IMPROVEMENT ON SOME PHYSICAL PROPERTIES OF SELECTED NIGERIAN CLAY

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Abstract

In metallurgical industries the quality of refractory clay depends largely on the physical properties of clay and proper selection of clay affect these physical properties which include Porosities, Compressive strength, Linear shrinkage, Thermal shock resistance, and refractoriness. This gives need on the improvement on some physical properties of selected Nigerian clays. Clay collected from Bida, Chanchaga, Kpakungu and Maikunkele areas of Niger State were analysed to determine the chemical composition of the clays samples and raw clay were beneficiated and mixed with additives which include ash of Sawdust, Ricehusk and Cornhusk in a ratio of 5, 10, 15, 20, 25 & 30% weight to produce clay bars which were subjected to tests to determine the effect of the additives on the physical properties of the clay samples. The result revealed Bida clay increase in porosity from 16.64% to 35%, Chanchaga clay increase in porosity from 9.98% to 38.38%, Kpakungu clay increase in porosity from 8.12% to 33.37% and Maikunkele clay increase in porosity from 10.50% to 35%. Compressive strength of the clay samples were reduced Bida clay reduced in compressive strength from 51.58N/m^2 to 8.63N/m^2, Chanchaga clay reduced in compressive strength from 65.85%N/m^2 to 29.11N/m^2, Kpakungu clay reduced in compressive strength from 63.59N/m^2 to 20.55N/m^2, Maikunkele clay samples reduced in compressive strength from 59.06N/m^2 to 18.52N/m^2. The refractory temperature of Bida, Chanchaga, Kpakungu and Maikunkele clay samples were increased from 1410°C to 1480°C, 1580°C to 1620°C, 1550°C to 1570°C and 1650°C to 1690°C at 5%wt of additives.

Keywords: Compressive strength, Additives, Porosities, Refractories, Properties.

1.0 INTRODUCTION

Clays by way of a compound inorganic combination has diversities of composition depending on it area of location. The quality of refractory clay depends largely on the physical properties of clay and proper selection of clay affect these physical properties which include Porosities, Compressive strength, Linear shrinkage, Thermal shock resistance, and refractoriness. This gives need on the improvement on some physical properties of selected Nigerian clays.

Refractories have been an essential element in heat engineering plants since the 1960s, where they were successfully used to improve performance and energy efficiency. This is because refractories are chemically and physically stable at high temperatures depending on the operating environment. Good fireclay refractories should always have 24% - 26% plasticity, the shrinkage after firing should be within 6% - 8% maximum and should not contain more than 25% Fe_2O_3 (Atanda *et al.*, 2012)

Fire clays are clays with high refractoriness and possess the capability of maintaining both physical and chemical identity at high temperatures. Clays used for furnace linings in metallurgical industries are classified as refractory clays. However, the degree of refractoriness and plasticity of any clay material is often influenced by the amount of the impurities contained in them. Moreover, the ability of selected refractory clay to withstand high temperature and resist physical and chemical corrosion determines the quality and the suitability of such material for use as furnace lining (Sanni, 2005)

Characterization of the refractory property of Osiele clay, revealed that the clay was silicious alimino- silicate with low content of Iron III Oxide. The water absorption, bulk density and apparent porosity decreased with the firing temperature, whereas the total shrinkage increased as the firing temperature increased. It was concluded that Osiele clay can be used as refractory material for the lining of furnace particularly for operating temperature in the pre-1100°C range. (Lawal *et al.,* 2008)

Investigation on the effect of additives (sawdust and ashes) on the thermal conductivity of clay, result obtained showed that with sawdust addition the clay was suitable as oven materials as well as good insulator (Folaranmi, 2009)

Termite hills can be used to produce insulating refractory when 25% additives (corn husk and sawdust) are used. However, low values of refractoriness 1200°C were recorded (Ndaliman, 2001)

It was discovered that addition of ash residues from agricultural waste gave an improvement in the apparent porosity and water absorption of the blended clays. (Odo & Mba, 2008)

Clays samples of Ifon, Ipetumodu, and iseyin investigated (Aramide *et al.,* 2014), Clays of Ifon contains low kaolinite (5.63%) which could not be used for making high temperature caliber refractories except with the addition of some additive that will improve on their refractory properties. Thermal conductivity decreases in refractory materials as its porosity increases with the pores acting as non-heat conducting media. Therefore, the refractories used in melting furnaces, are made to have low thermal conductivities, ensure minimal heat loss and maximum heat retention.(Titiladunayo & Fapetu, 2011).

2.0 MATERIALS AND METHODS

Ten kilograms (kg) of clay samples were collected per site from four different locations in Niger state, Nigeria, making a total of four clays samples weighing forty kilograms (40kg). The locations have some ample reserve of Kaolin Clay which could be used for industrial purpose as reported by (Okorafor 2001). The sites are located in four different areas in Niger State which include Bida, Chanchaga, Kpakungu and Maikunkele. The clays were blended with additives and were subjected to physical, chemical and thermal analysis at the Scientific Equipment Development institute (SEDI) Minna, Niger State, to determine the effect of the additives on the physical properties of the clay samples.

Determination of refractory properties

The properties of the pure clays and clays with different additive ratio such as linear shrinkage, bulk density, apparent porosity, compressive strength, thermal shock resistance and refractoriness were carried according to (ASTM, 1985a).

Linear shrinkage

The dimensional changes in length were taken and the results were used to determine the fired shrinkage after firing at 950^{o}C to 1150^{o}C in Daiki scientific furnace (MD010). The linear shrinkage was determined using equations 1. (ASTM, 1985a; Clay Shrinkage Testing, 2010)

$$\text{FIred Shrinkage} = \frac{L_d - L_f}{L_d} \text{ x } 100\%. \qquad (1)$$

Where: L_d = Dry length and L_f = Fired length

Bulk density

Bulk density was calculated using a direct volume measurement method. This method exploits the relative density of a substance multiplied by the density of water to obtain the required bulk density. Equation 2 was used to obtain the bulk density in *g/cm*^{3} (ASTM, 1985a; TBDBWD, 2010).

$$\text{Bulk density} = \frac{W_d}{W_s - W_{sp}} \text{ x Density of water} \quad (2)$$

Where W_s = soaked weight, W_d = dry weight and W_{sp} = suspended weight

Apparent porosity

The boiling method was used for this test at 1000°C for 2 hours. The test pieces were subjected to a two-hour boiling followed by an additional four hour water soaking and then weighed W_s. The soaked piece was then suspended from the beam of a balance in a vessel of water so arranged that the test piece under consideration was completely immersed in the water without touching the side of the vessel. The suspended specimen in water weighed as W_{sp}. Porosity was then calculated as a function of the specimen's weight difference between soaked weight and dry weight to specimen's weight difference between soaked weight and suspended immersed weight. The results were obtained by equation 3 (ASTM, 1985a; Calculate Apparent Porosity, 2010)

$$\text{Porosity (P)} = \frac{W_s - W_d}{W_s - W_{sp}} \text{ x } 100\% \quad (3)$$

Where: W_s = soaked weight, W_d = dry weight, W_{sp} = suspended weight

Compressive strength

The compressive strength of each brick was determined in accordance with the Specification of the Standard Organization of Nigeria (SON) as contained in Test for Compressive Strength of Solid Bricks using the Testing Machine. A 40 mm square platen was used on the compressive testing machine. Three test cubes were preconditioned by immersion in cold water at room temperature (29°C ± 2°C) for 24 hours, removed and all traces of water wiped off, and then stored under moist conditions for 24 hours prior to testing. Each test piece was centrally positioned between the platens of the testing machine, and the load was gradually increased until failure (Fayomi *et al.*, 2011). Mathematically, compressive strength can be determined using Equation 4 (Falodun *et al., 2017*)

$$\text{Compressive strength} = \frac{\text{Maximum failure load x Proving ring factor}}{\text{Area sample}} \ (\mathrm{N/m^2}) \quad (4)$$

Thermal shock resistance

This test was carried out with the help of an electrical furnace (Thermodyne 46200) heated at the rate of 5°C/min. The thermal shock resistance was determined by prism spalling test method according to ASTM C- 484 standard in which the spalling resistance was measured by the number of thermal cycles (heating, cooling and testing for failure). The test pieces of refractory bricks were thoroughly dried and placed in the cold furnace and heated at the rate of 5^oC/minute until the furnace temperature got to 1200°C. The samples were then removed using a pair of tongs and cooled in air for 10 minutes, and then observed for cracks. In the absence of cracks (or fracture), the bricks were put back into the furnace and reheated for a further period of 10 minutes and then cooled for another 10 minutes. This process or cycle of heating, cooling and observing for cracks was repeated until cracks were observed. The number of complete cycles that produced visible cracks in each specimen was noted.

Refractoriness

The refractoriness or softening point was determined using the method of pyrometric cone equivalence (PCE) in accordance with ASTM C24-79. The test pieces were mounted on the refractory plaque along with some standard cone whose softening points are slightly above or below those expected of the test cones. The plaque was then inserted into the electric furnace. The temperature was raised at the rate of 5°C per minute during which softening of Orton cone occurred along with the specimen test cone. (Etukudoh *et al.*, 2016).

Raw material beneficiation and production of clay bars for refractory test

The raw clay samples were air dried before processing. The raw dry clay samples were crushed in a mortar to small grain sizes and sieved. The samples were soaked in a plastic container of water and allowed to soak for three days. 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 filtered further by the use of a mesh sieve of size 0.18 mm in order to obtain finer particles. The filtrate was allowed to settle for three days after which excess water was decanted off. The clay slip obtained was sun dried for 2 days and then dried in an oven at 100°C.

The processed dried clay was pulverized and then passed again through a 0.18mm mesh sieve. Each of the clay samples was mixed with water and molded using different mould shapes and sizes that suited the respective tests they were to be used for. Bida, Chanchaga, Kpakungu and Maikunkele clays were blended with saw dust ash (SDA), rice husk ash (RHA) and corn husk ash (CHA) were blended at different ratios as shown in table 1 to develop different test samples.

Table 1: Different additive ratio of clay mixture

Clay	250 g	237.5 g		225 g		212.5 g		200 g		187.5 g		175 g	
	0%	5%	12.5g	10%	25g	15%	37.5g	20%	50 g	25%	62.5g	30%	75 g
RHA	-	2	5.00	3	7.5	5	12.5	6	15	8	20	10	25
CHA	-	1.5	3.75	4	10	5	12.5	7	17.5	8	20	10	25
SDA	-	1.5	3.75	3	7.5	5	12.5	7	17.5	9	22.5	10	25

Each of the samples (250 g) was mixed with 35% (0.087 Liters) of water to make the clay plastic for molding. The clay was then molded into shapes using pop moulds with the application of powder lubricant to the surface of the moulds to prevent the test pieces from sticking to the surface. An improvised wooden material was used for transmitting the molding pressure of 2 MPa to the mould when the required quantity of plastic molding mass was put into the mould, wooden plunger was used to extrude out the green brick from the mould. The test samples were sundried, oven dried to 110°C and finally fired to 1150°C before testing for the respective properties.

3. RESULTS AND DISCUSSION

Table 2: Summary of the experimental result

Properties	Bida Clay		Chanchaga Clay		Kpakungu Clay		Maikunkele Clay	
	0%	30%	0%	30%	0%	30%	0%	30%
Linear Shrinkage (%)	9.98	7.81	10.11	8.94	10.25	9.11	10.05	7.22
Bulk Density (g/cm^3)	1.99	1.22	2.23	2.00	2.04	1.90	2.07	1.93
Apparent Porosity (%)	10.24	35.13	4.05	38.33	4.67	33.37	6.72	35.99
Compressive Strength(MN/m2)	67.46	8.63	73.32	29.11	67.60	20.55	63.09	18.52
Thermal Shock resistance(cycles)	11	28	9	22	11	28	23	37
Refractoriness (°C)	1410	1480	1580	1620	1550	1570	1650	1690

Chemical composition

The chemical composition analysis of Bida, Chanchaga, Kpakungu and Maikunkele clay as done using X-ray fluorescence (XRF) and shows that the mined clays are rich in oxides of Alumina. It could be seen that there are oxides of iron, calcium, and titanium. From the result, it is evident that SiO_2 is a major component. Table 3 shows the chemical composition of the selected clay samples.

Table 3: Chemical composition of selected clay samples

Oxide(s)	**Bida(%)**	**Chanchaga(%)**	**Kpakungu(%)**	**Maikunkele(%)**
SiO_2	44.67	49.45	52.58	54.59
Al_2O_3	33.01	28.58	27.32	29.50
Fe_2O_3	2.1	6.50	4.50	4.50
TiO_2	0.3	0.25	0.10	0.02
CaO	1.90	2.59	2.90	2.10
MgO	1.1	2.41	2.30	1.90
K_2O	2.4	0.45	0.55	0.48
Na_2O	0.3	0.10	0.12	0.04
LOI	14.22	9.67	9.63	6.87

Below are the beneficiation result of all the clay samples

Table 4: Sieve analysis result of Bida clay

Sieve Size Mm	Weight of soil retained(g)	Cummulative mass retained(g)	% Cumulative Retained	% Passing
100	12	12	0.23	99.77
90	14	26	0.50	99.5
75	15	41	0.79	99.21
63	18	59	1.12	98.88
50	211	270	5.12	94.88
37.5	781	1051	19.95	80.05
25	950	2001	37.99	62.01
19	933	2934	55.71	44.29
16	1338	4272	81.11	18.89
12.5	895	5167	98.10	1.9
	100	5267	100	0

Total mass used = 5267 g

Table 5: Sieve analysis result of Chanchaga clay

Sieve Size Mm	Weight of soil retained (g)	Cummulative mass retained (g)	% Cumulative Retained	% Passing
100	26.57	26.57	2.31	97.69
90	73.02	99.59	8.66	91.34
75	122.82	222.41	19.34	80.66
63	136.28	358.69	31.19	68.81
50	99.13	457.82	39.81	60.19
37.5	102.12	559.94	48.69	51.31
25	108.44	668.38	58.12	41.88
19	70.38	738.76	64.24	35.76
16	112.6	851.36	74.03	25.97
12.5	162.25	1013.61	88.14	11.86
	136.39	1150	100	0

Total mass used = 1150 g

Table 6: Sieve analysis result of Kpakugu clay

Sieve Size Mm	Weight of soil retained	Cummulative mass retained	% Cumulative Retained	% Passing
100	16.10	16.10	1.4	98.60
90	64.06	80.16	6.97	93.03
75	133.05	213.21	18.54	81.46
63	97.87	311.08	27.054	72.95
50	137.54	448.62	39.01	60.99
37.5	109.94	558.56	48.57	51.43
25	131.22	689.78	59.98	40.02
19	123.39	813.17	70.71	29.29
16	110.17	923.34	80.29	19.71
12.5	127.07	1050.41	91.34	8.66
	99.59	1150	100	0

Total mass used = 1150 g

Table 7: Sieve analysis result of Maikunkele clay

Sieve Size Mm	Weight of soil retained	Cummulative mass retained	% Cumulative Retained	% Passing
100	64	64	1.22	99.77
90	192	256	4.9	99.5
75	470	726	13.7	99.21
63	693	1419	26.79	98.88
50	497	1916	36.16	94.88
37.5	510	2426	45.78	80.05
25	584	3010	56.81	62.01
19	688	3698	69.79	44.29
16	287	3985	75.20	18.89
12.5	1215	5200	98.11	1.9
	100	5300	100	0

Total mass used = 5300 g

DISCUSSION OF RESULT

The Linear Shrinkage occurred in the fired samples with the percentage of decreasing with increase in the amount of additives, Bida clay reduced from 9.98% to 7.81%, Chanchaga clay reduced from 10.11% to 8.94%, kpakungu clay reduced from 10.25% to 9.11%, Maikunkele clay reduced from 10.05% to 7.22%. Maikunkele clay has the least shrinkage property of 7.22% while Kpakungu clay has the highest shrinkage property of 9.11%. (Arowolo, 2000) pointed out that lower values are more desirable as this means the clay is less suitable to volume change. Figure 1 shows the effect of additives on linear shrinkage at a temperature of 1150°C

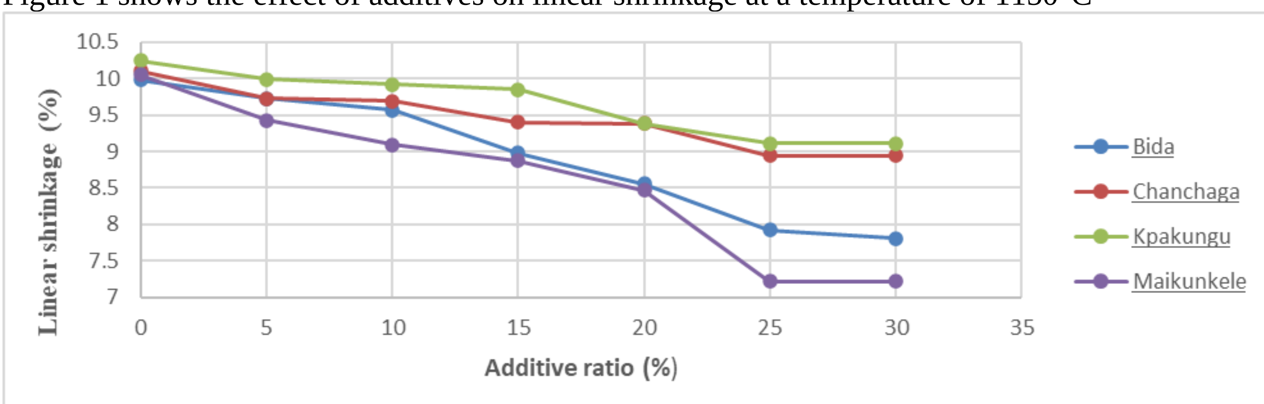

Fig 1: Effect of additives on linear shrinkage at a temperature of 1150°C.

Bulk density of fired clay was inversely proportional to the quantity of additives added.

The bulk density decrease with increase in the amount of additives added. Bida clay has the lowest Bulk density of 1.22g/cm^3 and Maikunkele clay has the highest Bulk density of 1.93g/cm^3. Low Bulk density can be attributed to some extent of mineral composition of the clay (Aliyu *et al.*, 2013). Figure 2 shows the effect of additives on bulk density.

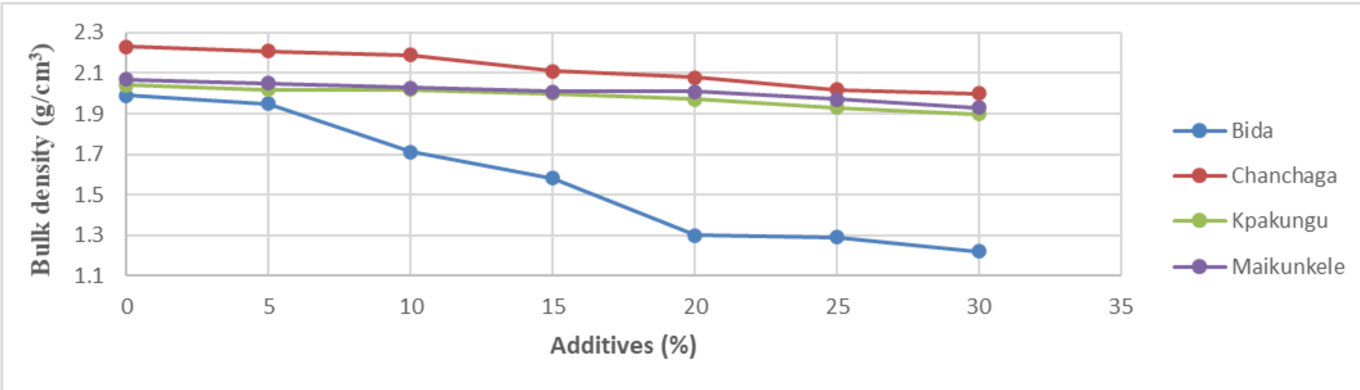

Fig 2: Effect of additives on bulk density at a temperature of 1150^{o}C.

The porosity of a refractory clay material is directly related to the air pocket contained in it hence the higher the porosity of the refractory clay material the higher the insulating property. Bida clay has porposity of 35.13%, chanchaga clay has 38.33%, Kpakungu clay has 33.37% and maikunkele clay has 35.99% ths values falls within the acceptable range of (10 – 30%) for refractories. Fig 3 shows the effect of additives on apparent porosity at 1150°C

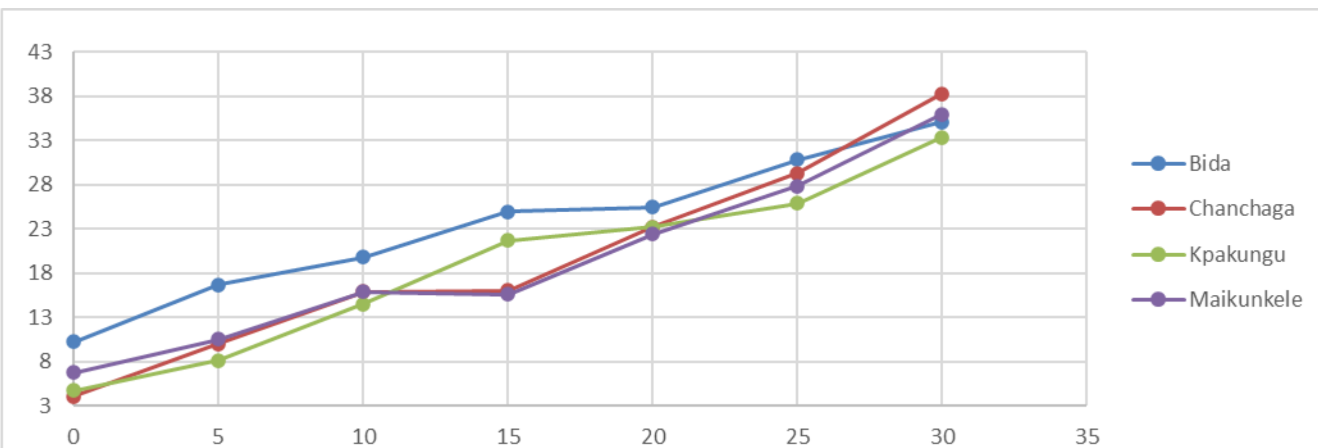

Fig 3: Effect of additives on apparent porosity at 1150^{o}C

The Compressive strength result indicated that the strength of the samples greatly depended on the amount of additives and the firing temperature. The compressive strength was 67.46 MN/m^2 73.32 MN/m^2, 67.06 MN/m^2 and 63.09 MN/m^2 at 0% additives ratio for Bida, Chanchga, Kpakungu and Maikunkele clays at a temperature of 1150°C. when the additives varies from 5% to 30% and the firing temperature from 950°C to 1150°C the compressive strength decrease with increasing additives. At 30% additives Bida clay shows a compressive strength of 8.63 MN/m^2, Chanchaga clay shows 29.11 MN/m^2, Kpakungu clay shows 20.55 MN/m^2 and Maikunkele clay shows 37 MN/m^2. Bida clay had a value in less of 18MN/m^2 at 8.63MN/m^2 which falls short of the 26.5MN/m^2 repoerted by (Ameh & Obasi, 2009) for Nsu clay. Compressive strength of Chanchaga clay, Kpakungu clay and Maikunkele clay meets the criteria of the TIS77-2545 that define compressive strength not lower than 17MN/m^2. Fig 4 shows the effect of additives on compressive strength at 1150°C

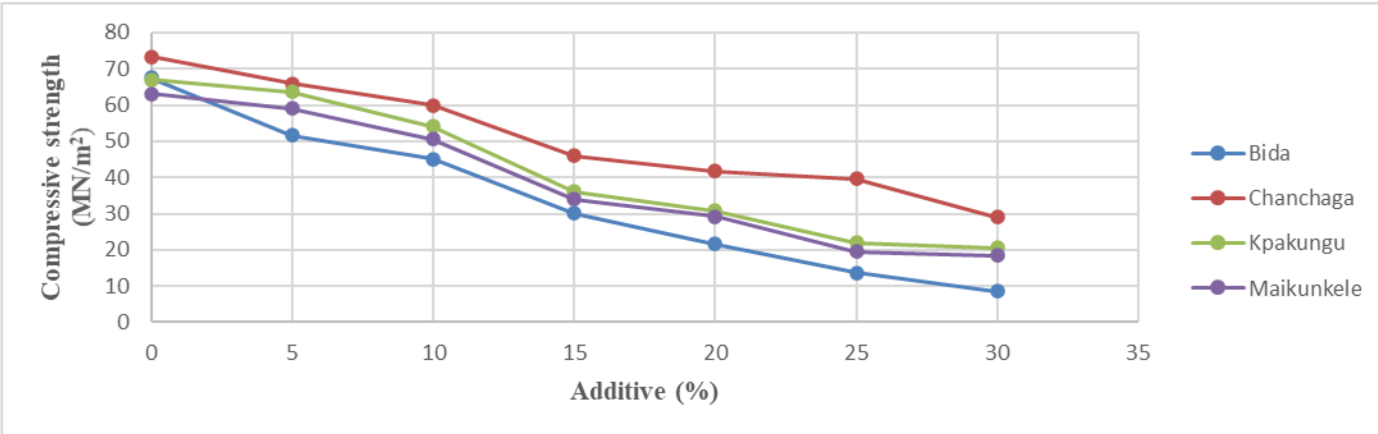

Fig 4: Effect of additive on compressive strength at 1150^{o}C

Thermal shock resistance of the clay samples increases with increase in additives ratio and decrease with rise in temperature. Bida clay show 36$^+$ cycles at 950°C and 28$^+$ cycles at 1150°C. Maikunkele bricks show 56$^+$ cycles at 950°C and 1150°C Kpakungu bricks show 42$^+$ cycles at 950°C and 28$^+$ cycles at 1150°C While Chanchanga clay bricks shows 31$^+$ cycles at 950°C and 22$^+$ cycles at 1150°C all at an additive ratio of 30%wt which gives an excellent thermal shock resistance. The excellent thermal shock resistance exhibited by all the clay samples can be attributed to the insulating property due to uniformly distributed pore at high ratio of additives that burns off at high temperature. Fig 5 shows the effect of additives on thermal shock resistance.

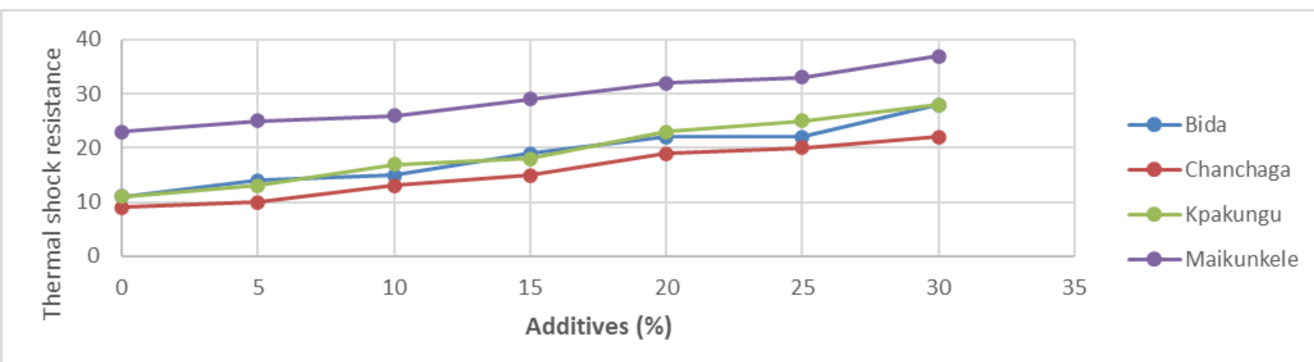

Fig 5: Effect of additives on thermal shock resistance at 1150°C

It was noted that for the clays without additives, the softening point occurred at 1410°C, 1580°C, 1550°C and 1650°C for Bida, Chanchaga, Kpakungu and Maikunkele clay samples respectively while for those blended with the additives ratios of 5%wt to 30%wt were 1480°C, 1620°C, 1570°C and 1690°C for Bida, Chanchaga, Kpakungu and Maikunkele clay samples respectively. This suggests an enhancement in the refractoriness value which may be traced to the presence of useful oxides found in the additives. It was found that combination of two or more additives yielded better refractoriness value than single one (Izwan *et al.*, 2011). Fig 6: shows the effect of additives on the refractoriness of the clay samples.

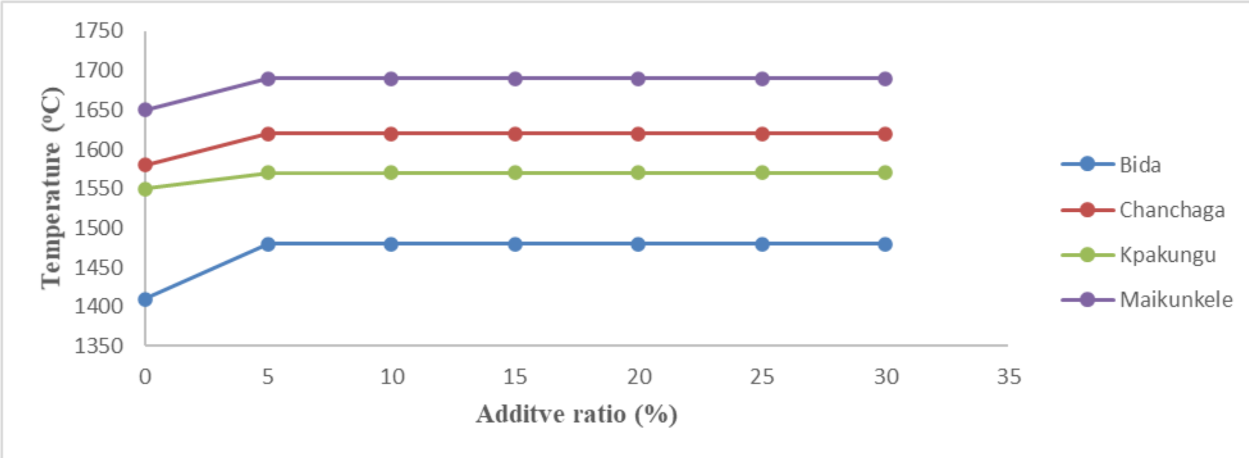

Figure 6: Effect of additives on refractoriness of clay samples

4 CONCLUSIONS

Linear shrinkage occurred in the fired clay samples with the percentage of decreasing with increase in the amount of additives, Maikunkele clay has the least linear shrinkage while kpakungu clay has the highest linear shrinkage.

The porosity of the clay samples increase with increase in additive ratio, the shows a good improvement in the insulating properties of the clay samples. The compressive strength of the clay samples greatly depends on the amount of additives and the firing temperature. Bida clay shows the least compressive strength of $8.63MN/m^2$. The fusion temperature of all the clay samples increases at 5% ratio of additives and remain the same for all other ratio of additives. The pyrometic cone equivalent temperature shows beyond 1500°C except for Bida clay which shows 1480°C. Considering the above the additives has a great influence on the refractory clay samples and has improved the refractory properties of the selected clays.

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