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Evaluation of the chemical and thermo-physical properties of locally aggregated kaolin-based refractory materials

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ABSTRACT

There is a continuous demand for refractory materials to meet the increasing expansion of industries and plants. Local clay materials are being explored to augment the inadequate supply of refractory materials. This study therefore evaluated the suitability of locally aggregated kaolin as refractory material. The kaolin was aggregated from Ipinsa kaolin, termite hill materials and bentonite in the ratio 5:4:1 by mass. Chemical analysis carried out on the materials using Proton Induced X-ray Emission (PIXE) Equipment revealed that the kaolin aggregate had a composition of 37.22% alumina (Al_2O_3) and 51.93% silica (SiO_2). The Ipinsa kaolin comprised Al_2O_3 at 43.05% and SiO_2 53.91%, termite hill material (Al_2O_3 22.69%, SiO_2 58.83%) and bentonite had 23.10% Al_2O_3 and 55.40% SiO_2. It shows that Ipinsa kaolin can be used for refractory materials in furnaces, kilns and stoves while the aggregated clay can be used in applications requiring more superior refractory properties. The thermo-physical analysis of the aggregated clay revealed a bulk density of 1.84 g/cm^3, apparent porosity 31.54%, linear shrinkage 4.00%, thermal shock resistance 40$^+$ and refactoriness 1900 ^oC. The refractoriness indicated that the aggregated clay is also suitable for use as ceramic fibre within the temperature range of 1800 and 2000 ^oC.

Keywords: Evaluation**;** chemical; PIXE; kaolin; termite

INTRODUCTION

Refractory clay minerals are part of the numerous natural resources in abundant supply in Nigeria. There is also a growing prospect for production of refractory clay bricks for companies and industries that deal in manufacturing of high operating temperature equipments such as furnace, boiler, oven and kiln. Metallurgical industries such as those for iron and steel consume about 70% of such refractory products [1]. Demand for refractory products in the non-metallurgical industries like the chemical, glass, boiler and petrochemical industries stand at about 20-30% [2] but the refractory needs of these industries rose to 300,000 tonnes at the end of the year 2000 [3].

Application of clay minerals in various engineering, petroleum and manufacturing industries are closely related to their structure and composition. The important characteristics associated with commercial application of clay minerals are particle size, surface chemistry, particle shape, surface area, and other physical and chemical properties specific to a particular application such as viscosity, colour, plasticity, green strength, dry and fired strength, absorption and adsorption, abrasion and others [4].

According to Yami and Umar [5] refractories of various types can be produced from kaolinite ($Al_2O_3.2SiO_2.2H_2O$), chromite ($FeOCr_2O_3$) and magnesite ($MgCO_3$), and these materials can be obtained from many clay types. Additives like sawdust, groundnuts shell, palm kennel shell, silica sand and binders are added to the clays improve the quality of refractories products and these materials can all be sourced locally.

Formation of kaolin may be through hydrothermal and volcanic clay deposits or by means of residual and sedimentary clay deposits [6]. In the last few years, there have been tremendous works in developing refractory products from local clay deposits and it has been found that local refractory clays are suitable for use in furnace lining and steel industries [5]. The characteristics of some Otukpo clays were studied [7]. They found that the clays had refractoriness of about 1710 ^{o}C and this compared favourably with the refractoriness of the usually imported refractory materials.

Refractory materials used for insulating purposes have high porosity with low thermal conductivity and high thermal insulation properties appropriate for minimizing heat losses and maximizing heat conservation in furnaces. Their low thermal conductivities are as a result of the pores and their heat capacity is determined nearly completely by their solid component. The alumina-silicate clay with high porosity has high insulating properties and low thermal conductivity [8]. Table 1 outlines some thermal and physical properties of clay materials evaluated from different locations within the country in the literature. Table 2 shows the chemical composition of several kaolin based clay materials from different locations in Nigeria.

Table 1. Summary of thermo-physical properties of some Nigerian kaolin

RESEARCHER NAME	SAMPLE LOCATION	BULK DENSITY (g/cm^3)	APPARENT POROSITY (%)	PERMEABILITY	LINEAR SHRINKAGE (mm)	THERMAL SHOCK RESISTANCE (Cycle)	REFRACTORIENESS (^{o}c)
Titiladunayo and Fapetu [9]	Ikere	1.7400	31.4400	-	5.0000	-	1500.0000
	Fagbohun	2.0000	20.6900	-	2.0000	-	1500.0000
	Ishan	2.0000	19.1000	-	1.5000	-	1300.0000
	Ara	1.9900	23.3100	-	1.9000	-	1300.0000
Yami and Umar [5]	Gur	2.1100	19.5000	215.0000	1.1100	7.0000	1370.0000
	Yamarkumi	2.0600	22.2600	489.0000	1.0000	5.0000	1400.0000
Ogunniyi [10]	Ijapo	1.3800	50.1500	-	-	-	-
	Igbokoda	1.7700	28.1800	-	-	-	-
Borode *et. al.* [11]	Onibode	2.6000	28.4000	87.0000	4.0000	30.0000	1760.0000
	Ara-Ekiti	1.8400	18.0000	75.0000	8.0000	26.0000	1650.0000
	Ibamojo	1.7600	16.0000	78.0000	4.0000	30.0000	1630.0000
	Ijoko	2.6000	22.0000	88.0000	6.0000	28.0000	1680.0000
	Ikere- Ekiti	-	43.1000	-	3.5900	20.0000	1450.0000
	Isan	-	49.7000	-	3.8900	32.0000	1520.0000
	Ezinachi-Okigwe	-	20.0000	-	7.2300	20.0000	1350.0000
Okoli [12]	Onibode	-	23.0000	Moderate	-	Fair	High
	Ozubulu	-	25.0000	Moderate	-	Fair	High
	Kankara	-	18.0000	Low	-	Fair	High
	SabonGida	-	20.0000	Low	-	-	High

Table 2. Summary of Chemical Properties of Some Nigerian Kaolin Materials

NAME OF THE RESEARCHER	LOCATION	YEAR	AL_2O_3 (%)	SIO_2 (%)	K_2O (%)	CAO (%)	TI_2O (%)	MNO (%)	FE_2O_3 (%)	OTHERS
Folorunso *et. al.* [13]	Ifon	2014	22.420	63.3500	2.8780	0.6890	0.9230	0.1117	6.1090	3.5193
	Igbara Odo		25.737	56.6360	2.9400	0.9110	0.8950	-	9.2260	3.6550
	Ipetumodu		25.030	59.4820	1.2590	0.7630	1.5120	0.0450	8.6520	3.2570
	Ihan		23.980	54.6570	2.5130	0.8430	1.5770	0.1090	10.4080	5.9130
	Iseyin		22.729	62.2920	1.3600	0.5410	1.0460	0.0500	7.2660	4.7160
Manukaji [14]	Uhodo	2013	35.000	44.0000	1.5000	0.5000	2.4000	-	1.3000	15.3000
	Oguma		34.000	45.0000	1.4000	0.4000	1.5000	-	1.5000	16.2000
	Odoji		34.000	46.0000	1.2000	0.2000	3.0000	-	0.9000	14.7000
Akinlabi, *e.t al.* [15]	Ijero	2013	39.600	58.0000	0.8950	-	0.0200	0.0510	0.6380	0.7960
Titiladunayo and Fapetu [9]	Ikere	2011	30.460	50.9200	0.3300	0.1900	1.7800	0.0100	2.0700	14.2400
	Fagbohun		18.750	53.9000	3.3000	0.7200	2.2900	0.0300	11.8000	9.2100
	Ishan		13.480	40.6800	2.8800	1.1200	2.6800	0.1500	25.5500	13.4600
	Ara		10.920	59.9000	3.2500	1.9000	2.7600	0.1900	11.4000	9.6800
Yami and Umar [5]	Gur	2007	21.250	59.2000	-	1.9200	-	-	15.7000	1.9300
	Yamarkumi		19.680	41.8000	-	1.5200	-	-	8.8900	28.1100
Ogunniyi [10]	Ijapo	2003	28.830	52.2000	-	-	-	-	3.5800	15.3900
	Igbokoda		1.1300	92.5400	-	-	-	-	1.1900	5.1400
Ijagbemi [16]	Ikeji- Arakeji	2002	19.690	48.2400	3.0000	0.5500	1.5100	-	10.8100	16.2000
	Ibule		19.250	56.0900	7.2100	0.3200	1.4800	-	7.2100	8.4400
	Ikere		30.820	47.1400	2.5300	0.2500	0.5000	-	2.0000	16.76
Borode *et. al.* [11]	Onibode	2000	36.600	46.1000	1.2000	0.1400	1.3200	-	0.7600	13.8800
	Ara		28.600	56.6600	0.0800	0.1500	1.8800	-	1.4700	11.1600
	Ibamojo		22.800	54.4400	1.0000	0.3000	0.8600	-	1.0000	19.6000
	Ijoko		37.240	47.1100	0.0400	0.0700	0.9200	-	0.5600	14.0600
	Ijapa		30.790	47.5010	1.9170	4.7700	-	-	0.4910	14.5310
	Ikere		31.460	47.3800	0.2962	0.0237	1.1380	-	9.8700	9.8321
	Ishan		19.510	51.1000	2.5290	0.3296	1.4840	-	9.8200	15.2274
	Ezinachi-Okigwe		34.730	45.0000	0.1400	Traces	4.0200	-	1.2700	14.8400
Okoli [12]	Onibode	2000	39.300	42.3000	-	-	-	-	Trace	18.4000
	Ozubulu		19.310	58.3000	-	-	-	-	1.5500	20.8400
	Kankara		38.640	44.5000	-	-	-	-	Nil	16.8600
	Sabon-Gida		25.880	25.3200	-	-	-	-	13.1000	35.7000
Delta Steel Company ltd.,Aladja [17]	Nsu	1984	30.220	50.6000	-	-	-	-	1.9000	17.2800
	Ukpor		33.200	48.0000	-	-	-	-	1.2000	17.6000
	Ozubulu		19.310	58.3000	-	-	-	-	1.5500	20.8400
	Enugu		22.710	55.0000	-	-	-	-	2.3200	19.9700
	Onibode		39.300	42.3000	-	-	-	-	Traces	18.4000
	Orun		34.550	50.5000	-	-	-	-	2.0500	12.9000
	Oshiele		28.300	53.4000	-	-	-	-	1.3500	16.9500
	Werromi I		36.120	45.1600	-	-	-	-	2.3000	16.4200

Werrom II	38.140	41.9200	-	-	-	-	-	19.9400
Alkaleri	25.430	54.5000	-	-	-	-	1.0500	19.0200
Kankara	38.670	44.5000	-	-	-	-	-	16.8300
Giro	38.720	41.2600	-	-	-	-	2.1000	17.9200
Sabon Gida	25.580	25.3200	-	-	-	-	13.1000	36.0000
Ifon	36.800	47.9000	-	-	-	-	0.6700	14.6300
Okpekpe	24.300	53.2000	-	-	-	-	1.4500	21.0500

Porous firebricks were produced from the mixture of clay with 10%, 20% and 30% recycled refractory wastes of expanded perlite [18]. The authors reported that the mixture containing 30% expanded perlite was the best as it had porosity of 65.8% as against 51.5% and 57.5% for the mixtures with 10% and 20% perlite respectively. The performance evaluation of refractory bricks of clay samples from Oghara, Ekpan, Ubeji and Jeddo communities were carried out in Delta State [19]. It was reported that the Oghara clay was the best among the four samples. It can therefore be used for wall lining material in high temperature equipment of Warri Refining and Petrochemical Company with temperature below 1200 ^oC. Clay samples from Nafuta in Barkin Ladi area of Plateau State, Nigeria were investigated for refractory bricks application [20]. The report was that the bricks had refractoriness of 1600 ^oC with low concentration of iron II oxide (Fe_2O_3) and they could be used as lining materials in furnaces, kilns, incinerators and reactors.

Clay material obtained from a single site cannot however possess all the required properties that will make it a perfect refractory material, hence the need to select clays based on their physical, chemical and thermal analyses. The selected refractory material will have to be beneficiated with refractory clay materials from other sites and properly blended with other additives to improve its properties [21]. For instance, the effect of Portland cement on the refractory properties of clay samples from Awo and Ipetumodu in Oyo State, Nigeria was investigated [22]. They reported that the thermal shock resistance of the clays increased when they were blended with 20% to 30% cement. The mechanical properties of Ifon clay from Ondo State were improved by bonding it with spent graphite electrode [23]. Studies on the refractory properties of the mixture of Uwana beach silica sand, Ekebedi and Unwana clay samples were carried out and it was reported that Unwana beach sand was most suitable for the manufacture of aluminosilicate refractory brick [24]. The characterization of Dabagi clay sample from Gwandu, Kebbi State was carried out and the authors reported that its apparent porosity of 28.46% made it suitable for use as refractory brick, fireclay, siliceous fireclay and ceramics [25]. Three clay soils from Abaji were investigated for refractory applications [26]. They found out that the clays were alumina-silicate clays as they respectively had 49.98%, 36.89% and 44.38% silica while the alumina contents in the same order were 16.39%, 20.12% and 18.33%. These clay samples were found suitable for furnace and heat treatment lining materials as each of them recorded refractoriness of 1100 ^oC. Studies was done on bricks made of charmotte obtained from calcinations of clay in Apata Ile Ife, Osun State mixed with potter's clays. The composition of the charmotte in the mixture was separately at 100%, 80%, 60%, 40%, and 20% [27]. They reported that the brick with 80% charmotte content and 20% raw kaolin recorded the highest thermal shock resistance. The thermal shock resistances and cold crushing strength of the bricks also increased with increase in the charmotte content in the mixture.

Refractory materials used especially for insulating purpose can also be produced from termite hill materials. Termite hill material mixed with 25% additives from corn husk and sawdust was used to produce insulating refractory material [28]. Low values of refractoriness (1200 ^{o}C) were recorded but the property improved through the addition of kaolin, and bentonite to attain the refractoriness of 1500 ^{o}C. The refractory properties of termite hill materials made it suitable for furnace lining [29]. Anthill clay from Cheptebo in rift valley, Kenya was investigated for the production of refractory materials [30]. The authors reported that the anthill clay was siliceous in nature and it was of the alumina-silicate family. This clay could be used for the manufacture of alumina-silicate fibre glass.
The objective of this paper therefore is to evaluate the chemical and thermo-physical properties of the aggregate formed from mixing together kaolin obtained in Ipinsa, termite hill materials and bentonite for refractory materials.

MATERIALS AND METHODS

During the process of material collection and preparation, five representative clay samples were collected from five different locations from a kaolin deposit at Ipinsa near the Federal University of Technology, Akure (FUTA) North Gate along Ilesha-Benin express way, Akure, Ondo State, Nigeria. Akure is located within the humid south western region of Nigeria on latitude 7˚16’ N; longitude 5˚13’ E.

The clay samples were properly blended together to have a very good representation of the kaolin deposit from the sites. The distance between the points in the field at which the clay samples were collected was 150 m. Termite hill materials was extracted from a termite hill within FUTA. Processed bentonite was purchased at Pascal Scientific Limited, Alagbaka, Akure and was mixed such that 50 kg of the Ipinsa clay material was mixed with 40 kg termite hill material and 10 kg of the processed bentonite to attain a ratio 5:4:1. The samples were crushed into powdery form using small porcelain mortar and pestle. They were then made into pellets of about 500 mg and 13 mm diameter using pellets making set, being the method used by [31, 32].

Proton Induced X-ray Emission Analysis

The elemental properties of the refractory materials was then analysed with the Proton Induced X-ray Emission (PIXE) equipment at the Centre for Energy Research and Development (CERD) at Obafemi Awolowo University, Ile- Ife, Nigeria. PIXE analysis use proton beams produced by Ion Beam Analysis (IBA) facility of 1.7 MeV Tandem Accelerators. The PIXE system was calibrated using the National Institute of Standards and Technology (NIST) and geological standard 278B_PIX_K8 was used for quality assurance and control of results.

The IBA facility used for this analysis consists of a 5SDH modelled NEC Tandem Pelletron accelerator complete with an end station made up of Aluminum chamber 150 cm diameter and height 180 cm. The samples were irradiated by a 4 mm diameter beam of protons with energy of 2.5 MeV and beam current of 0.2 nA for 900 seconds.

The chamber of the accelerator had four ports and a window. The second port, inclined at 135^{o} to the horizontal, is used for PIXE detector. This detector is an ESL X 30–150 model of a Cambera Si (Li) detector with resolution 175 eV at 5.9 Kev which is coupled to a Canberra Inspector 2000 Digital Signal Processor. Canberra Ganie-3.1 software was used for acquisition of the PIXE data [33-35].

Gupxwin computer code was used for fitting the experimentally generated PIXE spectrum prior to quantitative analysis [36]. A filter placed between the detector and the samples cut off unwanted signal frequencies. The physical and thermal properties were determined using the principle employed by [5, 32, 37]

Bulk Density and Apparent Porosity

These properties were determined in accordance with standard test procedures in BS 1902 part 1A [38].The aggregate mixture of the Ipinsa kaolin, termite hill materials and bentonite was mixed with water until it plastically formed. The sample was then moulded into shapes of 6cm × 6cm × 1.5cm and they were air dried for 24 hours. They were also put into a muffle furnace and dried at 110 ^oC for another 24 hours before they were fired to 1200 ^oC for 30 minutes. They were thereafter allowed to cool in the desicators for 24 hours. These specimens were used in the determination of their bulk density and apparent porosity.

The test samples, after they were fired to 1200 ^oC and cooled, were weighed and recorded as W_1. The specimens were attached to an inextensible string from which they were suspended, transferred and immersed into a beaker of water and heated for 30 minutes to assist in bobbling the trapped air in the specimen. The pores in the specimen were then filled with water. The weights of the specimen were now recorded W_2. The specimens were thereafter suspended in a beaker containing water placed on a balance. The suspended weight (W_3) was taken and the bulk density was calculated from equation (1).

$$Bulk\ density = \frac{W_1}{W_2 - W_3} \tag{1}$$

Apparent porosity is determined using equation (2).

$$Apparent\ \ porosity = \frac{(W_2 - W_1)}{(W_2 - W_3)} * 100\% \tag{2}$$

Thermal Shock Resistance

The samples upon preparation were dried at room temperature for 12 hours before they were put into an oven to dry at 110 ^oC for 24 hours. They were thereafter transferred to a muffle furnace now set at 1200 ^oC and the specimens were allowed residence there for 30 minutes. They were removed from the furnace to be cooled for 20 minutes and were put back to the furnace for another 20 minutes. The procedure was continued till the test pieces fractured. The alternate heating and cooling before the test pieces fractured determined the number of cycles they went through and this was the value of the thermal shock resistance [39].

Linear Shrinkage

The test pieces were made in rectangular form of 10 cm x 3 cm x 3 cm and a 6 cm line was marked along its length so as to keep the same spot after heat treatment. The length of the line on the specimen was measured with a vernier calliper. The samples were dried at room temperature for 24 hours before they were transferred to the oven to dry further at 110 ^oC for another 24 hours. They were then fired up to 1200 ^oC for 6 hours. The test pieces were cooled to room temperature and measurements of the marked line was taken again. The fired specimen linear shrinkage was calculated using equation (3). This method was employed in the ASTM 15.02; C326 method [40].

$$Linear\ shrinkage = \frac{(L_1 - L_2)}{L_1} * 100\% \tag{3}$$

where, L_1 is the length of the line on the unfired test specimen; and L_2 is the length of the same line on the fired specimen

Refractoriness

This is the temperature at which a refractory bends as it can no longer support its weight as it is exposed to high temperature [41]. The test samples were first dried at room temperature before being mounted on a refractory plague together with a standard cone with a melting point slightly lower than the melting point expected of the test cone. The set up was then put inside the muffle furnace and its temperature was raised at a rate of 100 ^oC per minute. The test continued until the tip of the test cone bent over the level with the base. The plague with the test piece on it was removed and cooled at room temperature. The test cone was examined with the microscope. The test was similar to those in ASTM 15.01; CO8.02 [42].

RESULTS AND DISCUSSION

The PIXE chemical analysis of the Ipinsa clay sample, termite hill materials, bentonite and that of their mixture aggregated at 5:4:1 by mass is shown in Table 4 while the spectral distribution of this PIXE analysis is shown in Figure 1.

Table 3. Elemental composition of ipinsa clay, termite hill materials, bentonite and the aggregated mixture.

Elemental Composition (%)	Refractory Materials Samples			
	Ipinsa Kaolin	Termite Hill Material	Bentonite	Aggregate Used
Alumina (Al_2O_3)	43.05	22.69	23.10	37.22
Silica (SiO_2)	53.91	58.83	55.40	51.93
Magnesium oxide (MgO)	0.26	0.84	2.50	0.71
Iron III oxide (Fe_2O_3)	1.72	2.42	4.40	8.08
Calcium oxide (CaO)	0.03	0.01	0.20	0.12
Titanium oxide (TiO_2)	0.12	0.72	-	0.86
Manganese oxide (MnO)	-	-	0.02	0.05
Strontium oxide (SrO)	-	-	-	0.01
Zirconia (ZrO_2)	0.03	-	-	0.09
Potassium oxide (K_2O)	0.88	2.10	3.00	0.90
Zinc oxide (ZnO)	-	-	-	0.02
Rubidium oxide (RbO)	0.01	-	-	-

Sodium oxide (Na_2O)	-	0.06	3.00	-
Others	-	-	0.58	-

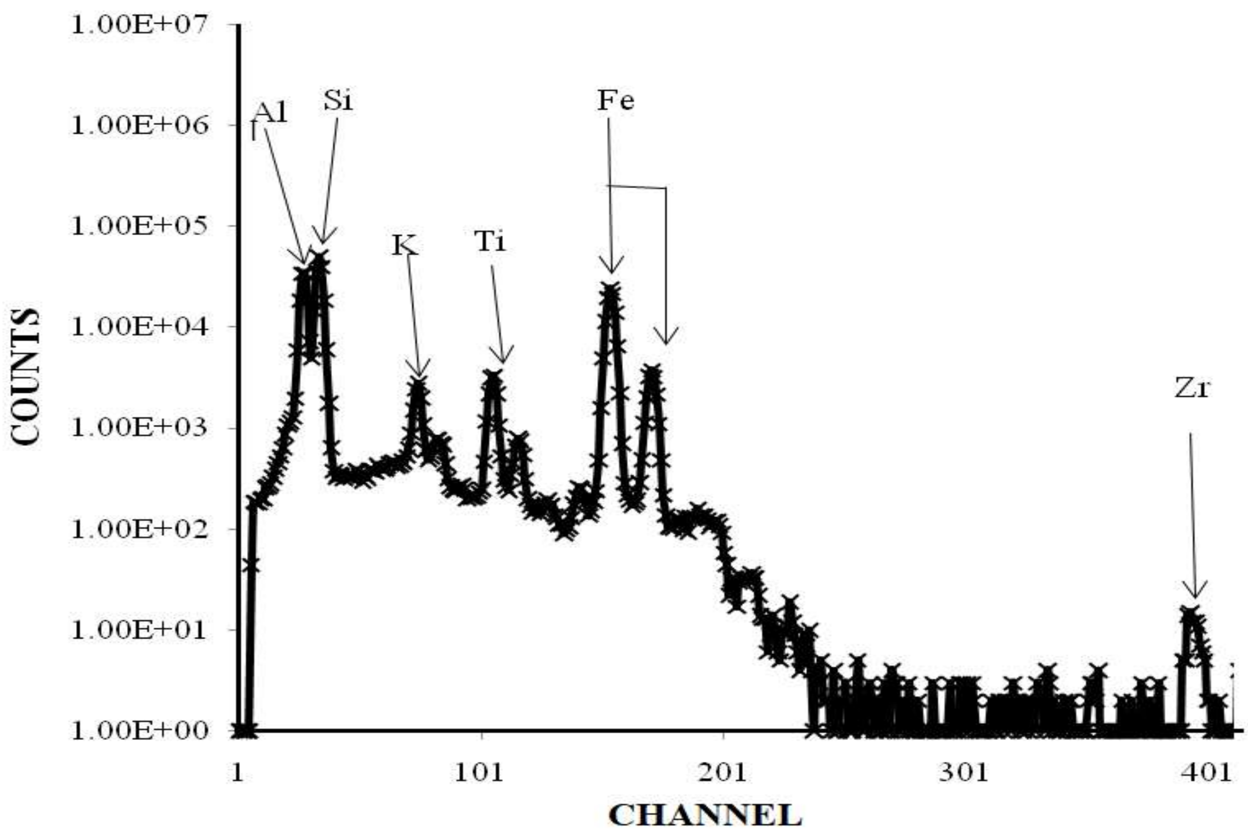

Figure 1. Proton induced x-ray emission (PIXE) analysis spectrum of the refractory materials.

As shown in Table 4, the alumina (Al_2O_3) content (43.05%) and that of silica (SiO_2) (53.91%) make the Ipinsa kaolin suitable for ceramic fibre materials for temperatures up to 1150 ^oC [31].The Al_2O_3 of termite hill materials (22.69%), for bentonite (23.10%) and that of the aggregate obtained from the combination of Ipinsa clay, termite hill materials and bentonite at ratio 5:4:1 by mass (37.22%) can therefore be used as refractory materials [7]. The percentage composition of alumina of all the samples conformed to major refractory clays in Nigeria with alumina content less than 45% [43].

The iron oxide contents of all the samples were high and met the requirement for both refractory and high melting clays. The high iron oxide of the Ipinsa kaolin aggregate of 8.08% perfectly supports the reddish colour when fired to 1200 ^oC. This makes it attractive as a ceramic raw material [44]. The high temperature characteristics of the fired bricks make the clay suitable for structural engineering works [7].

The amount of titanium oxide (TiO_2) in Ipinsa kaolin, termite hill materials and the aggregate are less than 1-4% recommended for refractory clays [45]. Rubidium oxide (RbO) was only visible in the Ipinsa kaolin with 0.01%, while zinc oxide (ZnO) was only present in the kaolin aggregate with 0.02%. Magnesium oxide (MgO) was detected in all the samples with the highest being found in bentonite which was 2.5%, termite hill material with 0.84%, and then kaolin aggregate with 0.71% while Ipinsa kaolin had the least with 0.26% but its fusion temperature is 2800 ^oC which is beyond all the melting temperature for non-ferrous metals.

The percentage of calcium oxide (CaO) with a fusion temperature of 2570 ^oC in bentonite, kaolin aggregate Ipinsa kaolin and termite hill material is also beyond the melting temperature of the non-ferrous metals. The sum of these oxides were less than 6% recommended for the total flux sodium oxide (Na_2O), potassium oxide (K_2O), calcium oxide (CaO) and magnesium oxide (MgO) for refractory clays [45]. Large amount of the oxides facilitates the formation of their liquid-phase at low temperature.

Manganese oxide (MnO) has the highest value in the kaolin aggregate (0.05%) composition while that of bentonite was (0.02%). With a fusion temperature of 1780 ^oC, it is very difficult to disintegrate at the melting temperature of non-ferrous metals. Strontium oxide (SrO) was mainly detected in the kaolin aggregate and the fusion temperature is 2415 ^oC. Zirconia (ZrO_2) was available in the kaolin aggregate in 0.09% proportion and in Ipinsa kaolin with 0.03% and fusion temperature of 2677 ^oC.

The fusion temperature of observed oxides that are dangerous to both health and the environment are all higher than the melting temperature of the non-ferrous scraps, therefore they are not expected to disintegrate and present health and safety hazard to plants and animals within the environment in which the equipment will be operated. Element like Zn is essentials for good health and development but they are also dangerous to health and environment when their concentration exceeds some limits [46].

In Figure 1, elements like Aluminium (Al), silicon (Si) and iron (Fe) have higher percentage as they recorded higher counts than those of potassium (K) and titanium (Ti) which are in turn higher than zircon (Zr).

Table 4 shows the thermo-physical analyses conducted on the kaolin aggregate. The bulk density of the aggregated clay was lower than the recommended value of 2.06 - 2.11 g/cm^3 for clay samples and 1.90 g/cm^3 for fireclay [47]. This can be improved with the addition of some additives. The apparent porosity (31.54%) of the aggregated sample falls within the range of 20-30% recommended values for clays [3]. The linear shrinkage (4.00%) of the aggregated clay fell within the recommended value of 4-10% for fireclay while the thermal shock resistance for the clay sample is even higher than the recommended value of 20-30 cycles for fireclay [3]. Refractoriness of the aggregated clay was higher than the value recommended for fireclay [5]. This value of refractoriness could be due to the high percentage of the alumina content after the aggregate kaoline had been fired [29]. The refractoriness of refractory materials is directly proportional to its softening temperature; this is expressed as its Pyrometric Cone Equivalent (PCE) [37]. The PCE that is equivalent to the refractoriness of the aggregate sample is cone number 40 which is equivalent to 1900 ^oC. This value is higher than the temperature range 1745-1760 ^oC for super duty clay which are used in furnaces, kilns and stoves [32].

Table 4. Thermo-physical analysis of the aggregated clay

S/N	Analysis	Kaolin Aggregate Used
1	Bulk density (g/cm^3)	1.84
2	Apparent porosity (%)	31.54
3	Linear shrinkage (%)	4.00
4	Thermal shocks resistance (cycles)	40+
5	Refractoriness (^oC)	1900

CONCLUSION

In this work, the chemical composition of clay sample from Ipinsa, termite hill material and processed bentonite as well as that for their aggregate at 5:4:1 are presented. The thermo physical properties of the mixture are also evaluated for refractory materials. The study indicated that the Ipinsa clay sample, termite hill material, the bentonite and their aggregate are kaolinitic as each of them contained higher percentage of silica than alumina**.** The Ipinsa kaolin can be used as refractory materials for furnaces, kilns and stoves. The aggregated clay from Ipinsa kaolin, termite hill materials and bentonite can find application in super duty refractories. The aggregated clay can also be used for ceramic material within the temperature range of 1800 and 2000 ^oC based on its pyrometric cone equivalent value of 1900 ^oC. The thermo-physical properties tested on this clay conformed to the recommended values for fireclay except the bulk density. It is opined that this would improve if some additives and binders are mixed with the clay. This shows that refractory materials from Ipinsa kaolin and the aggregated clay can compete favourably with the foreign refractory materials.

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