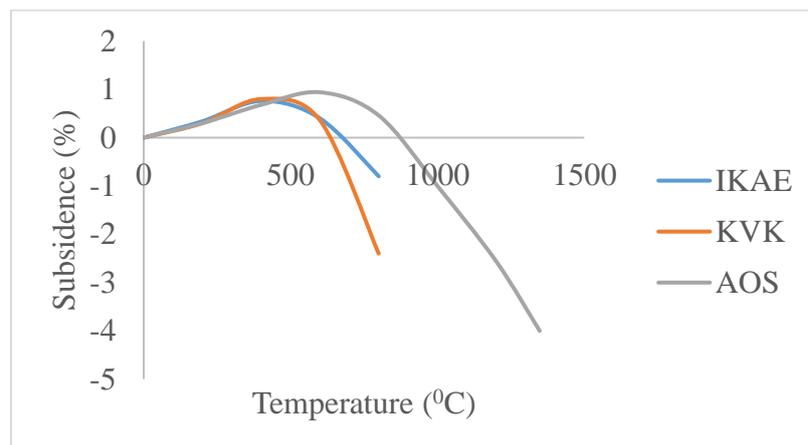
**Table 4:** Chemical analysis of the 15% addition of alumina to the kaolin clay samples

Location	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	MnO	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	ZrO <sub>2</sub>	L.O.I
EDO	38.12	45.58	0.78	0.17	0.098	0.013	0.009	0.007	1.93	<0.001	Nd	12.24
KEBBI	42.34	41.71	1.97	0.04	0.005	Nd	<0.001	0.013	2.00	<0.001	0.184	8.58
OSUN	34.15	48.00	0.38	0.060	0.065	0.017	0.042	0.096	0.005	<0.001	Nd	15.70

Nd = not detected

### 3.2 Refractory Under Load (RUL)

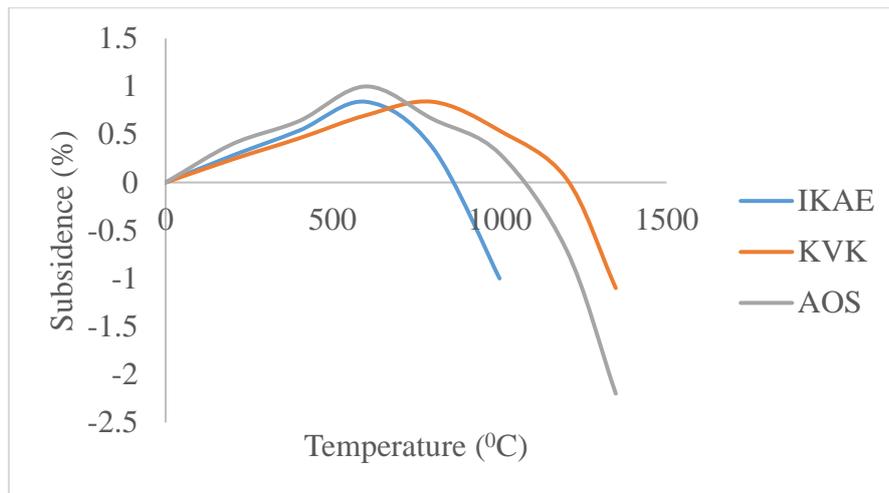
The variation of subsidence with temperature curve on the RUL test of the samples with no Alumina addition is presented in Figure 1. AOS sample recorded highest peak of 0.94% subsidence, at 670°C followed by KVK sample with 0.68% peak subsidence at 400°C. Sample IKAE recorded the least peak subsidence of 0.76% at 400°C. Sample AOS attained highest deformation and finally collapse at 1348°C, which was the highest temperature at a subsidence of -4%. The maximum expansion attained by the sample bricks was 0.94%, which were according to the method of John *et al.* 2004. The highest temperature attained for KVK was 800°C at a subsidence of -2.4%, which was the temperature at which the sample collapse, in accordance with Fayyad *et al.* 2012 method. IKAE sample attained highest temperature of 800°C, which was the temperature at which the clay sample collapse at a subsidence of -0.8% and maximum expansion of the clay sample was 0.76%, which was the highest peak attained before deformation commenced, at a temperature of 400°C. These results are in accordance with result presented by Fayyad *et al.* 2012.



**Figure 1:** Variation of Subsidence with Temperature curve on the RUL test of the Samples with no Alumina addition

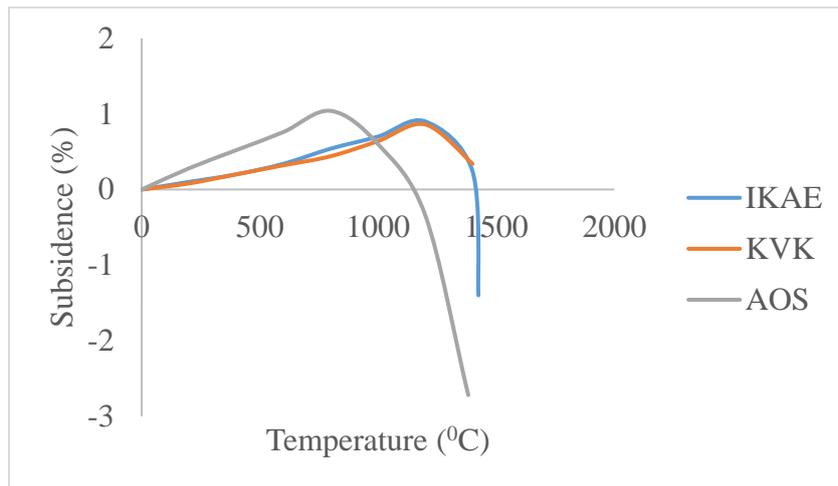
Figure 2 presented the variation of subsidence with temperature curve on the RUL test of the samples with addition of 5% Alumina. The beneficiated sample exhibited a maximum expansion of 0.8% and began to subside at 600°C, continuing until 800°C, where it exhibited a total subsidence of -2.4%. This indicates that the beneficiated sample has a relatively lower thermal stability compared to the other samples. The Kasadi (KVK) sample exhibited a maximum expansion of 0.84% and started subsiding at 850°C. The subsidence continued until 1368°C, with a total subsidence of -1.1%. This suggests that the Kasadi sample has a higher thermal

stability and can withstand higher temperatures before collapsing under load. The Ikpeshi (IKAE) sample also showed a maximum expansion of 0.84%. However, it began subsiding at a lower temperature of 670°C and continued until 1000°C, with a total subsidence of -1%. This result is in accordance with that of John *et al.* 2004. This indicates that while the Ikpeshi sample can expand similarly to the Kasadi sample, it has a lower collapse temperature and thus lower thermal stability under load. The Alaasan (AOS) sample demonstrated a maximum expansion of 0.7%, beginning to subside at 650°C and continuing until it reached 1375°C, with a total subsidence of -2.2% which was the temperature at which the clay sample collapse under a constant load of 0.2N/mm<sup>2</sup>. Despite having a slightly lower initial expansion compared to other samples, the Alaasan sample could withstand the highest temperature before collapsing, indicating a higher thermal stability under load. The results indicate that the Kasadi and Alaasan samples exhibit higher thermal stability under load compared to the beneficiated and Ikpeshi samples. The addition of 50% alumina appears to enhance the refractory properties of these kaolin clay deposits, particularly in terms of their ability to withstand higher temperatures before significant subsidence occurs.



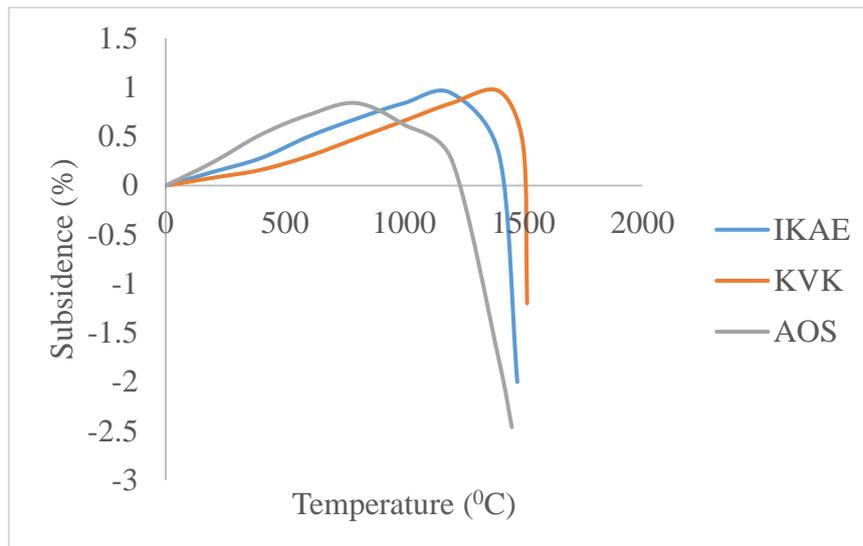
**Figure 2:** Variation of Subsidence with Temperature curve on the RUL test of the Samples with 5% Alumina addition

Figure 3 presented the variation of subsidence with temperature curve on the RUL test of the samples with addition of 10% Alumina. The beneficiated sample, displayed a maximum expansion of 0.8%. It began subsiding at 600°C and continued until 800°C, showing a significant total subsidence of -2.4%. This indicates a relatively low thermal stability, as the sample could not withstand higher temperatures before subsidence occurred. The Kasadi sample, with an alumina content of 0.86%, exhibited a maximum expansion of 1.04%. It began subsiding at a much higher temperature of 1300°C and continued until 1475°C, with a total subsidence of -1%. This suggests that the addition of 10% alumina significantly enhanced the thermal stability of the Kasadi sample, allowing it to withstand higher temperatures before subsidence. The Ikpeshi sample showed a maximum expansion of 0.54%. It began subsiding at 1350°C and ended at 1425°C, with a total subsidence of -4%. Despite starting subsidence at a high temperature, the Ikpeshi sample exhibited the highest overall subsidence, indicating that while it can initially withstand high temperatures, it undergoes significant deformation once subsidence begins. The Alaasan sample, containing 1.04% alumina, demonstrated the highest maximum expansion of 1.04% which was the temperature at which the clay sample collapse under a constant load of 0.2N/mm<sup>2</sup>. It started subsiding at 880°C and continued until 1382°C, showing a total subsidence of -2.72%. This indicates that the Alaasan sample, while having a high initial expansion and a moderate start temperature for subsidence, undergoes substantial deformation and subsidence. Addition of 10% alumina has varying effects on the refractory properties of the kaolin clay samples. The finding is in agreement with the findings of Kirabira *et al.*, 2003. The Kasadi sample showed the most significant improvement in thermal stability with the highest subsidence temperature and the least overall subsidence. In contrast, the Ikpeshi sample, despite its high subsidence start temperature, exhibited the greatest overall deformation. These findings suggest that 10% alumina addition improves the thermal stability and load-bearing capacity of some kaolin clay deposits, but the specific effects can vary depending on the clay's composition and properties.



**Figure 3:** Variation of Subsidence with Temperature curve on the RUL test of the Samples with 10% Alumina addition

Figure 4 presented the variation of subsidence with temperature curve on the RUL test of the samples with addition of 15% Alumina. The beneficiated sample exhibited a maximum expansion of 0.94%. This sample began subsiding at 670°C and continued until 1348°C, resulting in a significant total subsidence of -4%. This suggests that while the sample can withstand initial heat, it undergoes substantial deformation upon reaching higher temperatures. The Kasadi sample, with 15% alumina content showed a slightly lower maximum expansion of 0.84%. It began subsiding at a higher temperature of 900°C and continued until 1452°C, with a total subsidence of -2.46%. The higher temperature range for subsidence and lower overall subsidence indicate that the addition of alumina improves the thermal stability of the Kasadi sample, allowing it to withstand higher temperatures with less deformation. The Ikpeshi sample, also with a maximum expansion of 0.94%, began subsiding at 1360°C and ended at 1475°C, resulting in a total subsidence of -2%. This sample exhibited the highest initial temperature for subsidence and the lowest overall subsidence among all samples, suggesting that the alumina addition significantly enhanced the Ikpeshi sample's thermal stability and load-bearing capacity. The Alaasan sample, with 15% alumina content demonstrated similar properties to the Kasadi sample. It had a maximum expansion of 0.84%, began subsiding at 900°C, and continued until 1452°C, with a total subsidence of -2.46%, which was the temperature at which the clay sample collapse under a constant load of 0.2N/mm<sup>2</sup>. These results indicate that the Alaasan sample, like the Kasadi sample, benefits from alumina addition by exhibiting improved thermal stability and reduced deformation under load. Addition of 15% alumina enhances the refractory properties of the kaolin clay samples, increasing their thermal stability and reducing deformation under load. The Ikpeshi sample showed the most significant improvement, with the highest initial subsidence temperature and the lowest overall subsidence. Both the Kasadi and Alaasan samples also demonstrated improved properties, though to a lesser extent. These findings suggest that alumina addition can effectively enhance the performance of kaolin clay deposits used in refractory applications. The result is in accordance with the results of Fayyad *et al.*, (2012).



**Figure 4:** Variation of Subsidence with Temperature curve on the RUL test of the Samples with 15% Alumina addition

Table 5 shows the Summary of the influence of Alumina Contents on the Refractory under load (RUL) of Ikpeshi beneficiated Kaolin Clay Samples at varying percentages of 0, 5, 10 and 15% alumina, for no addition of alumina oxide the beginning of subsidence temperature (TI) was 500°C and end of subsidence temperature (TE) was 800°C at a subsidence of -0.8 % which was the maximum temperature and subsidence attained before the clay sample collapse, at a maximum expansion of 0.76%, for 5% alumina content addition the highest temperature attained was 1000°C at a subsidence of -1% which was the subsidence at which the brick sample collapse at a maximum expansion of 0.84%. For 10 and 15% alumina content addition the maximum temperature attained before collapse was 1350 and 1360°C at a subsidence of -1.4 and -2 respectively, both with maximum expansion of 0.54 and 0.94%. All this results were in accordance with Fayyad *et al.* (2012) and John *et al.* (2004) methods.

**Table 5:** Summary of the Influence of Alumina Contents on the RUL of IKAE Sample

Alumina content (%)	ME (%)	TI (°C)	TE (°C)	S (%)
0	0.76	500	800	-0.8
5	0.84	670	1000	-1
10	0.54	1350	1425	-1.4
15	0.94	1360	1475	-2

\*ME- Maximum Expansion; TI-Beginning of Subsidence; TE- End of Subsidence; S- Subsidence

Table 6 shows the Summary of the influence of Alumina Contents on the Refractory under load (RUL) of Kasadi beneficiated Kaolin Clay Samples at varying percentages of 0, 5, 10 and 15% alumina, which were in accordance to the method of Fayyad *et al.* (2012) and Kirabira. *et al.* (2003), for no addition of alumina oxide the beginning of subsidence temperature (TI) was 600°C and end of subsidence temperature (TE) was 800°C at a subsidence of -2.4 % which was the maximum temperature and subsidence attained before the clay sample collapse, at a maximum expansion of 0.76%, for 5% alumina content addition the highest temperature attained was 1368°C at a subsidence of -1.1% which was the subsidence at which the brick sample collapse at a maximum expansion of 0.84%. For 10 and 15% alumina content addition the maximum temperature attained before collapse was 1475 and 1516°C at a subsidence of -1 and -1.2% respectively, both with maximum expansion of 0.86 and 0.96%.

**Table 6:** Summary of the Influence of Alumina Contents on the RUL of KVK Sample

Alumina content (%)	ME (%)	TI (°C)	TE (°C)	S (%)
0	0.8	600	800	-2.4
5	0.84	850	1368	-1.1
10	0.86	13	1475	-1
15	0.96	1450	1516	-1.2

Table 7 shows the Summary of the influence of Alumina Contents on the Refractory under load (RUL) of Alaasan beneficiated Kaolin Clay Samples at varying percentages of 0, 5, 10 and 15% alumina which were all in accordance to the method of Fayyad *et al.* (2012) and John *et al.* (2004), for no addition of alumina oxide the beginning of subsidence temperature (TI) was 670°C and end of subsidence temperature (TE) was 1348°C at a subsidence of -4 % which was the maximum temperature and subsidence attained before the clay sample collapse, at a maximum expansion of 0.94%, for 5% alumina content addition the highest temperature attained was 1375°C at a subsidence of -2.2% which was the subsidence at which the brick sample collapse at a maximum expansion of 0.7%. For 10% and 15% alumina content addition the maximum temperature attained before collapse was 1382 and 1452°C at a subsidence of -2.72 and -2.46% respectively, both with maximum expansion of 1.04 and 0.84%.

**Table 7:** Summary of the Influence of Alumina Contents on the RUL of AOS Sample

Alumina content (%)	ME (%)	TI (°C)	TE (°C)	S (%)
0	0.94	670	1348	-4
5	0.7	650	1375	-2.2
10	01.4	880	1382	-2.72
15	0.84	900	1452	-2.46

**Table 8:** RUL of Kaolin Clay Refractories made in Various Countries of the World Compared with the RUL of the Researched Area

Country	U.K	USA	Russia	Germany	France
RUL (°C)	1200-1400	1150-1410	1305-1390	1230-1430	1140-1300
	<b>NIGERIA/ALUMINA CONTENT (0%)</b>			<b>NIGERIA/ALUMINA CONTENT (5%)</b>	
Location	IKAE	KVK	AOS	IKAE	KVK AOS
RUL (°C)	800	800	1348	1000	368 1375
	<b>NIGERIA/ALUMINA CONTENT (10%)</b>			<b>NIGERIA/ALUMINA CONTENT (15%)</b>	
Location	IKAE	KVK	AOS	IKAE	KVK AOS
RUL (°C)	1475	1425	1382	1475	1516 1452

### 3.3 Evaluation of the Firebricks Production Using Each of the Samples

Firebricks were produced using the kaolin clay samples and ball clay as binder, alumina oxide was also added in suitable composition and proportions, corresponding to that used for laboratory testing for the firebricks mixtures (John *et al.*, 2004). Each of the kaolin clay samples were mixed with the corresponding weight of ball clay, alumina and water individually. The clay samples produced are those that their refractory under load (RUL) was found to compare favourably with those of other countries of the world (John *et al.*, 2004). The procedures followed for the production of the firebricks samples were according to the ASTM C288-87 standard.

### 3.4 Testing for Suitability of the Refractory Bricks for Industrial Application

The suitability of the produced kaolin refractory bricks were tested at Scientific Development Institute (SEDI), Tunga-Goro, Minna, Nigeria. The bricks were used to line the inside of a crucible furnace at the foundry workshop of the institute; the lined furnace was then used to melt an aluminum ingot at a superheated temperature of 800°C, the produced kaolin bricks was then used continuously in the crucible furnace to melt non-ferrous metal for a period of two weeks, the refractory bricks produced were found to be suitable as their products compared favourably with that of standard refractory fire clay (Fayyad *et al.*, 2012). Plate 1a-d shows the testing of the produced refractory bricks in a crucible furnace.



**Plate 1:** Crucible Furnace: Cover (a), Furnace (b), Furnace lined with Researched Bricks (c-d)

### 4.0 Conclusion

The effect of alumina addition on the Refractory Under Load (RUL) of kaolin clay samples from Nigeria have been investigated. Alumina addition led to improvements in RUL performance, with higher alumina contents resulting in increased peak temperatures before sample collapse. The studied samples that improved the most with increased alumina content were Kasadi (KVK) and Alaasan (AOS), particularly at 10% and 15% levels where they demonstrated stronger stability at higher temperatures and less overall subsidence. The Kasadi sample showed the maximum thermal stability, with sinking temperatures for 10% and 15% alumina concentration of 1475°C and 1516°C, respectively. Comparably, the Alaasan sample showed excellent refractory qualities, especially at higher alumina concentrations, albeit showing less early expansion. However, even though the Ikpeshi (IKAE) sample was able to sustain high temperatures at first, it had more overall deformation. This suggests that although it can endure initial subsidence, it might not be as effective when exposed to excessive heat for an extended period of time. The results has demonstrated that addition of alumina enhances thermal stability and load-bearing capacity of the kaolin clay, making it suitable for industrial applications such as lining crucible furnaces for melting non-ferrous metals. The produced refractory bricks showed promising performance in industrial settings, meeting standards comparable to international refractory fire clay products.

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