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Nigerian Clay Deposits for use as Refractory Materials in Metallurgical Industries - A Review

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***Abstract*:- Clay is one of the most important materials used by the metallurgical industries. The characterization of clay in order to understand its mineralogical constituents, chemical and physical properties is of significant importance. In this paper, the significant of clay as raw material used by the metallurgical industries for the production of refractory materials were reviewed. Emphasis on the estimate of Nigerian clay deposit, and its suitability for use in the metallurgical industries as refractory materials were highlighted. Several research work exploring the potentials of Nigerian clay deposits conducted by different researches were summarized.**

Keywords: Clay, mineralogy, refractory materials

INTRODUCTION

Clay is a natural material formed by the progressive deterioration of rocks in silicate layers containing low carbon acid and other diluted solvents with a particle size of less than 2 µm, which are plastic with a content of suitable water, which shrinks on drying, expands on wetting and hardens when fired (Edozuino *et al.*2016; Ochieng 2016; and George, 2011). Clay is composed of minerals with small particles and a complex porous structure with a high specific surface which allows a strong physical and chemical interaction with the dissolved species (Faheem, 2018; Murali *et al*, 2018; and Muhammad, 2017). These clay constituents have made them useful in various metallurgical applications (Oziegbe *et al., 2019*; Katsina *et al.*, 2013; and Umbugadu *et al.*, 2019) such as refractory materials, binders in the metallurgical industries (Sani *et al.*, 2013). Clay particle size varies according to different field of studies (Guggenheim *et al.*, 1995; and Moore *et al.*, 1997). For this reason, Ordinary microscope is insufficient to provide an in depth knowledge of the crystal structure of clay. X-ray diffraction, X-ray fluorescence, energy-dispersive X-ray analysis, differential thermal analysis, infrared spectroscopy and electron microscopy are best employed to study the crystal structure of clay (Obaje *et al.*, 2013; and Yusuf *et al.*, 2018). Clay is classified according to its structure, chemical composition, origin and nature of occurrence. The difference between the types of clay is explained by the octahedral and tetrahedral arrangements of clay structure (Oziegbe *et al.*, 2019). In general, clay comes in three main forms with similar chemical compositions and different physical properties. This includes surface clays, shale clays and refractory clays (Okpanachi *et al.*, 2017). The major clay mineral groups include kaolinites, vermiculites, palygorskite, mica, smectites, chlorites and other weathered minerals. The mixture of different clays in various proportion results in the formation of clay deposits with one group or type normally being dominant (Sani *et al.* 2013). For this reason, Oziegbe *et al.* (2019) characterized Origo and Awo clay deposited in the Southwestern part of Nigeria based on their mineralogical contents and chemical composition. The result obtained from the analysis proved kaolin as the dominant clay mineral while smectite occurs in small amount which makes the clay suitable for refractory composite. Base on the nature of application, clay can be blended to achieve the required properties (Titiladunayo *et al.*, 2011). Hence a comparative study on refractory properties of Dolomite using clay as additives was conducted by Oyetunji *et. al.*, (2018), the result obtained from the study was compared with imported fireclay bricks and ASTM standards for refractory grade dolomite and found the mixture to be suitable for melting metals at a temperature not exceeding 1100^{o}C.

SOME ESTIMATED CLAY DEPOSIT IN NIGERIA

Each region of Nigeria is said to have a large deposit of clays (Richard *et al.*, 2017). Research conducted by Raw Materials Research and Development Council of Nigeria (RMRDC), Nigeria is reported to have billions of tones of clay deposits that spread throughout entire states (Muhammadu, 2013). An insight research conducted by Richard *et al.*, (2017) showed that Nigeria has an estimated reserve of bentonite clay of about 700 million metric tons. Afuze town of Edo state in Nigeria is reported to contain 70-80 million metric tons of bentonite clay. Moreover, Bauchi and Taraba state in the north eastern state of Nigeria has an estimated reserve of barites clay holding up to 7.5 million metric tons of barite clay. Additionally, 4billions reserves of clay were found to be deposited in the Niger Delta region of Nigeria. The north eastern region of Nigeria is reached with about 700 million metric tons of clay deposited that is yet to be characterized. The table below gives an estimated quantity of some of the clay minerals found in some part of Nigeria.

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Table 1: location of some clay minerals in Nigeria with their estimated quantity

No	Clay mineral	Site location	State	Estimated Reserve (tones)
1.	Kaolin	Kankara	Katsina	20, 000, 000
		Major potter, Jos	Plateau	19, 000, 000
		Darazu	Bauchi	10, 000, 000
		Ozubulu	Anambra	769, 000
2.	Common clay	MararrabanRido	Kaduna	5,500, 000
3.	Quartz/ silica	Lokoja	Kogi	4, 000, 000
		Biu	Borno	2, 540, 000
		Pankshin/shabu	Plateau	27, 962
4.	Talc	Kumunu	Niger	40, 000, 000
5.	Limestone	Okpila	Edo	10, 161, 000
		Jakuru	Kogi	68, 000, 000
		Igumala	Benue	30, 161, 000
		Mfamoging	Cross river	26, 000, 000
		Ewekoro	Ogun	7.1billion
		Aruchukwu	Imo	101, 000, 000
6.	Dolomite	Osara	Kogi	2, 000, 000
		Itobe	Benue	1, 000, 000
		Burum	Abuja	8, 000, 000
		Kwakuti	Niger	2, 540, 000

Source: Adelabu (2012)

SUITABILITY OF NIGERIAN CLAYS FOR REFRACTORY APPLICATIONS

With the emergence of new trends in technology in Nigeria such as development of iron and steel industries and other related industries that uses refractory materials, clay have found several applications in various sectors of Nigerian metallurgical industries. One of the most important uses of clay is its application in the production of refractory materials. These materials are employed in metallurgical industries for furnace constructions, productions of moulds for castings purposes, and smelting vessels (Oke *et al.*, 2015). Refractory materials are composed of high melting oxides such as SiO_2, Al_2O_3, MgO, Cr_2O_3, ZrO (Ibrahim *et al.*, 2018). Their outstanding properties which include the ability to resist heat at elevated temperature make them suitable for use in metallurgical industries (Muhammadu, 2013). Furnace linings, kilns, reactors and crucibles are examples of products produced from such material (Mokwa *et al.*, 2019).

Furthermore, refractory materials can be classified into groups depending on the desired temperature, chemical compositions and shape of the refractory material. Titiladunayo, (2011) reported that refractory materials can either be acidic such as silica (SiO_2) and zirconia (ZrO_2); basic such as magnesia (MgO) and chromites (Cr_2O_3); or Neutral refractories such as carbon graphite and alumina. Ibrahim *et al.*, (2018) stated that refractory materials can be classified according to temperature ranges at which they are used. This include low temperature range refractory materials that can perform below 1770^{o}C; medium temperature refractory materials which can be used in between 1770-2000^{o}C range and high temperature refractory materials that can perform above 2000^{o}C. Oyetunji *et al.*, (2018), stated that the composition of each refractory material possesses a desirable heating condition to be considered to prevent failure during a specified operation. Therefore, to ensure durability in the usage of refractory material, proper selection of such material should be considered. For instance, zirconia, silicon carbide and graphite are employed in a severe temperature condition (Amkpa *et al.*, 2016; Folorunso, 2015). Physical properties such as refractoriness, thermal strength, crushing strength and color play an important role in determining the industrial and commercial value of any refractory material and are used in quality control during the production processes. These properties differ according to the chemical composition, and structure of the clay (Abdelaziz *et. al.*, 2019; Paul *et al.*, 2011 & Ibetoye *et al.*, 2014). Table 2 below outlined some of the important physical and thermal properties of refractory materials with their standards.

Table 2: Physical and Thermal Properties of Refractory Clay Based on International Standard

PROPERTIES	VALUES
Linear shrinkage (%)	2-10
Permeability to air	25-90
Apparent porosity (%)	20-30
Bulk density (g/cm^3)	1.71- 2.8
Cold crushing strength (Mpa)	15.0 minimum
Thermal shock resistance, cycle	20-30
Refractoriness (^{o}C)	1500-1750
Moisture content (%)	1-13

Source: Ugwouke *et al.*, (2018)

Despite the plenitude amount of clay deposits available in Nigeria and the various research that have been carried out in the development of refractory products, Nigeria continues to rely on imported refractory materials for its industrial applications (Oke *et al.*, 2015). Investigations of clay deposited in any region provide the general information required in the field of metallurgy (Omowunmi, 2000). Hence, tremendous works were conducted by several researchers on clays deposited in different part of Nigeria ensuring that it properties compare favorably to standard requirements; most of the results obtained showed that the clay deposits possessed the required physical, mechanical and chemical properties to be used by metallurgical industries. For instance, an investigation into the refractory properties of Jalingo clay in Taraba state of Nigeria was conducted by Adamu *et. al.*, (2018), the result showed that the clays possessed a temperature of 1300ºC which qualifies the clay for use in melting of nonferrous materials. The performance assessment of the physical properties of Kadna, Tagwai, and Gbakoita town clay deposits as refractory for furnace lining in Niger state of Nigeria was conducted by Okpanachi *et. al.*, (2017), the result obtained was compared to standards. The clays indicated a refractoriness temperature of 1600ºC, with a bulk density of 2.7g/cm^{3,} apparent porosity of 29.6%, linear shrinkage of 9.21%, thermal shock resistance of 17cycle, and cold crushing strength of 310.7kg/cm^2. The parameters obtained qualify the clays for use as a good fireclay refractory and furnace lining application. Assessments of the industrial potentials of some Nigerian Kaolinitic clay deposits conducted by Ovat *et. al.*, 2017 showed that the physical and chemical properties of the clays assessed were in agreement with standards. The evaluation of the chemical and mechanical properties of some Nigerian clay sample for foundry applications was carried out by Yusuf *et al.*, (2018) and discovered that the Nigerian clays could suitably replace imported clays. Additionally, the investigation of some selected kaolin clay deposits in Nigeria for furnace lining applications was conducted by Mokwa *et al*., (2019). Moreover, a tremendous work that studies the chemical and physical characteristics of clay samples in sokoto state of Nigeria proved the clay satisfactory for used as furnace lining (Sani *et al.* 2013). Clays deposited in Niger state, Agbaja town in kogi state, Afuze clay in south-south of Nigeria were investigated and found to be suitable for the production of fireclays bricks for furnace lining (Abdullahi *et al.*, 2012; and Elakhame *et al.*, 2016). Also, the evaluation and characterization of Gakem and Abouchiche clay samples in Bekwarra L.G.A of Cross River state by Ovat *et al.*, (2017), showed that the clays exhibited the required properties for production of refractory materials. Firing temperature algorithm on the physiochemical properties of Ishiagu clay deposit for refractory application was investigated by Chidinma *et al.*, (2017), the result obtained proved the clay satisfactory for the production of refractory materials.

However, reference to the research works conducted by several individuals, some of the result showed that not all the clay deposits available in Nigeria possess the required properties for metallurgical activities. In order to utilize these locally sourced clays in the production of refractory materials, the physical, thermal and chemical properties have to be improved. This can be achieved by either blending two or more different clay obtained from different source or treating the clay with certain additives. Richard *et al.*, (2017) stated that the additives can either be locally sourced from Nigeria or conventional additives. For instance, Ogunsemi *et al.*, (2017) investigated the effect of certain additives on some selected refractory properties of ant-hill clay for furnace lining application. In his work, pulverized glass wastes, bentonites, clean water and 100% ant hill clay were mixed at an appropriate proportion. The result obtained reveals an improvement in the properties of the anti-hill clay to suit the desired requirement needed for the production of refractory materials. Furthermore, an evaluation of the chemical and thermo-physical properties of locally aggregated kaolin-based refractory materials was conducted by Olare *et al.*, (2019), in this work, the chemical composition of clay sample from Ipinsa town in Ondo state of Nigeria, termite hill material and processed bentonite were mixed at an aggregate proportion. From the result obtained, the refractoriness of the clay was found to be 1900ºC which qualifies the clay satisfactory in the production of refractory materials.

CONCLUSION

The following can be drawn from the above reviewed:

1. Local clays deposits in different part of Nigeria can serve as a good replacement for imported clays for used in metallurgical and other related areas. This can be achieved by establishing proper scientific records of the clays and comparing them with standards.
2. Refractory clays constitutes certain properties which include moisture content, bulk density, thermal resistance, refractoriness, loss on ignition, plasticity, modulus of rapture and linear shrinkage. These properties have significant effects on performance and durability of the material in metallurgical applications. However, it is very difficult for refractory clays collected from a single site to possess the satisfactory properties required for metallurgical applications. Hence, proper blending of the selected clays with good additives to improve their physical, chemical and thermal properties is important.
3. The mineralogical and chemical compositions of refractory clays are best examined and evaluated using the following method: X-ray fluorescence, X-ray diffraction, energy-dispersive X-ray analysis, electron diffraction, differential thermal analysis, infrared spectroscopy and electron microscopy.

CONFLICT OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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